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# The Integration of Smart Meters Into Electrical Grids to Ensure Maximum Benefit for Consumers, Generators and Network Operators.

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# The integration of smart meters into electrical grids to ensure maximum benefit for consumers, generators and network operators.

Tom Bean

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*"What gets measured gets managed"*

Dr. Peter Drucker

May 2010

# ABSTRACT

The term "smart metering" has been used in many project descriptions and publications produced by utility companies (e.g. gas, water and electricity), conference papers and journal papers, but the true meaning of the term has been fudged. Does smart metering signify rapid recording of data (i.e. data logger) or does it give totals (e.g. maximum, minimum and average), as neither of these are truly "Smart" or "Intelligent" virtues in themselves, or is there some additional role that needs to be explored. This dissertation examines the "smart metering" idiom jointly from energy supplier, grid manager and consumer perspectives and formulates a detailed model of the interfaces that are currently being touted as necessary for realising a smart system. Other aspects such as infrastructure, networking of data, ownership, location etc are also explored. Using a base model of the existing approach, this research shows where true "Smart" or "Intelligent" virtues could be incorporated. The proposed model alterations are verified using scenarios, thereby stress-testing the use of the components employed and illustrates limitations of the approach. This research highlights the necessity for a Home Area Network (HAN), to manage the use of energy in the home, and for a Consolation Entity, to fairly distribute and manage in a collaborative way the available energy on the grid. Not only are the needs for these shown but functional definitions for the HAN and consolation entity are also introduced. These two aspects have a particular importance as we, as a nation, introduce more renewable resources (e.g. wind, wave, solar), that are variable in their availability.

**Key words**: Smart meter, smart grid, electricity grid, energy efficiency, renewable energy, energy management, domestic loads,

Declaration:

I hereby certify that this material, which I now submit for assessment as a final thesis in Energy Management DT015, is entirely my own work and has not been submitted in whole or in part for assessment for any academic purpose other than in fulfilment for that stated above.

*Signed: ……………………….. Date: ……………………………….*

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# ACKNOWLEDGEMENTS

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# 1 Introduction

## 1.1 Introduction

This chapter introduces the dissertation and sets out the background to the project and states the goals and aims of the research performed for, and documented in this dissertation. Section 1.2 discusses the growth in energy consumption and shows how this is being driven by both a growth in world population as well as a growth per-capita in energy consumption. Section 1.3 sets out how smart meters play such an important role in managing the growth of electricity consumption by providing the parties in the electricity supply chain with a means of measuring and controlling electricity usage. Section 1.4 outlines how electricity has become such an important source of energy for modern day society and how our life styles have come to depend on it. Section 1.5 sets out the aims and objectives of this research. Section 1.6 outlines the research methodology and the sources of data to be used. Section 1.7 outlines the organisation and framework for the remaining chapters of this dissertation.

## 1.2 Growth in energy consumption

Over the last century the human race has, continued to consume energy on a scale that continues to break records decade after decade. By 2050 the world's population is estimated to grow from 6.7 billion to 9.2 billion as reported by The United Nations, (2007). This, coupled with the per capita growth of energy consumption as predicted by Briol (2009), has created a modern day 'energy time bomb' for mankind. In Ireland alone our medium term trend is to continue to consume more and more energy in transportation, electricity generation and heating as can be seen from figure 1.1 below documented by the SEI (2009).

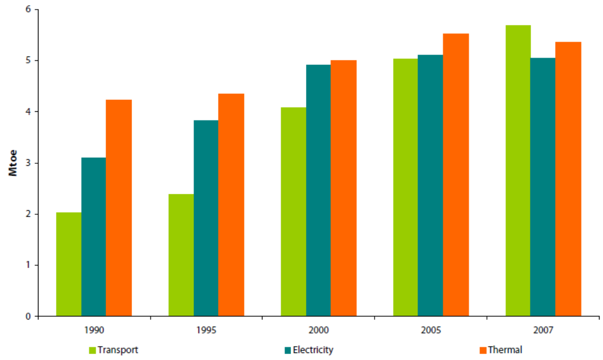


**Figure 1.1: Energy in Ireland - SEI**

This insatiable desire for energy in our daily lives, and its by-product carbon dioxide, has led the scientists of the IPCC to conclude that $CO_2$ is one of the major contributors to global warming. This is now seen as the greatest single risk to mankind's survival which is discussed in the IPCC AR4 (2007).

Electricity generation is a major contributor to world $CO_2$ levels. In the US which is the largest electricity market, a staggering 49% of all electricity is generated from coal as outlined by the IEA (2007). In addition to this, China is allegedly reported to be building one coal fired electricity power station ever week, and in 2007 is reported to have surpassed the US as the largest $CO_2$ emitter as reported by The Guardian (2007). Thermal electricity generation from fossil fuels, e.g. turning 'coal into electricity' is highly inefficient with sometimes as little as 30% of the energy being converted to usable electricity. While tackling all our energy consumption is an important task, tackling the reduction of electricity consumption in domestic homes is a key place to focus.

So where does one start? In Ireland, 32% of all our electricity is consumed in domestic homes SEI (2009), thus there is a significant opportunity to focus on how to manage and consume this domestic electricity. In addition, because the domestic load contributes significantly to the 5-7pm peak on the grid, there is a huge value to many parties to be able to 'control' and 'predict' these loads. Ireland has an abundance of renewable energy sources off the coast of Ireland which does not have the same carbon content as traditional 'fossil fuel electricity'. Thus getting people to match their usage with the availability of renewable energy could greatly reduce our carbon footprint from electricity generation and consumption. It is shown in this dissertation that smart meters are an important tool to ensure that these goals are achieved.

This research is not solely focused on the challenges facing Ireland. However, much of the data from the Irish economy and electricity market is used.

### 1.3 Background to the project

The future of smart metering will depend heavily on the policy and decisiveness of all governmental bodies responsible, as large capital investment is required to rollout such projects, according to Gerwen, Saskia et al (2006). A more recent report from the UK, DECC UK (2009) shows that the cost of deployment and ownership is significant and the approaches to calculating the payback can require many assumptions. Energy savings and an increased security of supply are some of the main drivers and many now believe the smart metering of electricity as a means to reach these goals is indispensable. However, how consumers interact and respond to the services and functionality of smart meters, which is beyond any pure technical solution, are shown in this research to be vital to the success of smart meters delivering on all the benefits that the supporters of smart meters currently promise. In the Olympic Peninsula project in Washington State it was shown that significant savings can be made by providing an integrated smart grid solution for consumers as documented by Kiesling (2008).

This research shows how important, both the human interface and ergonomics of smart meters are, to realising many of the goals that smart meter projects set out to deliver. Without humans changing their behaviour many of the expected benefits may not be realised. To change consumer behaviour, the correct approach that delivers tangible results with consumers must be understood and delivered in the appropriate manner.

The installed landscape of smart meters and smart grids in Ireland, as well as the rest of the world, will change dramatically over the next ten years as many of the leading markets rollout out more and more projects. This has been discussed often in the press going back over several years - Irish Times (2007). This dissertation proposes how smart meters may be integrated into domestic homes for the benefit of the homeowner, the grid manager and residential electricity supply companies with a focus on the future functionality rather than the current capabilities.

In the remainder of this chapter, the specific aims and objectives of the dissertation will be discussed, and the research methods to be used in support of these aims and objectives explained. The structure of the dissertation chapters will then be outlined. This will be followed by a brief overview of smart meter technology in order to provide a context for the subject area of this dissertation.

## 1.4 Electricity and society

Lovelock (2009) discusses how electricity is a key source of power for our modern society and its economies, and thus, it is imperative to have a strategy in place to ensure that correct generation mix and the right smart transmission and distribution are in place, to deliver the electrical requirements to match our economic and social growth.

Electricity is one of the most pervasive, flexible and complicated power sources that are available. Unlike most other energy sources such as hydro, oil or coal, electricity currently cannot be stored in large scale volumes in a cost effective way other than some pumped storage plant as discussed by O'Malley (2007). Most renewable energy sources such as wind, solar photovoltaic (solarPV), tidal, wave, fuel cells and large scale geothermal plants all generate electricity as their primary energy output. The world's consumption of electrical power continues to increase, as can be seen from figure 1.2 below. Emissions from the electricity generation sector is one of the largest global emitters of $CO_2$.

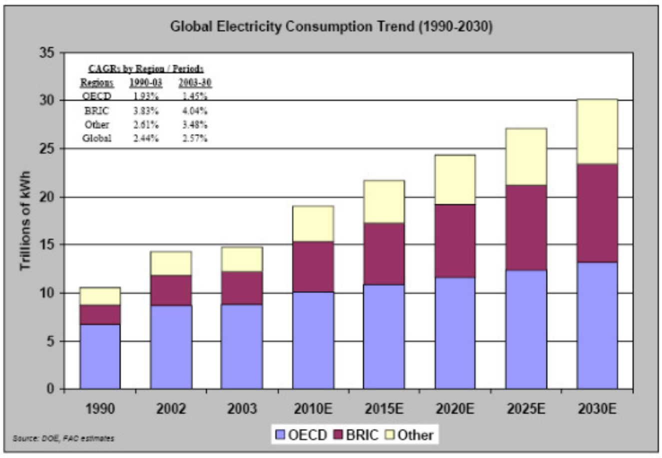


**Figure 1.2: Global Electricity consumption - Source IEA 2009**

Electricity is needed all the time for our modern day society to operate. Our cities would cease to function in a very short time if there was no electricity as outlined by

Lovelock (2009). Our sewage systems, hospitals, traffic lights, cooking, heating, telecommunications, computers, home appliances, etc., all depend on electricity For these and many other reasons, the implementation of smart grids, which will transport and manage electricity, has become a very important area of research, development and deployment. So much so, that one now observes unlikely bedfellows such as Google and GE forming partners in this space as discussed by Google and GE executives Google (2007). Because electricity is difficult and expensive to store, there is a requirement to transfer it from wherever it is generated, to wherever it is needed with as few losses as possible. Transmission losses can account for as much as 10% of the electricity generated. While hugely important this research is not focused on the transmission of electricity and the associated losses.

In Italy, where Enel have rolled out over thirty two million smart meters, their primary focus was to stop consumer fraud of electricity and to provide better and cheaper meter reading capability as discussed by Gerwen, et al (2006). Enel is now planning to upgrade these meters with ‘smarter’ meters that can provide more functionality as outlined by Enel (2010). European regulation is also mandating that smart meters are rolled out across national networks - EU Directive (2004). In addition, the Obama administration has recently approved $8bn for smart meter and smart grid research, development and deployment - Business Week (2009).

One of the aims of future Smart grids is to find the most efficient way to transfer energy from a plentiful supply, where generation occurs, to another geographical region where it is needed. This will grow in importance as more renewable energy is harnessed in remote locations. In Ireland there is an abundance of wind and wave power off the west coast, however, the demand for energy is primarily on the south and east coasts. In addition, the intermittent nature of these types of renewable power requires ‘smart management’ in order for it to be fully utilised. Thus the challenge of ‘moving electricity’ efficiently from one place to another will increase as more and more renewable energy comes on stream. This is discussed further in Chapter 2.

Today in Ireland a smart meter pilot is being rolled out across the country with up to 10,000 meters installations planned, according to The CER (2009) status report. Across the globe large scale smart meter projects are being rolled out in Canada, the US, Australia, Sweden and the rest of Europe.

## 1.5 Research Aims and Objectives

To understand the opportunity for smart meters the current and future landscape are researched and documented. The overall aim of this dissertation was to research the importance of how the human interface and their engagement to smart meters can be implemented to achieve the best response from consumers. This research focused on four key pillars:-

- The research and analyses of the key commercial driving factor for the introduction of smart metering by electricity providers. Why will smart meters be installed? Why is this happening now? What are the commercial, technical, energy and environmental reason for doing it?
- The accurate categorisation of the functionality that the industry defines as "smart metering" in relation to the different needs of the various parties such as the consumer and electricity providers. What benefits justifies the rollout of a network of smart meters. Is it automated billing, load shedding, variable tariff implementation or network management?
- An investigation to examine the current technology available to provide smart metering as defined by the benefits delivered to the various parties. What benefits are delivered to each part and what is likely to be the future goals of smart meters.
- The research and analysis of the techniques and approaches to improve the interaction with the home and the smart meter with a view to giving better tariffs to consumers by controlling the house's load and supplying useful feedback to encourage and aid in behavioural changes, both leading to 'load balancing' and 'load shedding'.

The importance of this research can be justified on the basis that smart meters will become ubiquitous over the next decade and are an important part of the electrical grids of the future. Thus, a sound understanding of their impact and potential benefits with existing and future technologies and market developments is a valuable research exercise. How humans interact with smart meters is an important part of the deployment strategy of future smart meter projects.

### 1.5.1 Expected challenges

Smart metering is such a nascent industry that there is not an abundance of information freely available. Many of the business cases are still to be proven especially when it comes to the integration of future functionality such as load shedding and the integration of renewable energy and electric vehicles.

## 1.6 Research methods

The research for this dissertation used three methods:

- Secondary research
- Primary research
- Critical analysis

*Secondary* research consisted of a search and review of available literature. This included a full search of international journals, conference proceedings, international standards, and published texts from respected bodies and parties in the area. Internet based searches of online articles, press releases, government documents, professional publications, vendor literature and industry publications. White papers where appropriate will also be used In the use of secondary research, it will be necessary to distinguish between information based upon latter day 'green enthusiasm', and proven, credible facts about the smart meter industry. Given the hype and inflated optimism of the 'green' industry today, some of the material produced may be influenced by unrealistic expectations of the costs and installations of smart meters.

Research material will be obtained by using the library facilities at the Dublin Institute of Technology, and Trinity College Dublin.

*Primary research* was required in order to provide partial validation of market view as discussed in chapter 4. This involved face-to-face interviews with appropriate representatives from the selected organisations as well as the execution of a consumer survey.

The secondary and primary research is critically reviewed in order to formulate and review the best approach to smart meters and the conclusions arrived at in this dissertation.

## 1.7 Organisation of dissertation – Should I make these sentences?

The contents of chapters two through five are as follows:-

Chapter 2:- is a review of the current infrastructure that is in place. How the energy grid is structured, managed, regulated and operated and the opportunities and challenges for smart grids within this framework. This chapter will look at the challenges facing electricity grids today; how renewable energy is changing the way electricity grids need to be managed. What smart meter technology is already deployed and some of the key projects are discussed.

Chapter 3:- Discusses the author's proposed architectural design to implementing smart meters. UML is used to document the proposed workable data flow between the parties, the processes and the technology. The approach taken to the survey that was carried out, the objectives of the survey and how it was implemented are discussed. The challenges and issues faced by the author to collect the energy usage and behavioural data are discussed.

Chapter 4:- Discusses the results of the survey that was carried out. The implication of the results on how smart meter technology may be rolled out is discussed. A review of the workable solutions interface consumers are most likely to respond to and why. How UML was use to develop the proposed solution.

In Chapter 5, a summary of the dissertation is provided and conclusions are restated. The contributions to the body of knowledge are defined and recommendations on areas for further research are provided.

# 2 Overview of the electricity market

## 2.1 Introduction

This chapter focuses on clarifying the fundamental aspects of the Irish electrical supply network from a technology, organisational and legislative standpoint. Section 2.2 describes the Unified Modelling Language (UML) paradigm for modelling systems. UML is a generic open standard modelling language that greatly enhances the assimilation of system design through to system implementation, irrespective of the application domain. It has been used successfully in aircraft design, museum exhibits and medical software domains. UML is used through all chapters of this thesis for consistency purposes, to illustrate the systems in additional depth other than just a written description. Section 2.3 introduces the structure of the Irish market including the Commission for Energy Regulation (CER) highlighting the structures and importance of key stakeholders in the Irish market. Using the existing topology as shown in figure 2.1 below, section 2.4 describes the generation aspects of energy which will be supplied to the national grid. This includes both traditional and renewable energy production. Section 2.5 explains the network grid and interconnection points between the suppliers of electricity, from all its various forms (i.e. fossil fuels wind, renewables) and the consumers of electricity (i.e. electrical cars, domestic and industrial customers). Section 2.6 details the issues and factors with regard to the consumers, relating to their impact and possible energy saving capacity in the larger energy supply system. Section 2.7 introduces the concept of existing metering approaches and Section 2.8 details the smart metering aspects in relation to the current market direction. This section also reviews the categories of smart meter technology currently in the market. Section 2.9 provides a high level review of a number of existing projects in the area of smart metering from different countries attempting to incorporate this metering dynamic. Section 2.10 outlines the options available to implement a robust consumer interface. Section 2.11 discusses where the costs lie and who pays for smart meters infrastructures. Section 2.10 summarises the main points of this chapter.

Figure 2.1 below shows at a high level in diagrammatic format the key parties in the electricity supply chain. This format is used throughout the document to show the progression of the design and implementation of the author's solution.

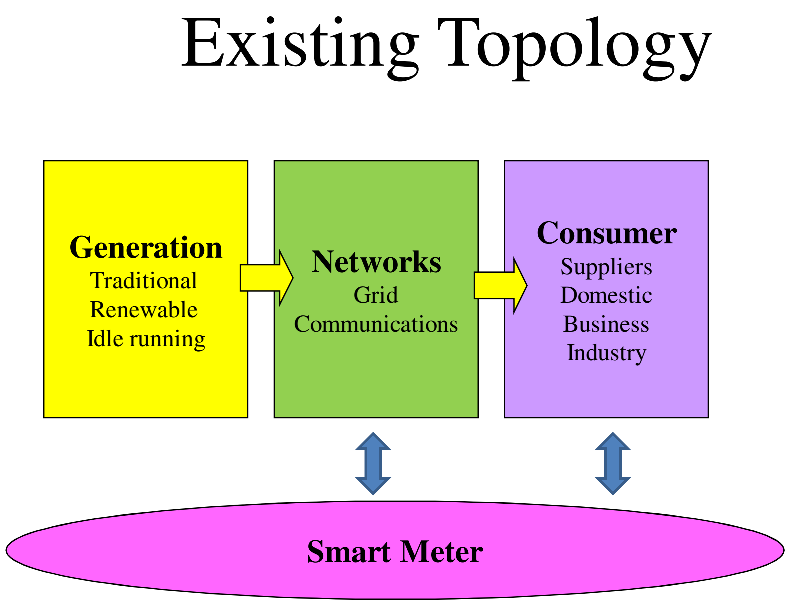


**Figure 2.1: Existing Smart Meter Topology**

## 2.2 The use of Unified Messaging Language (UML)

Unified Messaging Language (UML) is a generic open standard modelling language that greatly enhances the assimilation of system design through to system implementation, irrespective of the application domain. It has been used successfully in aircraft design, museum exhibits and medical software domains. Throughout this report the author has used UML as the standard for depicting the process and data flows between the various parties. Further details on UML can be found at http://www.uml.org/

This tool was chosen because it is an open standard that aids in the assimilation of system design to system implementation. All the available structured diagrams and resources available in UML were not required. Sequence diagrams and Activity diagrams were mainly employed to convey findings and designs as these allowed the author to easily depict the interaction between users, process and data structures in a consistent manner.

## 2.3 The structure of the Irish market

This section outlines the key parties and structure of the Irish market with respect to the rollout of a smart meter project.

### 2.3.1 The Commission for Energy Regulation

The Commission for Energy Regulation (CER) is responsible for putting in place regulatory mechanisms to ensure that significant and sufficient investment takes place to support the energy needs of the Irish economy. Under the Electricity Regulation Act 1999, CER was given this responsibility. This involved the deregulation of the market in order to encourage the entry of competition and new investment into the market by new and existing players. Rules were established for both a wholesale electricity market and a retail electricity market.

In Ireland CER is responsible for the planning and justification of the smart meter project rollout. It has the important role of setting out the economic framework for the parties and where the capital payment for the project will lie. CER will also set the regulation for market trading and dynamic pricing of energy to consumers.

### 2.3.2 Key structure of the Irish market

Figure 2.2 shows the structure of how the Irish market operates as outlined in the Helicopter guide published by CER (2007). The basic principle is that generators forward sell their capacity to the pool. Suppliers forward or spot buy their power from this pool. Suppliers sell electricity to their end customers which can be consumers, businesses, governments bodies etc. Consumers do not currently forward purchasing their power from suppliers. New 'Pass-through' (purchase price tracking the half hourly spot price) tariffs from suppliers such as Vayu are becoming more popular with business customers, but these have not yet being offered to consumers.

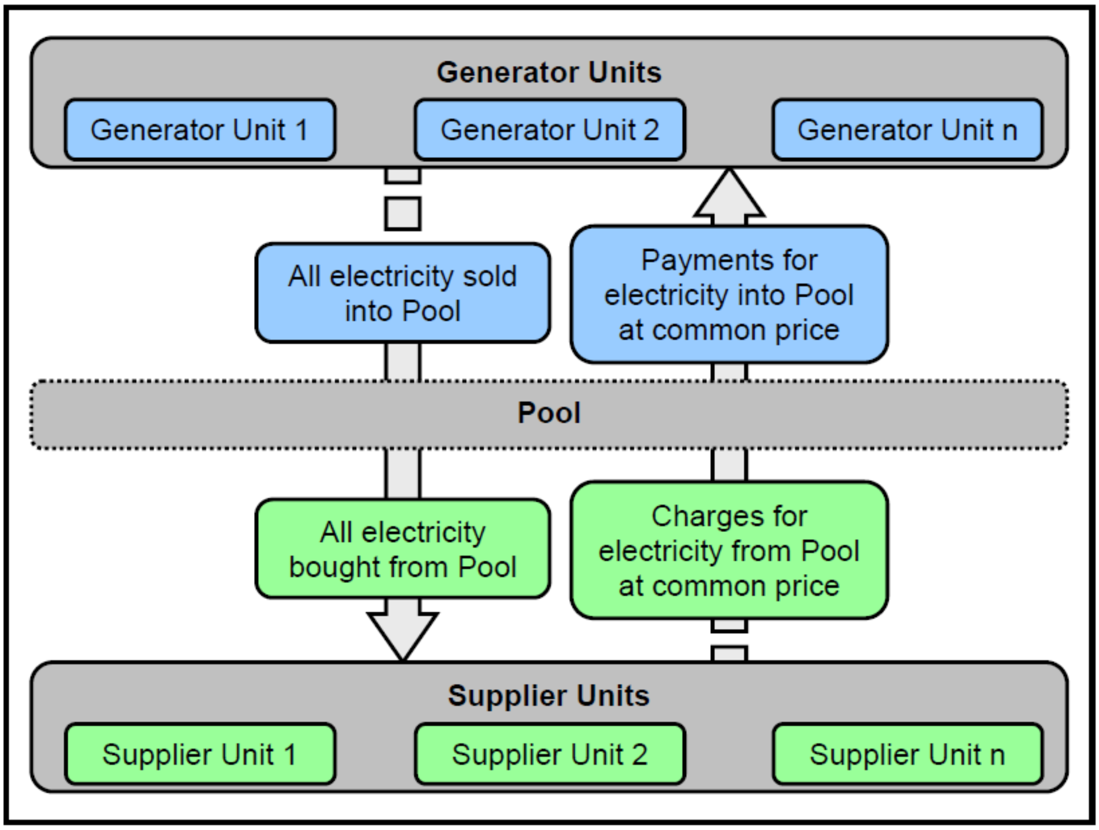


**Figure 2.2: Operation of the Irish electricity market - CER**

The real challenge for both the generators and the suppliers is that they have very little or no control over the domestic home owners' demands on the market. Along with generating plant failure, this is one of the key reasons for the huge over capacity, in the form of ancillary services and spinning reserve that must be kept in place in all electricity grids. These services must be provided by traditional generation plant being kept idle or in standby mode. This is at a significant economic and environmental cost to the economy of Ireland - Eirgrid (2010). Ancillary services are required to ensure that there is enough spare generating capacity in the network in the event of a fault in transmission or generation. Generators are contracted by Eirgrid to keep their plant 'spinning' in order to be able to meet this requirement. This has the negative environmental impact of 'wasting' energy that is not generating any useful electricity. As more 'Peaker plants' such as Open Cycle gas turbines, which have got a fast response time are built, the requirement for spinning reserve is being reduced.

The opposite of generation is load shedding which has the same impact on the network as adding generation (virtual generation), but requires far less capital to implement. In Ireland this is called Winter Peak Demand Reduction Scheme (WPDRS) which is open to large energy users with interruptible load to participate in. With smart meters in every home the ability to create virtual power plants is greatly increased. Smart meters could possibly allow the grid operators to turn off a home's electrical appliances such as fridges, water and space heaters, dishwashers and washing machines to provide virtual capacity in times of network shortages. The corollary of this would also work in times of high generating capacity from renewable energy. In this instance home appliances could be 'turned on' to create a demand for the power that is generated. This concept will be expanded and explored later.

### 2.3.3 Meter Registration System Operator (MRSO)

In Ireland the MRSO is a key player in the rollout and implementation of a smart meter project. A key function of smart meters is recording usage by time so as to allow accurate billing. With a smart meter rollout the complexity of the operatoin of the MRSO is greatly enhanced.

Under The Electricity Regulation Act, 1999, some of Ireland's largest customers became eligible to purchase electricity from any authorised supplier. To support this new environment, a number of new parties had to be set up to support this new competitive electricity market. The Meter Registration System Operator (MRSO) which provides a central registration and data management services to the market was one of those new parties.

The MRSO is a "ring fenced" function within ESB Networks responsible for the Change of Supplier process and the processing/aggregation of meter data required to support Trading & Settlement in the competitive electricity market.

A central meter registration system is essential in order to associate each metering point with a supplier. This ensures that each supplier can be billed for the energy consumed by their customers and to ensure that transmission and distribution use of system charges can be calculated for the metering points for which each supplier is responsible.

With smart meters and the likely introduction of dynamic pricing created by time of use tariffs as well as significant intermittent renewable energy generation, the market and the settlement process will get more complex in the future and the role for the MRSO more cumbersome. However, this complexity is still several years away.

Figure 2.3 is a simplified view of the structure and function of the MRSO.

See

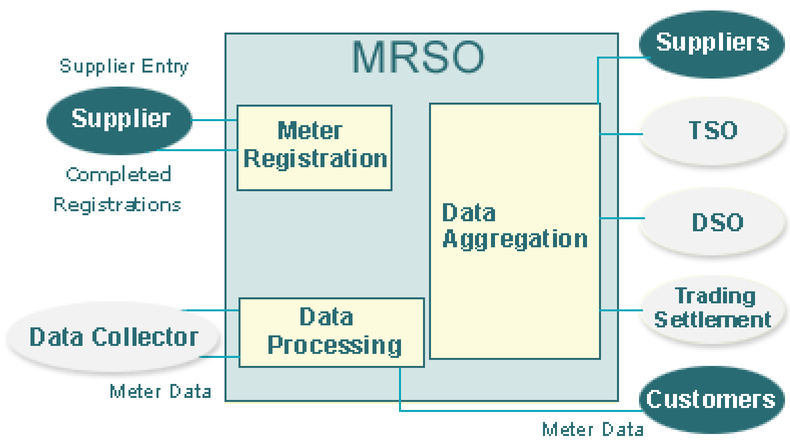


**Figure 2.3: Structure of the MRSP – Source: MRSO**

## 2.4 Electricity generation

This section is a high level review of the current generation capacity, fuel sources and economics of electricity generation. It outlines the scale of the planned introduction of wind energy into the Irish national grid and outlines some of the challenges faced.

### 2.4.1 Generation today

The majority of Ireland's electricity generation is from central power plants such as Moneypoint (coal), and the growing number of combined cycle gas turbines (CCGT's). In Ireland gas now accounts for 55% of our total supply. In addition 93% of our total electricity is from fossil fuels which have a direct impact on our reliance of imports and the long term security of our supply.

Looking at the percentage share from 1990 to 2008 what figure 2.4 below shows is:-

- Wind has the biggest change from 0% to 4%
- Gas has jumped significantly from 27% to 55%
- Fossil fuels has reduced from 98% to 93%

In Ireland, like so many other countries there is a huge dependence of fossil fuels while also emerging is a huge growth in the deployment of renewable energy.

| | Growth % | Average annual growth rates % | | | | | | Shares % | |
|---|---|---|---|---|---|---|---|---|---|
| | 1990 – 2008 | '90 – '08 | '90 – '95 | '95 – '00 | '00 – '05 | '05 – '08 | 2008 | 1990 | 2008 |
| Fossil Fuels (Total) | 57.4 | 2.6 | 4.4 | 4.9 | -0.2 | 0.2 | 1.5 | 98.1 | 92.9 |
| Coal | -16.0 | -1.0 | 3.8 | -0.9 | -0.2 | -9.6 | -6.9 | 40.3 | 20.4 |
| Peat | -6.3 | -0.4 | -1.0 | -3.1 | 0.8 | 3.5 | 29.2 | 19.5 | 11.0 |
| Oil (Total) | 2.8 | 0.2 | 12.9 | 10.7 | -5.7 | -23.2 | -13.2 | 11.0 | 6.8 |
| Fuel oil | 0.3 | 0.0 | 12.6 | 10.5 | -6.9 | -21.7 | -8.0 | 10.8 | 6.5 |
| Gas oil | 43.4 | 2.0 | 16.5 | 13.3 | 18.8 | -46.7 | -67.2 | 0.2 | 0.2 |
| Gas | 233.5 | 6.9 | 4.7 | 11.5 | 2.3 | 11.2 | 2.7 | 27.3 | 54.7 |
| Renewables (Total) | 448.5 | 9.9 | 0.9 | 13.4 | 8.9 | 22.3 | 27.5 | 1.9 | 6.4 |
| Hydro | 38.9 | 1.8 | 0.5 | 3.5 | -5.7 | 15.3 | 45.3 | 1.9 | 1.6 |
| Wind | - | - | - | 72.4 | 35.4 | 29.4 | 23.1 | 0.0 | 4.0 |
| Combustible Fuels (Total) | 58.7 | 2.6 | 4.4 | 5.1 | -0.2 | 0.3 | 1.6 | 98.1 | 93.6 |
| Electricity Imports | - | - | - | 45.6 | 83.6 | -39.6 | -66.2 | 0.0 | 0.8 |
| **Total** | **66.2** | **2.9** | **4.3** | **5.2** | **0.7** | **0.3** | **1.3** | | |

**Figure 2.4: Electricity Generation in Ireland 2008 – Source: SEI (2009)**

Because the majority of our power plants are large and often in remote regions such as MoneyPoint their electrical output could incur significant transmission losses (circa 5-10%) getting power to end users. With more wind generation on the network in remote regions on the West coast of Ireland, there will be an increase in this phenomenon. While Money Point is seen as a 'base load' provider to the Irish grid, and due to its operational parameters, is unlikely to be turned on/off or up/down in short timescales, having intelligence and flexibility in the grid would greatly improve how such plant is dispatched on the network.

With a smart grid, the transmission on the network could be greatly optimised by matching the location and time of the generation to allow for both more efficient generation and consumption of power across the grid. This balancing will not be possible in all cases but an improvement on the current situation is possible.

### 2.4.2 The economics for the generators

Figure 2.5 below shows the economic challenges for generators and grid managers in matching the demand and supply curve. The generators want to produce enough electricity that allows them make a profit in line with their capital investment in their generating plant. Consumers want to buy electricity at the cheapest rate. However, very little use (purchase) of electricity is discretionary, as power is required for basic living needs. Thus there will always be a demand for electricity even at exceptionally high prices.

The simple economics are, the higher the price the lower the demand and vice-versa. Without the ability to have variable tariffs the supply/demand curve remains very static.

In theory, once consumer behaviour can be changed, smart meters allow the dynamics of the supply/demand curve to vary by changing the price. Thus the demand (consumer usage) can be better matched to the generating capacity (supply). This is a win-win scenario, as the consumer gets cheaper electricity and the generators get to sell more electricity when it is economically more beneficial for them to produce it. In addition the grid managers do not need to build expensive grids to deal with peak capacity as the peaks can now be curtailed to a somewhat predictable amount.

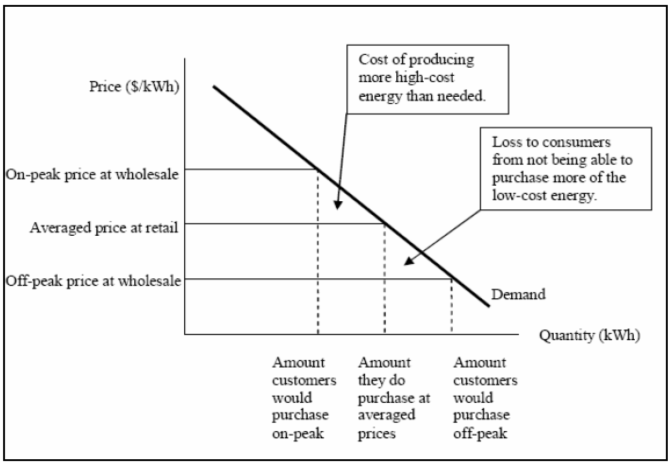


**Figure 2.5: Economics of Generation - Source Edison Electric Institute (2006)**

### 2.4.3 Renewable energy coming on the grid

Electricity is the most common output of power from wind turbines, solar power, geothermal and ocean and tidal energy. Unlike many other forms of energy such as petrol, gas coal etc., electricity for grid consumption cannot today be stored in large quantities that make economic sense for the generator or the end consumer as discussed by Keane & O'Malley (2005).

Like many other countries, Ireland has plans to install significant amounts of wind power onto its electrical grid. See figure 2.6 below. Without significant interconnectors, if the demand side of the electrical system is not managed, significant ancillary services will have to be kept in place to stabilise the grid in times of poor wind output. This is discussed later. For Ireland, this could actually lead to an increase in the price of our electricity as the regulator would have to put levies on our bills to pay for ancillary services; provide economic support for the REFIT tariffs that are in place; and to build the network required to support wind generators most of which are in remote westerly locations in Ireland.

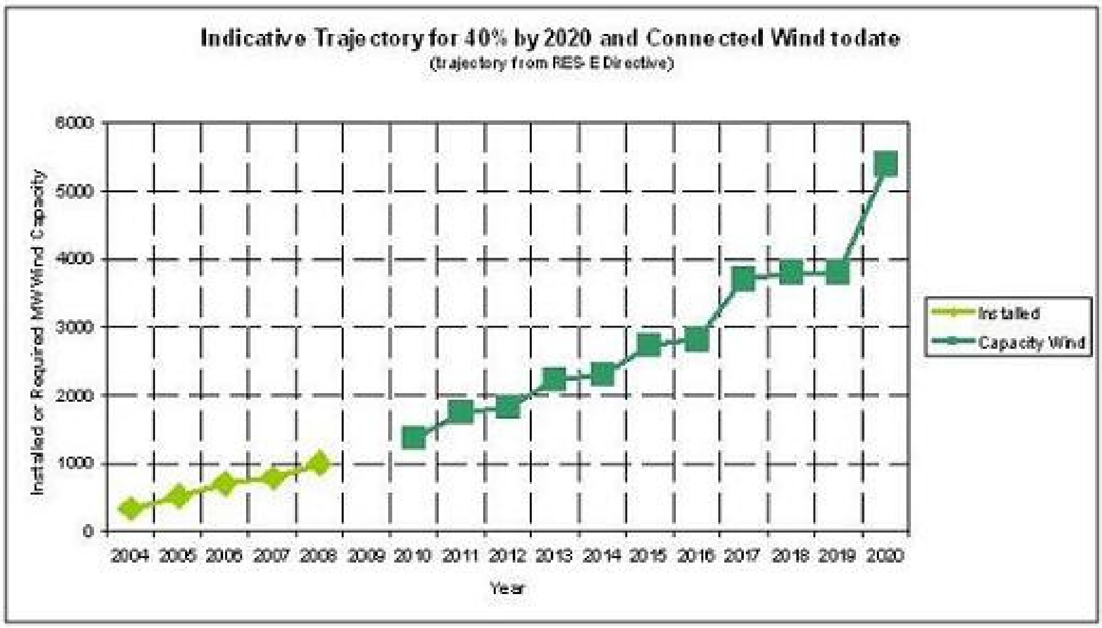


**Figure 2.6: Wind generation capacity in Ireland – Source: Eirgrid (2010)**

### 2.4.4 The variable nature of wind

With the increase of renewable energy coming on to national grids there is an urgent requirement for the energy to be transmitted and consumed in an efficient way that can match the demand curve of the grid. It is possible to forecast with reasonable accuracy when wind energy will be generated for a wind farm or single turbine as shown by Kariniotakis (2004). While forecastable, renewable energy such as wind energy becomes available to the grid operator at random times during the day. The grid operator has limited user friendly options to control the demand side of the network thus to keep the network stable he must resource to having traditional generating capacity available to them.

Figure 2.7 below shows the electricity generated in MW from the wind sites in Ireland on the 7th September 2009. What can be seen from the graph is the random nature of the curve. The power output is at its lowest at 9am (80MW) and at its highest close to midnight (940MW). Reviewing the data available on the Eirgrid website one can see visually the variable nature of wind generation. It is this variation that is one of the challenges for the integration of large scale wind into electrical grids.

So while the planned installed capacity of wind on the Irish network (6MW) might exceed the current maximum winter demand of the network (5.3MW) it is still not possible for the grid operators to rely on wind as a stable source of energy to match the demand on the network.

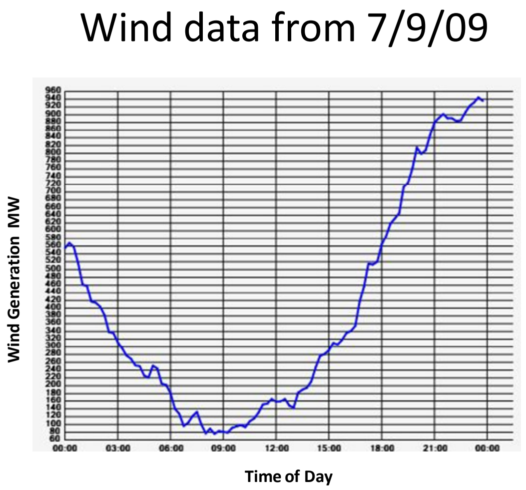


**Figure 2.7: Daily wind data – Source: Eirgrid (2009)**

With smart grids, the benefit to the system and the customers is that excess energy could be used when it is available at a cheaper rate. In addition the grid operators would have the ability to 'turn down' demand when the energy is not there, thus creating a 'virtual power supply'. This will be discussed in the next chapter.

## 2.5 The electricity grid

This section outlines the key components of the electricity grid from a transmission and demand management perspective. It looks at seasonal variation as well as user driven demand curves.

### 2.5.1 The transmission network

The electricity transmission system, commonly known as the national grid or 'The Grid', is a high voltage network for the transmission of electricity around Ireland. The high voltage lines deliver electricity from Ireland's generation sources to the transformer stations, where the electricity voltage is reduced and taken onwards through the distribution system to individual customer's premises.

Eirgrid is the independent state-owned body licensed by the CER to act as Transmission System Operator (TSO) and is responsible for the operation, development and maintenance of the system. ESB Networks is licensed by the CER as the owner of the transmission system and is responsible for carrying out the maintenance and construction of the system. Transmission Use of System (TUoS) tariffs is the charge paid for using the transmission system. These charges are ultimately passed onto customers. CER directs and carries out annual reviews of these charges.

### 2.5.2 The distribution network

The distribution network is the medium and low voltage electricity network used to deliver electricity to houses, offices, shops, and street lights. The Distribution System Operator (DSO) is responsible for building, maintaining and operating the entire distribution level network infrastructure. This is currently ESB networks. Distribution Use of Service (DUOS) is the charge paid for using the distribution system. These charges are ultimately passed onto customers. CER directs and carries out annual reviews of these charges.

For the implementation of a smart meter project the costs of the meters and the installations are likely to reside with the distribution network. Thus the cost of the project is likely to be passed on to the end user in some form of tariff or levy. This is an important point as both ESB Networks and the CER, as the two key players, must agree a common approach to how this would be achieved.

### 2.5.3 Demand for electricity on the grid

The demand for electricity is important to understand as this is the driver to the cost of building and running the network. Any opportunity to reduce of shift peak loads can greatly reduce capital and operational costs.

The demand for electricity, including the consumer demand can be broken out into three distinct categories:-

- Yearly demand – variations across 365days - the entire network
- Daily demand – variations across 24 hours - the entire network
- User demand – variations across 24 hours for a typical home

The daily peaks, and in particular the winter peak demand, is what drives the sizing of the network.

#### 2.5.3.1 Yearly demand

The generation capacity for the Irish network must be big enough to meet the needs of the Irish economy. As can be seen from the Eirgrid graph in figure 2.8, this peaks at about 5,200MW during December/January time. There are two very interesting observations on this graph. Firstly, Eirgrid's strategy Eirgrid_a, (2009) for the development of the network shows uninterrupted growth of the demand on the Irish network going forward. However, the blue line shows that 2009's economic downturn had a direct impact on the demand for electricity, the lowest demand for the previous 2 years, which was not predicted in the strategy. Secondly, the cold snap at the start of 2010 can be seen as the green line in weeks one and two, showed a spike in demand for electricity greater than experienced during the previous three years. Planning for these peaks is crucial as unlike roads where traffic jams occur at peak times, the electricity network does not allow 'electron jams' as this would result in unplanned load shedding, or worse a serious or complete network failure which happened in the last decade in both Italy and in several US and Canadian states.

There is a long lead time in providing generating and transmission capacity on the network and thus predicting and managing the demand for electricity at the peak load is crucial, challenging and very capital intensive.

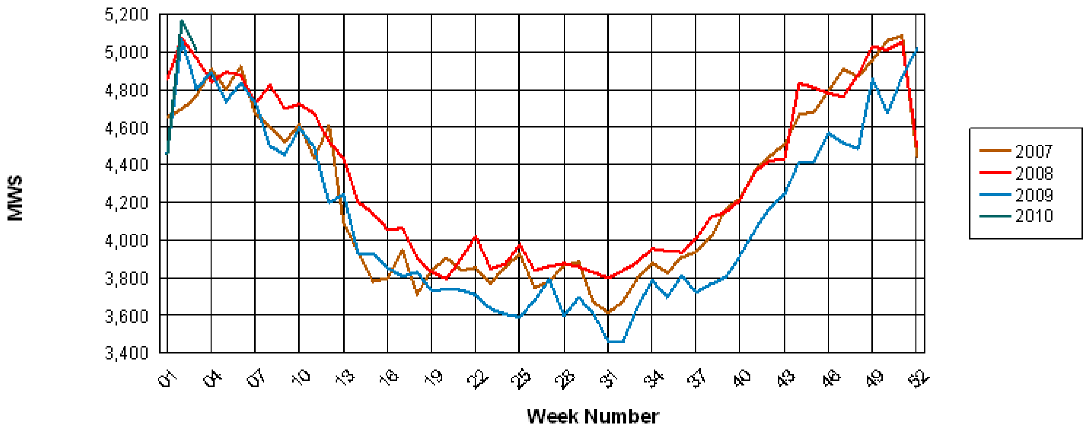


**Figure 2.8: Max energy demand by week – Source: Eirgrid**

For organisations that cannot afford to lose power they usually deploy their own generating capacity in the form of on-site generators. While seldom used, these generators also have the capacity to provide the smart grid with standby or virtual power generation. While this is an important part of the Smart Infrastructure this is not discussed in this dissertation.

### 2.5.4 Daily demand

Figure 2.9 below shows the daily demand for electricity on the network over a 24 hour period in March 2009. It is measured in MWs. What is clearly visible here is the significance of the 17:00 to 19:00 peak. It is this the ‘flattening’ of this peak that is one of the key objectives of smart meter rollouts.

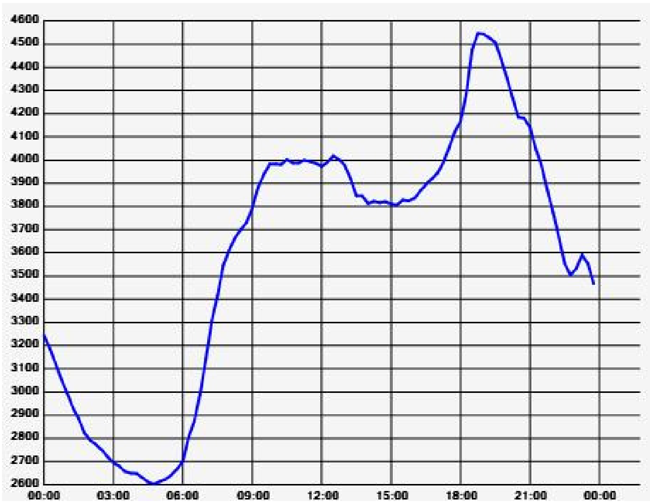


**Figure 2.9: Max energy demand by week – Source: Eirgrid**

### 2.5.5 Seasonal variation in daily load demand

The actual daily load demand curve for the Irish grid in January 2008 (blue) and August 2008 (red) is shown below in figure 2.10. This is for a typical winter’s and a summer’s day, Conlon (2008). What can be seen on these graphs are the actual variations over time from the base load. The network manager must adjust, in real time the generation capacity to meet this demand curve. Significant statistical data is available to be able to predict this with some degree of accuracy.

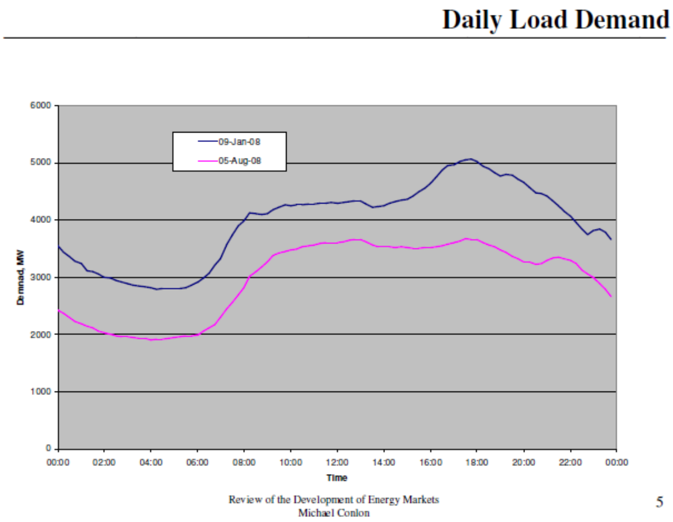


**Figure 2.10: – Seasonally load comparison – Source: Conlon (2008)**

The challenge is that network manager must have at his disposal the appropriate backup or ancillary power to meet these peaks as well as providing for any outages that may happen on the generation or transmission side of the network CER (2007). As can been seen from the Helicopter Guide, there is a financial cost as well as an environment cost to providing these ancillary services by network operator.

HydroPower generating plants such as Turlough Hill with a generating capacity of 292MW are ideal for dealing with such demand fluctuations. In addition new Combined Cycle Gas Turbines (CCGT) such as those in Aghada, Co Cork will be used to provide ‘peaking power plants’ capability - ESB (2009) - which gives the grid greater flexibility for rapid deploy of new generation to the grid. Providing ‘virtual power’ by having the capability to load shed based on consumer demand profile will also contribute significantly to managing this challenge.

### 2.5.6 Electric vehicles and the smart grid

As discussed, renewable energy will continue to increase year on year. In addition, there will be a huge growth of electric vehicles on our roads over the medium term. The Irish government has stated its target is to have 10% of all vehicles on the road by

2020 electric as stated by the ESB-EV (2009). The two areas of focus with electric vehicles for smart grids area:-

- Grid to vehicle – Charging the vehicle
- Vehicle to grid – Providing backup power to the grid

Electric vehicles may provide the 'storage capacity' that would allow excess power from renewable energy to be stored at the time the power is being generated. A smart grid could determine the best time to charge or discharge the batteries within electric vehicles. The options could be:-

- When tariffs are lowest e.g. at night-time - charge up batteries;
- When excess renewable energy is available such as when the wind is blowing or solar power available – charge up batteries;
- If the network needs more power to keep its frequency stable, the car's battery could be used to discharge power to the network.

In this simple scenario, the grid has access to 'virtual generation' or 'virtual storage' through the car battery. While this is still a very nascent industry, one could envisage great strides being made in this area. However, this option is challenged by 'a transportation' peak called 'Rush Hour'. The rush hour in Ireland occurs between 17:00 to 19:00 matching exactly the peak on the grid. While not all cars will be in 'Rush Hour' traffic, it could be reasonably assumed that a significant amount of the new electric vehicles on the road would be. However in other countries, where certain applications such as air conditioning often causes network peaks at different times, using electric vehicles for such a solution could deliver real benefits.

There is much debate about electric vehicles storing electricity to allow it to be exported to the grid as outlined by McGrath (2009). Smart meters will play a key part in the rollout of the Electric Vehicle infrastructure as they are likely to be the interface to the grid and control the charging times.

## 2.6 The consumer's usage and demand

Figure 2.11 below shows a graph of the typical domestic load for electricity in the UK. This shows 48 half hour settlement periods during a 24 hour day. The UK's electricity profile is very similar to Ireland's as they have similar climatic and lighting conditions. Two key observations to be made here is that there is always a base load. Thus our homes are always consuming electricity, even during the night. The peak load 17:00-19:00 has a very close correlation to the grid's peak load and thus it significantly contributes to the total peak demand on the network.

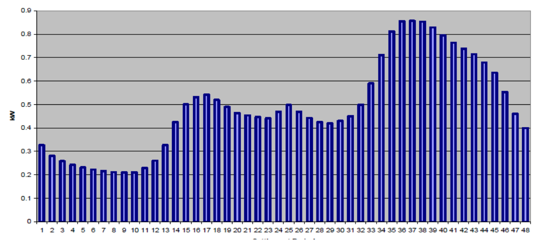

**Figure 2.11: Max domestic profile 24 hours – Source Elexon (2005)**

For both the domestic and business users there are currently no incentives to change their peak load away from the peak on the grid. Our society has built up around at 'nine to five' mentality and thus there will always have increased loads on the grid at these times. For electricity, some simple changes to behaviour, supported by control systems, will help manage the peak. These are:-

- Lighting – Home owners using lights when they are not required. These could be controlled by simple PIR's;
- Hot water is heated using immersions – these could be pre programmed to come on earlier or later;
- Clothes washing and drying cycles are turned on – with the correct control these could be performed at an off peak time;
- Cooking food - it is unlikely that the timing of cooking food by electricity could be changed much;

- Space heating:- with the growing number of geothermal and electrically powered heat exchangers, the timing and running of these could be modified.

### 2.6.1 Economics of electricity pricing for the consumer

Figure 2.12 below shows one of the key challenges facing the current pricing of electricity. Classical economic pricing says that as price falls demand goes up or as available stock reduces the price also goes up.

Utility companies to date have been unable to price domestic power differently as they could not tell when their customers consumed their power. Thus the price was always the same regardless of the demand (D2). While this gives the consumer transparency on their costs, it does not give them any sense of the cost to the 'utility companies' in providing this service. No matter how much electricity is demanded from the utility company, the domestic consumer expects to pay the same price.

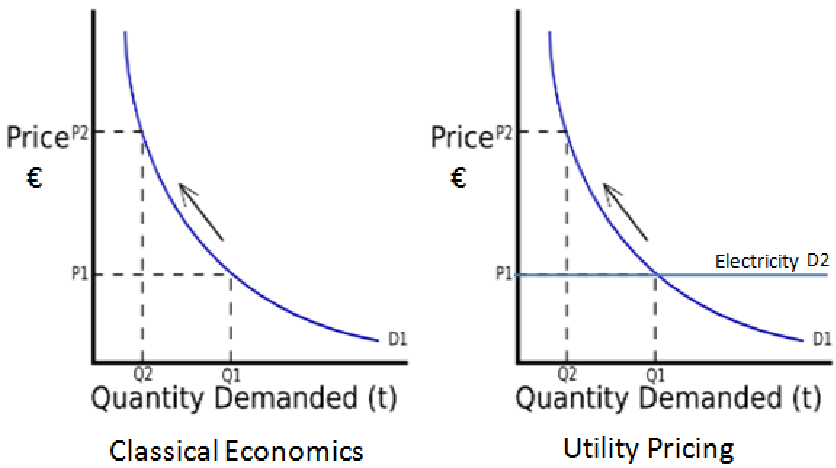


**Figure 2.12: Utility pricing model**

### 2.6.2 Domestic load profile & flat pricing

Domestic load profiles taken from British research, figure 2.13, carried out by Elexon (2009). The author superimposed on this a flat pricing model based solely on KWh and not time of use. For the consumer, it is clear that there is no incentive for them to change their behaviour and thus change their usage patterns.

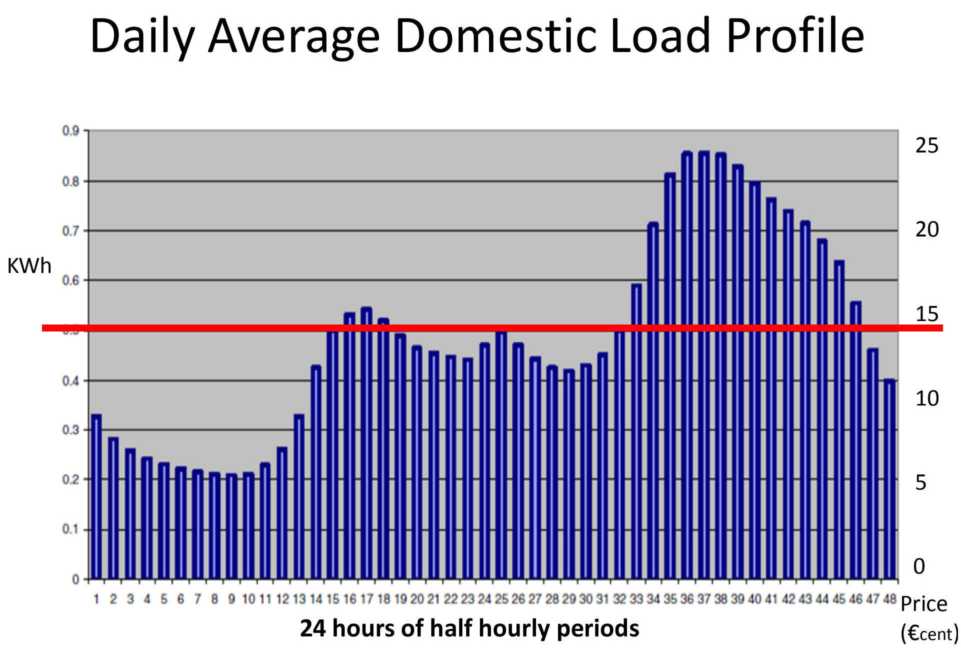


**Figure 2.13: Typical flat utility pricing**

Our society has developed over time in that the majority of people come home for work at the same time. Domestic customers turn on lights, heat their homes, cook their food and use their washing machines and tumble dryers in an unconstrained way. In general consumers know little about the details of energy consumption and for the most part are neither aware nor incentivised to use electricity at different times.

This is a very similar challenge to that faced by the mobile telecom operators. They experience a huge spike in demand as people leave work and start to return home or go out for the night. One way they have attempted to 'flatten' this curve is by offering price plans that offer 'off-peak' peak rates after 8 pm. However, these price plans are often considered complicated and unwieldy and people tend to make calls when they want to and don't always consider putting off making calls because of price.

### 2.6.3 User demand changes

By changing pricing, traditional economic models suggest that consumers will change demand. However, as will be seen later in the chapter, changing people's behaviour is not that straightforward a task and 'convenience of use is' something consumers feel is worth paying for. This reflects what the mobile telecom companies experienced.

An overlay illustration in red on figure 2.14 below shows indicative pricing at the peak demand. This pricing is likely to see some consumer usage move outside of the peak demands. How this is achieved with total reliance on behavioural change was seen as a key insight to the research of many smart meter projects.

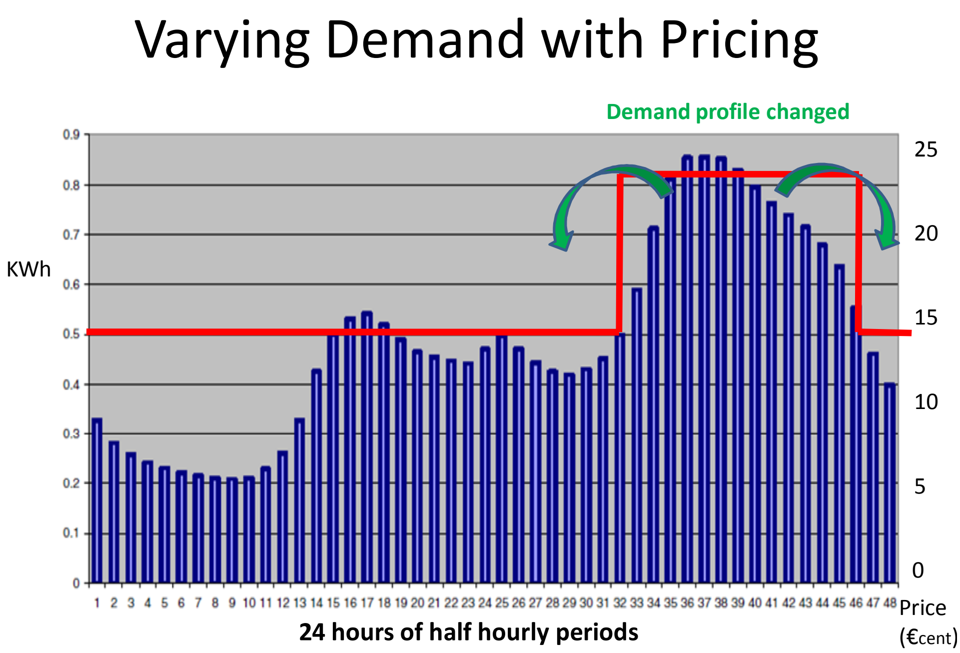


**Figure 2.14: Utility pricing peak rate**

## 2.7 Metering today

For the vast majority of retail customers, the supply of their electricity, the metering of its usage and the billing and invoicing, have been performed in the same manner since electricity metering first begun. A mechanical meter is placed in a customer's premises and this records the usages in KWh. These meters have no intelligence and can only read by human intervention. They are often called 'dumb meters' and were first introduced in 1889 and are only now being replaced by electronic meters as discussed by Boyle, et al (2003). Once the usage data is collected and allocated to the correct customer, the electricity supply company issues an invoice ('a bill') for the usage every month or every two months.

### 2.7.1 The cost of Meter reading

Today in Ireland there is a cost associated with both reading electricity meters, with customer fraud and bad debts. For the most part, residential electricity meter reading is now outsourced. In Ireland, meters are supposed to be read four times a year according to ESB Customer Supply (2010). In the United States, utilities have reported between 0.2 percent to as much as 0.7 percent or more of their revenues as bad debt ESRI (2007).

The author calculated that these two costs together combine to give total costs of €15 million per year for Ireland – (See Appendix G). The Cost Benefit Analysis (CBA) for the Irish network is due to be completed in 2010/2011 by the ESRI Ireland for the CER which should identify the savings and returns from the projects. While there are huge complexities in the development of a fully justified CBA, what is clear is that there are significant savings to be made from meter reading, bad debt and fraud when viewed over a twenty year payback period. Any further return on investment, such as renewable energy integration, improved grid management, electric vehicle rollout etc. are unknowns at this time and are of a more speculative nature as they are market dependent. The UK report compiled by DECC UK (2009) views the data in a different manner but believes that theft could be reduced by as much as 20-30%.

### 2.7.2 The process of metering today

Below in figure 2.15 the UML representation of the process and the data flows between the customer and customer billing as documented. For simplicity the billing entity represents both the entity that reads the meter and the supplier of electricity that generates the bills.

This UML diagram represents how the data flow and activities must occur with the current mechanical meter reading environment. This example shows that there is no link between the meter in the house and the consumption profile from the individual houses. The consumer blindly uses power without knowing their usage, time of use or cost per period of their consumed power.

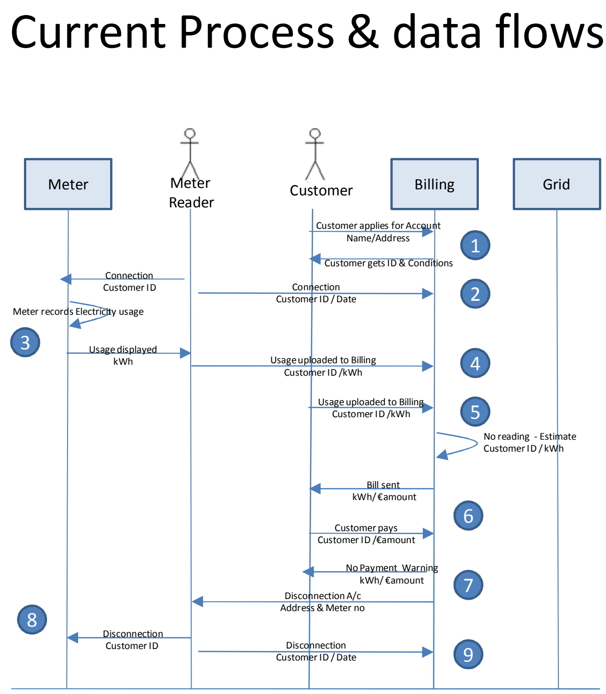


**Figure 2.15: UML Meter reading today**

The steps in the existing process are:-

1. The customer is set up with an account;
2. The date of connection is recorded in the billing system;

3. The meter records electricity usage in the customer’s property and this is available for the meter reader or home owner to read;
4. The meter is manually read by a meter reader, which requires a visit to the property several times a year according to ESB networks - ESB Customer Supply – (2010).
5. The customer may read the meter and dial in readings; If no readings are received the billing system generates an estimate of the usage;
6. The customer is sent out an invoice for their retrospective usage and the invoice is paid;
7. If the customer fails to pay on time they are issued with a warning;
8. If the invoice continues to remain unpaid the ‘meter reader’ must visit the property to disconnect the service;
9. The disconnection date is recorded in the billing system.

The shortcomings of the existing process are:-

- A manual intervention is required to read a meter by either:-
  - a meter reader (which is costly) or
  - by the customer entering a reading over the phone
- Estimated readings are often used if readings are not received on time, which can lead to inaccuracy in billing runs and ‘bill shock’ for customers.
- The customer does not realise the usage until the bill arrives.
- The customer pays the same amount for the electricity regardless of use of electricity (unless the customer is on a ‘night rate’ tariff.)
- Regardless of what is happening on the electricity network, the operator of the network cannot control or influence the customer usage profile as there are no tariff incentives for time of use changes.
- To disconnect a customer, human intervention on the customer site is required which is costly.

- The network operator or meter reader cannot tell if any fraud (stealing of electricity) is occurring until a meter reading takes place or if a site inspection is performed.
- What it shown later is that the majority of currently deployed smart meter models are no more than glorifed 'data collectors' replicating the mechanical meters. This does not add greatly to any pre planning of electricity consumption for the grid operator. A more sophisticated data model is required to deliver all the benefits promised. This is discussed later.

## 2.8 Smart metering – definition

The term smart metering today is used to define a class of meter that has intelligence built in to the meter. This intelligence allows the smart meter to record the usage (KWh) over the course of a day into regular intervals such as hours or half hours. Having recorded this information, the party that is responsible for performing the meter reading, can 'connect to' the meter and collect the customer usage since the last connection. This connection may be performed using several technologies as discussed in later in this chapter. In Ireland this function is currently performed by the Meter Registration System Operator (MRSO). Once this usage data is collected a tariff may be applied to the bill based on usage (KWh) and the time of use of each KWh.

Net metering is another possible function of smart metering technology. Net metering is typically deployed where a home or building has a micro-generator or distributed generation on or near their site. The electricity that is generated on site is recorded and compensated for usually under its own scheme. Smart meters can be deployed as net meters CER – MicroGen (2009) but this is not the subject of this research.

### 2.8.1 Smart meter Data flow – today

The UML diagram below in figure 2.16 depicts the data flows in the typical deployment of smart meters today. This smart meter model, as deployed by Enel in Italy is no more than a glorifed collector of data. The consumer is not aware of the usage by period and the cost associated with that usage, until after they receive the bill. Ideally there would be some automation by which the consumer's consumption is controlled locally or remotely (by the grid) to both match the customers desired profile and to provide load balancing (demand/ generation) capability for the grid.

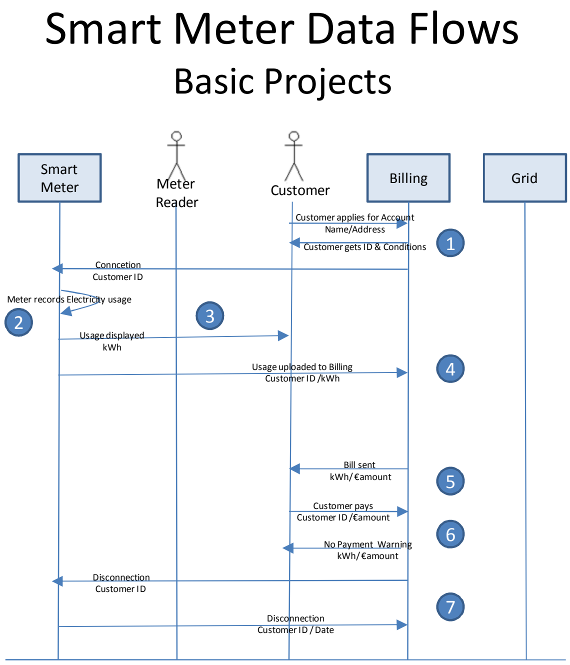


**Figure 2.16: UML Smart meter data flow today**

The data flows and steps in the existing process are:-

1. As with the previous scenario the customer is set up with an account. A smart meter is installed before or at this time;
2. The meter records electricity usage in the customer's property;
3. If the home owner can access the meter it can be visually read to get the current reading;

4. The meter automatically transfers the reading over a communications network;
5. The billing cycles are the same as before;
6. The credit management process is the same as before;
7. If the customer fails to pay then the supply can be turned off remotely using the smart meter. The disconnection date is recorded in the billing system.

While cost savings are delivered implementing this simple model, it does not give the consumer or the grid the data or the control to change the profile of the load profile in the customer's house. A more sophisticated model is required to deliver this benefit. However, Enel have found that some consumer behavioural changes are achieved by the implemention of a time based tariff alone. Enel (2010).

### 2.8.2 Categories of 'smart meters'

There are several different categories of 'smart meters' that currently exist. Below is a summary of the different classes. As more products come into the market they will be hybrids or extensions of what these products have to offer. This section below discusses the functionality of each product and the importance of such functionality to smart meter projects going forward.

### 2.8.3 Typical smart meter for domestic use

Today's typical smart meter just replaces the standard mechanical meter in place for many decades. The meter digitally records the usage in KWh on the customer's sites. The meters shown below are from Echelon and Landis & Gyr. These models have the capability to be 'dialled into' using GSM and to turn the power on and off remotely. Additional safety standards must be adhered to when power is being turned on in the house. There are many millions of these genres of smart meters installed around the globe and there are many projects currently on trial.

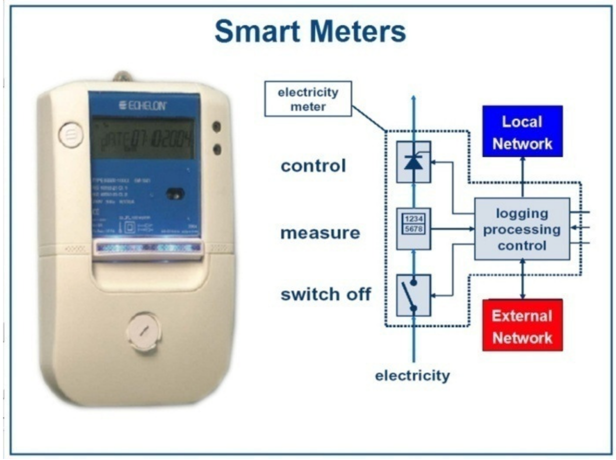


**Figure 2.17: Echelon smart meter - Source: Echelon (2009)**

**Figure 2.18: Landis & Gyr smart meter – Source Landis & Gyr (2009)**

The functionality provided by these smart meters is key to providing billing and reading capability. They also have the ability to terminate supply. However, these meters are not very user friendly and do not provide the consumer with data in a way that their usage could be understood. In most cases homes will not have easy access to these meters as they will be located outside the home.

### 2.8.4 Wattson meter

As part of this research, the author purchased a Wattson meter for his home. This is a simple device that uses a Current Transformer (CT) to measure the power coming into the house from the electricity grid. The meter was located in a central location for the householders to see. The CT and the display unit seen below in figure 2.19 are connected using wireless communications. The unit can display the power being consumer in KW or the current annual cost of consuming power at the current run rate of power usage. In addition the unit can be switched to display various colours green, purple, and red for low, medium and high usage of electricity respectively.

**Figure 2.19: Wattson Meter – Source: Wattson (2009)**

This is a very simple and clever meter in that it was easy to install and user friendly. The author was able to place the meter in my home and everyone in the house was able to understand what the information meant. The key here was user friendly.

### 2.8.5 Google power meter

The concept behind Google's power meter is to display what electricity usage there is in a person's home. A simple current meter is put in the house that can record the units of electricity that are consumed in the home. This is then linked to Google's PowerMeter. (www. google.org/powermeter.)

Google's PowerMeter is an opt-in software tool that allows users to see detailed home energy information on their computer. It is a secure 'Google gadget' that displays data on home energy consumption received from either a "smart meter" or another electricity monitoring device.

This product is still in test but is expected to display data as in figure 2.10 below. By showing users their power usage, the user can then investigate what is using power and 'tune' or turn on/off various appliances. The labels on the graphs here are for illustration purposes only.

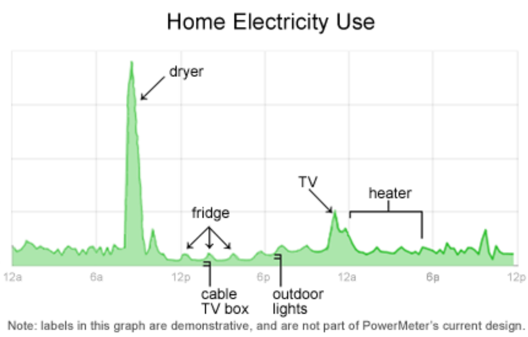


**Figure 2.20: Google Power Meter – Source Google (2009)**

Google believes that if consumers are provided with information, they will respond by changing their behaviour. Several testimonials on the Google PowerMeter web site are documented in Appendix D as further proof that providing information is key to behavioural change. While clearly, different people and different social and economic groups will behave differently, there is little doubt that with information and incentives, behaviours can be changed.

### 2.8.6 Ecobee

The Ecobee is a good example of a genre of 'smart meter' that controls appliances in the home, based on personal setting and preferences. This product has been developed in Canada.

The first variant of the product if primarily focused on controlling thermostats, as harsh winter months demand good heating control in homes. What is different about this product is that the consumer decides the profile and the product remembers it. There are different profiles allowed on the product which allow for weekends, vacation etc. The device works in standalone mode but more importantly it can be connected to a dedicated web server using a home's 'Wi-Fi' network.


**Figure 2.21: Ecobee Smart meter – Source: Ecobee (2009)**

Unlike the current Google meter there is no capability of showing the electricity consumption. However, the product does allow the user to remotely set and control the heating in the house and thus to dynamically respond to weather conditions or personal needs.

This product has the huge benefit to the consumer in that it automates the control of appliances in the home. This automation, based on the desired environment the homeowner requests, is provided through a simple and easy to use interface. While providing very different functionality, the human interface deployed here is very similar to the interface that the ESB are trialling as discussed later in this chapter.

### 2.8.7 Summary of meters

The table in figure 2.22 is a summary of the different types of meters and the functionality that each of them delivers. None of these meters provide information to the grid manager. There is currently a divide between the different 'meters' that required to be integrated going forward. The smart meter that is required by the utility company for billing is still a relatively 'dumb' meter. The second class of meters provide usage information to the consumer such as the Wattson and the Google meter. The third class are 'meters' that actually take control of appliances in the home such as the Ecobee.

The Holy Grail for smart grids is the integration of the functionality of each of these different classes of meters into a single solution that provides the consumer and the grid manager with the information and the capability to make real changes to the energy consumed in domestic home for the ultimate benefit of both parties.

| Product | Standard Meter | Wattson | Google | Ecobee |
|---|---|---|---|---|
| Utility reading for billing | This is the primary function of this meter | Only for in home display | Only for in-home and web display | Currently only control heating loads. Not utility meter. |
| GSM | Most have either GSM or Powerline capability | No - Used as a standalone device | The power usage is delivered over the web | Currently connected by broadband connection in the home |
| Control house appliance | No control is available from the standard meter | This only displays usage | This only displays usage | Aircon, heating and electrical loads can be controlled |
| Consumer human interface | Very simple units usage display | Good user friendly display that is mobile | Web based display which has good qualities | Excellent interface and easy to programme and use |
| Human interface via net | Not unless provided by utility company | Data can be manually uploaded to PC | Good web interface in place | Remote access and control via the net provided |

**Figure 2.22: Meter comparison Matrix**

The high level of communications required to implement a smart meter project is documented in Appendix C. While the communication infrastructure is key to the rollout of smart meters, this dissertation is not focused on these components.

## 2.9 Existing smart grid projects

In this section the scope of the rollout of smart meter projects is discussed to show how ubiquitous smart meter projects currently are. One of the most in depth and interesting trial projects conducted to date has been the 'Gridwise project' on the Olympic peninsula. This is discussed further in this section. While not discussed, there are projects ongoing in most developed countries e.g. South America, Australia, Asia, and South Africa. Not only are the big electricity markets looking to develop their capability, but also electricity markets such as South Africa which has serious problems with fraud and with keeping its national grid stable during peak times. See Appendix A which depicts some of the project currently being rolled out.

### 2.9.1 Smart meter project Ireland

There are currently many commercial and trial projects ongoing around the globe. These vary in scope from standalone meter trials, to integrated billing and customer behaviour trials. Ireland has two phases to its current smart meter project. Phase 1 is the evaluation of technology and the communications that supports it. The second trial is a Customer Behaviour Trial CER-SM (2009). Ireland's Smart meter CBT project is deployed mainly using Elster meters with GPRS as the communications layer between the consumer home and the data collection 'node'. There are over 10,000 meters now being installed as part of this trial.

### 2.9.2 Enel Italy

The smart meter project by Enel in Italy is cited as an example of the largest single deployment of smart meters in the world. The Italian utility ENEL introduced smart meters in 2001 in their "Telegestore project". The justifications for the project for

ENEL were the expected savings in the areas of purchasing and logistics, field operations, customer services and revenue protection (fraud). ENEL chose communications through Power Line Communications (PLC) to the nearest substation. Centralised control rooms read the data over GSM. By the end of 2005, ENEL had 32 million smart meters installed, of which 24 million meters are being remotely managed and bimonthly read - Enel/IBM (2006)

### 2.9.3 Olympic peninsula – Washington State USA

The project on the Olympic peninsula in Washington State, USA is one of the most ambitious pilot projects to date. One hundred and twenty volunteers were part of a project called "Gridwise". Usage was monitored based on real time pricing rather than fixed rates. Users decided how much they were willing to spend and their appliances were automatically adjusted with changing prices. The automated system installed in the home responded to the market price but transparent to the home owner and no action was required on their behalf. However the homeowner was allowed to override the system at any time if they required power for an appliance - PNL (2007).

The results on the Olympic peninsula were:-

- Reduced short-term distribution loads by 50% and overall peak loads by 15%
- Decreased the consumer electricity bills by an average of 10%
- Projected reduction of $70bn USD in infrastructure spending over 20 years through better control of existing resources
- Reduced impact and costs of blackouts and power shortages IBM_a (2008).

What is observed above is that the rollout of a smart meter project has important benefits, not only to the end consumer but also to the generation and distribution network. Below is a short analysis of how these goals have been achieved and what the implication is in general for smart meter projects.

1. Reduced short-term distribution loads by 50% and overall peak loads by 15%
    - By changing people usage behaviour, the demands on the network can be altered significantly. By reducing peak loads by 15% ensures that the grid can better manage peak loads, which is one of the greatest challenges in network management. Peak loads typically require three times the capital to deploy as the base load.
2. Decreased the consumer electricity bills by an average of 10%
    - Consumers benefit from their changed behaviour and usage patterns by the utility companies being able to offer them new and more competitive tariffs. In this project this was achieved through automated control of appliances.
3. Projected reduction of $70bn USD in infrastructure spending over 20 years through better control of existing resources
    - As discussed in the last chapter, electricity networks have to be built to cope with the maximum load on the network. By reducing and/or controlling this peak load the capital expenditure required to provide the same service is significantly reduced.
4. Reduced impact and costs of blackouts and power shortages
    - With better control of the network the grid manager is able to provide a more stable electricity network for all customers. This ensures that the country can be seen as having a solid electrical infrastructure for which companies that depend on energy for their key operations may look for in making any inward investment decisions.

### 2.9.4 Smart Meter Architecture - Gridwise

Figure 2.23 below shows a configuration that was implemented in Washing State (USA) on the Olympic Peninsula in the 'Gridwise project'.

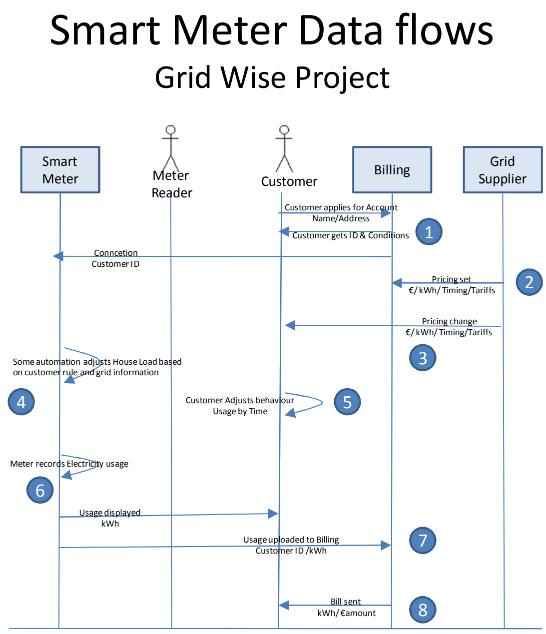


**Figure 2.23: UML Gridwise architecture**

The steps and data flows in the model are:-

1. The customer is set up with an account;
2. Unlike previous billing, the grid has the capability of setting the pricing dynamically based on the generation or demand on the grid;
3. The consumer is informed of these price changes and can make usage or behavioural changes;
4. There is an automated control tool which adjusts house loads based on the home and on price signals sent from the grid;
5. The consumer also has the opportunity to amend their loads and this includes overriding some of the automated control;

6. The meter records and displays the electricity usage;
7. The usage data is uploaded to the billing system;
8. The invoice is calculated based on time of usage and the variable price set by the electricity supplier.

This architecture allows the network to set pricing. It also provided a mechanism for the consumer to be informed. The significant change here from the previous smart meter UML diagram in figure 2.16 earlier in the chapter is:-

- The network defines the price based on generation demand or load demand;
- The 'smart meter' has some control over the home's load in order to provide maximum economic benefit to the home owner based on the tariffs that are available.

## 2.10 The consumer interface

How to communicate price with consumers is key. There are many channels of communication available. Several of the key channels of communication available with the consumer are outlined here:-

- Paper – using the existing billing systems it is possible to generate high quality information that people will understand but it is not real-time;
- Email is very effective and timely but not all elderly people or social classes will have access to it;
- Text messages – while most people will have access, is the communication likely to be appropriate or effective with all segments of society?
- Mobile phone application – mobile applications such as those on the iPhone are very powerful and can serve up useful information as well as giving control to the consumer.
- Display application in the home, which is likely to be effective requires another piece of hardware in the home, it needs to be installed, training

provided, and is likely to be costly to install. This could be an LED of a more powerful display such and the Ecobee or user interface being tested by ESB networks which is discussed later.

Each 'channel type' of communication needs to be evaluated with the following criteria:-

- Timely – can the information be provided in a timely manner so that the customer can respond?
- Information – can the channel provide information in a format that the customer can both understand and take action on?
- Setup cost – are there setup costs to deploying this channel?
- Running costs – are there increased costs in running this channel?
- Ease of use – how easy is this channel to use for the majority of the population?
- Access – how easily can the customer access the information when it is required?

| | **Paper** | **Email** | **Text** | **Mobil app** | **Display** |
|---|---|---|---|---|---|
| **Timely** | Low | High | High | High | High |
| **Information** | High | High | Low | High | Med |
| **Setup cost** | Low | Low | Low | Med | High |
| **Running cost** | High | Low | Low | Low | Med |
| **Ease of use** | High | Med | Low | Med | High |
| **Access** | High | Med | Med | Low | High |

Key High = Good fit; Med = Medium fit; Low = Poor fit.

**Figure 2.24: User interface comparison matrix**

There are many other proprietary types of communication such as Twitter, Facebook and many of the other social networking and digital media available today. However, the utilities companies must ensure that they pick a base line format that is common and acceptable to all of their customers. Once this has been achieved, then social media and other forms of communication channels can be deployed in parallel.

In the discussion section of the survey results these various categories are discussed from the responses to the survey

### 2.10.1 Communicating new consumer tariffs

Without doubt, consumers will have to adapt to new consumer tariffs going forward. Unlike the existing tariffs, which are a single price, or in the case of those with night meters, day/night tariffs, there are likely to be three bands of tariffs. The 'tariff disk' below in figure 2.25 is one visual representation of how consumers may be informed of the changes to the pricing structure with the introduction of new tariffs. While this is very clear at a simple level, it does not communicate the level of pricing at the peaks nor how this would impact a typical household with a typical load profile that is highest between 5 and 7pm. This type of communication method does not cover any price variation that may occur due to the variable nature of wind.


**Figure 2.25: – Tariff disk for smart meters tariffs - Source CER_sm2**

If more dynamic pricing is implemented for consumers such as ‘pass-through’ tariffs, then the complexity of pricing communication dramatically increases.

### 2.10.2 Communication with the customer

To date the only regular communication that occurs with the customer is the sending of a monthly or bi monthly bill. Some other marketing communications is performed from time to time. In today’s digital world the consumer has many media outlets through which they can receive information. Traditional paper bills are likely to continue for short to medium term. However, like the mobile phone industry, any billing regimes that are retrospective (after the event), are unlikely to ensure any significant or sustainable change.

In the UK Brandon and Lewis (1999), a study used a computer to help homeowners to understand electricity usage. The computer used in this study was not automatically updated, but required the user to input the meter readings. These readings could then be plotted on a graph and compared to previous consumptions. The computer also offered a questionnaire and advice on energy saving. During a nine month study in Bath, 120 houses were divided into seven groups including one control group. The group with the computer was compared to five other groups that were provided with written information about their electricity expenditures (self-versus-others, self-versus-self, leaflets, money and environment). The computer group performed consistently better than the other groups with respect to reducing rates of energy-consumption. Brandon and Lewis reported that 80% of the households with the computer group reduced their electricity consumption, whereas collectively only 55% of the households in the other experimental groups reduced their energy consumption.

What this clearly shows is the more engagement the consumer has with the process, in this case recording their own usage, the greater the likelihood of success in reducing the energy consumption in their homes. One assumption that can be drawn from the behavioural change is that if a consumer can reduce the energy consumption, the customer is also likely to be able to change the times of day when electricity is used. While Brandon and Lewis research did not categorically prove this, the assumption can be made on the basis that consumption in the household on the whole was reduced.

While this research is now over 10 years old it is valid, as it shows just how important providing information is to the psychological side of achieving behavioural changes.

### 2.10.3 Irish Smart Grid Project

Jumping forward to today one can look at how today's technology might be implemented to achieve the same result. The CER's paper CER-SM (2009), on Ireland's smart meter project refers to 'Smart Web'. According to the paper 'The Smart Web Application' will provide online access for a subset of Residential & SME customers, allowing them to view their consumption & costs in various formats as seen in the figure 2.26 below.

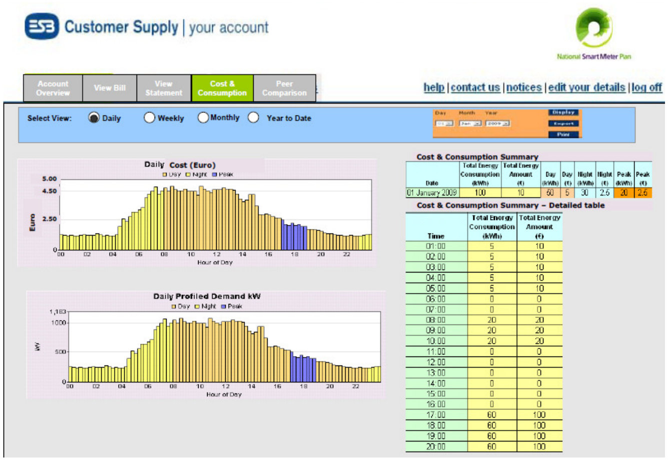


**Figure 2.26: – Tariff Disk Peak rate explained- Source: CER_SM2 (2009)**

While this gives detailed information on usage and may appeal to SME's or SOHO segments, it is a format that is unlikely to be used regularly by the majority of domestic customers.

For consumers, an In-home Display (IHD) which may have a display like figure 2.27 below is been tested by the smart meter project. This has a simple format and one which could easily be understood by technical and non technical people. The development of this product is currently underway with both ESB networks and Elster. The functionality delivered by this meter is very similar to the products discussed earlier in the meter section. What is shown in the results of the survey is that some form of in home display is required to achieve behavioural change.

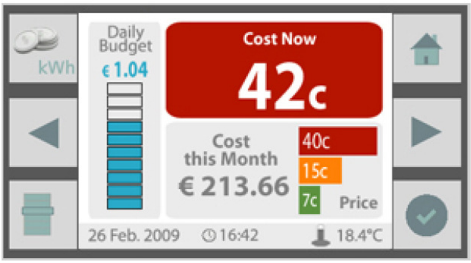


**Figure 2.27: In- home display Source - Source CER_SM2 (2009)**

### 2.10.4 How effective is the interface

The true effectiveness of the interface can only really be measured by human testing of various types of interfaces. This testing is not part of this research. However, the survey does ask people what mode of communication they would be most comfortable with. See Appendix B on user interface design methodology.

## 2.11 Who pays for the smart meter

Entering this period of rising cost of fossil fuels, the possibility of a carbon tax and the environmental challenges of global warming, consumers are becoming more aware of their energy footprint and costs. The payback period for smart meters may be significant if the capital costs are high. Thus who pays for the meter is a question that needs to be addressed.

In general, the meter is installed and paid for by the company that manages or owns the distribution side of the network. In Ireland this is currently ESB Networks. In the UK it is owned by the electricity suppliers. In Ireland the cost of a large scale deployment is so significant that the costs are likely to be passed on to the consumer through a Public Service Obligation (PSO) levy. While this is speculation on the author's behalf, recent reports in Irish media would suggest that this is a likely outcome. This raises the question as to whether smart meters will be mandatory or will consumers be able to keep their existing meter as discussed by Gordon et al (2006). In different markets different ownership models and 'who pays' debates are ongoing. In the UK several models are documented by DECC UK (2009). The total cost for the UK outlined in this document are circa £13-15bn, with a net benefit to the all parties circa £4-5bn. Some market commentators believe that the cost outlined in this report may be significantly short (100%) of the final cost of the project.

## 2.12 Summary

This chapter reviewed the current state of the electricity regulation, market operation, generation, transmission and metering in Ireland covering:-

- The structure of the market and how it is regulated. This included a brief review of all the key players and the roles that they play in the governance of the electricity market.
- Generation:- The chapter then went on to focus on the generation in the Irish market and how it is operated. The plans for future wind generation and the impact that this would have on the grid was discussed. The economics for the generators are also outlined;
- Networks and regulation – Key components of the networks and how they are managed are outlined. The challenges facing the grid managers based on the growth and variable nature of demand curves were investigated;
- Consumers – what are the behaviours of the consumer and how are they currently served? What are the current challenges and needs facing them? The economics of how price impacts consumer behaviour is critiqued;
- Smart meters – what is currently being deployed in Ireland and in other projects. What technology is currently available. The technology and process structures that are currently in place were modelled using UML. What opportunities are there for improving the way smart meters are rolled out? How can smart meters play a significant role in the future development of wind energy in Ireland and beyond?

What is shown is that there are many projects and many different type technologies in the market place. The rollout of smart meters along with the growth of renewable energy offers a great opportunity for grid manager and consumers to benefit from reduced costs, cleaner energy and the ensuring that Ireland and other countries with wind and intermittent renewable energy sources can be fully utilise this power for the maximum economic benefit for the consumer and the grid operators. How this should be achieved is proposed and documented in the next chapter.

# 3 System design and validation

## 3.1 Introduction

Using the contents of chapter 2 as a foundation layer, this chapter builds on these concepts and ideas, by introducing the design aspects of smart metering for the future. The main emphasis is to identify the fundamental changes that need to be incorporated to make the new smart metering paradigm a success for the suppliers of electricity, the grid operators and consumers alike using a pragmatic and tangible approach. Section 3.2 introduces the proposed architecture which was developed as part of this thesis. It provides a detailed breakdown of the recommended paradigm which includes descriptions and needs of the Home Area Network (HAN) and a new concept called the 'Consolidation Entity', which is required to provide the grid operator with more vision and control of domestic energy consumption and to provide the tool to aid in balancing demand against supply on the network. This paradigm is then constructed in Section 3.3 using the UML modelling approach, which increased the granularity of the system's definition. UML allows the complexity of implementation to be removed and focuses on the operational components. This approach is then verified using standard scenarios used to describe the systems operation as it processes everyday situations. In addition to the proposed model, Section 3.4 analysed electricity usage using a Watson meter a single domestic instance, which is used to emphasis key aspects of consumer usage and behaviours with a view to reaffirm from a different perspective the important need for both a HAN and the proposed Consolidation entity. Section 3.5 shows the approach used to give a balance to the survey questions and maximise the information which can be gathered from the group completing the survey itself. As part of this research a survey of 106 domestic users from different backgrounds was undertaken to underpin the prioritising of any future developments in smart metering. Section 3.6 focuses on problems and challenges associated with the project with a view to highlight some of the important issues that need to be addressed on any future research of activity in this area. Finally Section 3.7 summarises the key aspects of this chapter.

## 3.2 The new architecture

The objective of the new architecture is to move from a task based control system to a goal based control system. These terms are explained below:-

- **Task based control** Most existing controls in dwellings are task based, in that a person or timer switches on/off equipment. However this does not allow for any intelligence or collaboration in energy savings to take place across the network.
- **Goal based control** Goal based control is performed where a goal is chosen and there are a number of paths by which the goal state can be achieved. By centrally sharing goals and path options real energy savings can be achieved. This is discussed later with the introduction of the Consolidation entity to the solution.

The existing smart meter architectures that are installed are simple billing systems that have automated reading. What is required to perform more complex and responsive controls of domestic homes is a Home Area Network (HAN) integrated with a Consolidation entity. The Gridwise project had a very simple implementation of this. In this architecture, the HAN, the generators and grid operators are required to be able to communicate with the smart meter.

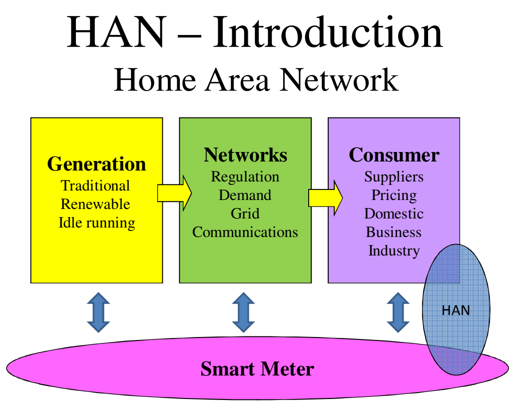


**Figure 3.1: Next generation smart meter Architecture**

### 3.2.1 How the HAN is configured

The configuration of the HAN is key to the success of this. The author proposes that a home would have a series of circuits, either wired or wireless that could be switched or controlled by the HAN. What is proposed as a solution is the configuration of control in the home categorised in three ways:-

- Green loads circuits: - Circuits that can be turned on/off when there is a price variation. This would be very similar to the Gridwise project. Some high level and basic rules would be that when electricity is :-
    - Cheap, run appliances that are set as 'needing to be run' eg dishwashers, washing machines, immersions
    - Expensive, then turnoff all these circuits.
- The green circuit would also be available if there was a demand response event on the network to provide load shedding.
- The consumer is rewarded:-
    - For not running non essential appliances when electricity is expensive;
    - By being able to purchase cheaper electricity when it is available;
    - By receiving a payment for responding to demand responses on the network;
- Amber load circuit:- This is a circuit that could be switched off in the event of a demand response request on the network. This would typically have appliances such as fridges (within parameters), TV's, electronic and white goods. As demand responses are likely to be requested with short notice, care must be taken to select these circuits.
- Red Load circuits:- These are circuits that should not be switched on unless there is a critical event on the network. These may need additional intelligence to control them which may come from sensors e.g.
    - Fridges – turn off if temperature is < 4 degrees C
    - Lights – turn off if no one is in the room.

Today, in the event of a critical event the, operator is more than likely to switch out an entire region of load indiscriminately. Having this functionality would give a different load shedding option for the network operator to deploy while achieving the same results and yet not fully interrupting critical loads in people's homes and businesses.

The cost of retrofitting a HAN into people's home would be a significant capital outlay. The value to the parties involved would have to be clearly identified early in the project lifecycle. This is not part of this research.

### 3.2.2 Scenario modelling – Price change

The UML model below in figure 3.2 shows the steps and the data flows that occur if a 'price change' alert was issued by the network. In this model the consumer is still involved in the process. However, it is anticipated that the HAN will control and take advantage of the alert.

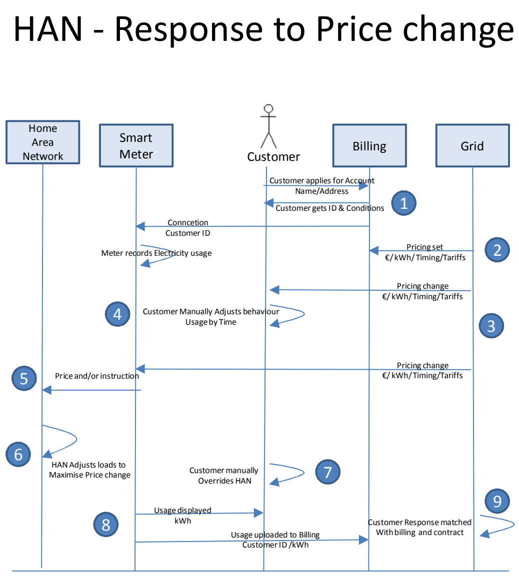


**Figure 3.2: – UML HAN response to price change**

The steps and data flows in the model are:-

1. The customer is set up with an account. The customer account would have to set up for the customer with a HAN, and an appropriate contract has been selected.
2. Like the previous model the grid/supplier has the capability of setting the pricing dynamically based on the generation or demand on the grid;
3. The consumer is informed of these price changes;
4. The consumer may make usage or behavioural changes;
5. The smart meter receives price data, and this is passed to the HAN;
6. The HAN adjusts house loads based on the home's status and on price signals sent from the grid;
7. The consumer also has the opportunity to amend the loads and this includes overriding some of the automated control;
8. The meter records and displays the electricity usage and uploads it to the billing system;
9. The billing system calculates the bill based on the customers contract and their usage profile.

The UML diagram in figure 3.2 above shows two significant changes to the previous UML diagrams that represent traditional smart meter rollout. Here the meter reader is removed and the HAN is added. Additionally the termination process is removed at the bottom of the diagram as this is likely to be a standard procedure.

The challenge now is that the smart meter must record usage information and reconcile this with:-

- price changes ;
- requests from the network;
- responses from the home through the HAN;
- manual intervention by the home owner.

Figure 3.2 above shows a proposed future configuration for a two way smart grid. The big change in this model is the dynamic setting of pricing by the network to reflect any excess renewable energy generation that may be on the network. This architecture allows the network to dynamically set pricing and change the load in a customer's home. For this to be implemented, a homeowner must give over dynamic control of some of the significant discretionary and non time dependant loads in the home.

The author's believes that if a homeowner needs hot water for a shower at 6am it is not a concern if the water is heated at 1.00am, 3.00am or 5.30am provided that that there is hot water at 6.00am. The cost must be the same or less than normal and the consumer must have their 'hot water' needs met. Similarly if a homeowner wants their home to be warm and comfortable for a particular time the concern is not with when the heating takes place, only the end cost. It is under this premise that the grid could dispatch excess energy to domestic homes on the grid and thus change the usage profile of the home and take advantage of intermittent renewable energy sources using the home for 'thermal storage' of electricity.

### 3.2.3 HAN Consolidation Entity

The existing smart meter architecture is a very simple billing system that has automated reading. What is required to perform more complex and responsive controls of domestic homes requires a far more complex solution than already exists. What this proposal introduces is the concept of a HAN Consolidation entity that brings together the capability of the domestic home with the needs of the grid to deliver new smart grid solutions

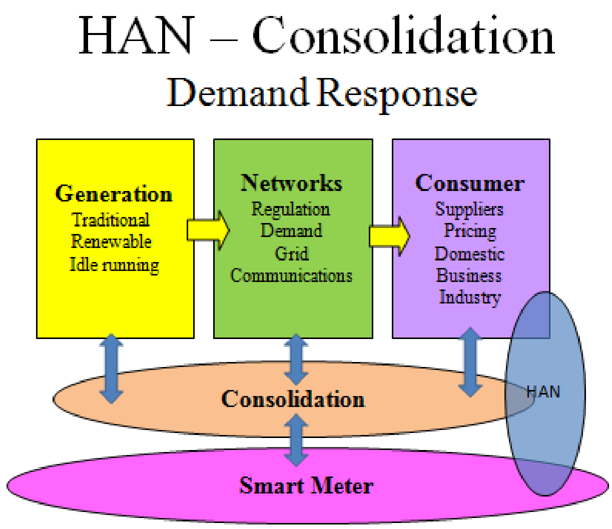


**Figure 3.3: – Architecture (New Consolidation entity)**

The ultimate desire for the network operator is to be able to understand what loads can be shed or what loads are available to them. This is not possible to achieve with existing tasks or timed based control systems.

## 3.3 Proposed design – UML Model

The author's design focus has been how to get a change in energy usage in domestic homes based on price or demand requirement (over/under supply on the network). In reviewing this existing technology and projects the author observed that there are two main areas where gaps or huge variations in rollout of projects appear today. These are:-

- How is the consumer informed of price variation in the network or a demand response request in the network;
- How can a home be automated in such a way that both price variations and demand response requests can be acted upon.

The author proposes the addition of a HAN and a Consolidation Entity to deliver this functionality. In addition, it is proposed that the homeowner should also be kept informed of the price or demand changes in homes where a HAN has not been installed and manual intervention is required. Manual intervention has many shortcomings as discussed in the next chapter.

To ensure that networks communications are simple and cost effective, there needs to one master of this price/demand data. The author proposes that the smart meter is always the master of the communications and the data. The smart meter in turn can be queried by the HAN, the consolidation tool and the billing system.

### 3.3.1 Scenario modelling - Demand response

A demand response (the network requesting that the load on the network be changed), is likely to be very unpredictable and thus the HAN will play a key role in managing a response to this. A demand response, and in future a 'Supply Response' (response to excess power), are treated in the same manner in this design.

A demand response will be required to turn off appliances. A supply response will be required to turn loads on. These are likely to be the same circuits as discussed earlier; however different logic is required on the HAN to be able to process both.

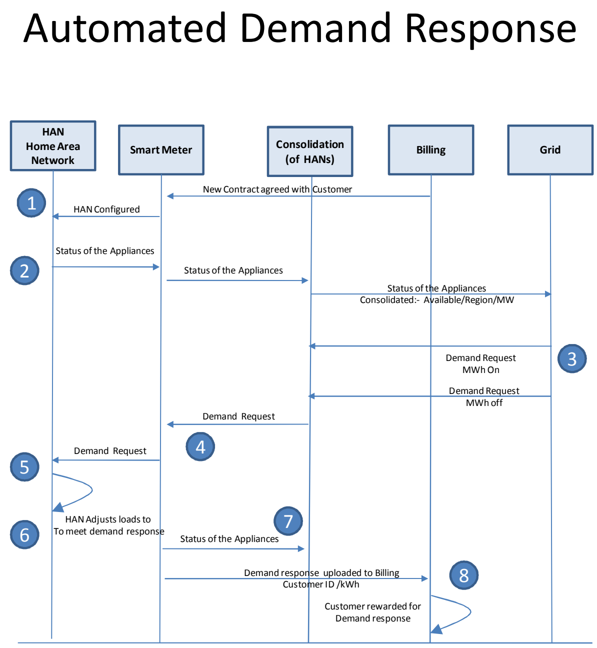


**Figure 3.4: UML Demand response model**

The steps and data flows in the model are outlined below:-

1. The customer is set up with an account. A HAN is installed in the house and the circuits in the house are configured as discussed;
2. The HAN updates the smart meter with the status of the appliances and in turn this updates the Consolidation tool. This data must then be made available to the grid operator in a format that they can easily used to select both ‘where’ and ‘which’ loads that are able to turn on or off;
3. The grid issues a command to turn on/off (x)MHW to the consolidation tool;
4. The HAN Consolidation tool issues commands out to the appropriate and selected smart meters;
5. The smart meter issues instructions to the HAN;
6. The HAN adjusts the loads in the house according to the home logic;

7. The smart meter updates the consolidation tool with new status of the appliances in the home received from the HAN;
8. The billing system is updated with the customer's response to the demand response.

The UML diagram above in figure 3.4 shows two significant changes to the previous UML structures. The HAN consolidation entity is added and the end user is removed. If a customer is signed up on a contract or tariff that includes a payment similar to Eirgrid's WPDRS (Winter Peak Demand Reduction Scheme) then any load change requests and actions need to be recorded against this customer.

This is a very complex scenario to manage as the consumer may be able to override the commands sent by the grid if the entire ownership of the HAN is not in the 'control' of the grid. What is key is how the HAN is implemented and managed and what type of contract the homeowner enters into with the supplier of their electricity.

As more and more micro generators such as wind turbines and solar photovoltaic are installed, the complexity of the response of the domestic load, and possibly a different Renewable Energy Feed-In Tariff (REFIT) will also need to be considered. To ensure that the solution is future proofed against this inevitability, the meter, the software and the HAN need to be designed with this in mind. This analysis and configuration is not part of this research.

### 3.3.2 Information required by the network

For the grid to be able to use this configuration of a HAN, it requires up to date information of the status of the entire network of HANs that were currently on the network and were available to be 'called upon'. Some of the high level information required is:-

- How many MW can be switched off/on for green, amber or red circuits;
- How long can they be switched on/off for;

- On what geographic region of the network are the loads available;
- How many MW per region;
- What is the cost of calling on the HAN's and would it be cheaper to dispatch traditional generation or load shedding methods.

Once the network operator has this information it can treat the load shedding as a virtual power plant and can thus rebalance the network as much as possible, without dispatching new generation into the grid. To get this information to the network operator, the HAN through the smart meter, needs to be able to keep the operator up to date with the available loads. It is envisaged that a sophisticated tool or mechanism for consolidating and classifying this information by region and by load would be required in order to provide the operator with a fast and easy to use tool. The author has called this a Consolidation Entity. Not only should this tool be able to control the turning off/on of these loads, it also needs to be able to turn them back on/off after the event. This may require new regulation to overcome health and safety issues.

The algorithms to mange this process at a grid operation level require a sophisticated tool. The communications tools and infrastructure to communicate with and mange the HANs is also significant as the smart meter and HAN's are required to collect and report all the data and usage patterns for any billing or contractual implications that may occur in relation to grid requests or instructions. However, the same physical network could be used to handle the data.

### 3.3.3 Keeping the customer informed

The author proposes that a standard method of communicating with all customers is necessary in the early stages. While additional new media services may be used at a later stage, the utility company must try and find a solution that works for the vast majority of its customers. A simple display unit in the home would seem to be the most effective way for this to be achieved. This should be deployed in conjunction with on-line access via the web for anyone requiring to 'drill down' for further information about their usage or profile.

The author proposes that this is a simple device, similar to the display that ESB Networks is currently working on for the smart meter rollout here in Ireland (as discussed earlier). However, it is was not clear to the author if this unit:-

- Allows the user to set up their 'energy' profile;
- Can control home load in the house on various circuits;
- Can respond to demand responses from the network.

A roadmap for ensuring that these functions are catered for is important for future proofing the rollout of the smart meter project.

### 3.3.4 Communicating with smart meter and HAN

A key part of the solution that needs to be implemented is the integration of smart meters with a HAN or device that can actually control loads in the home. To future proof the smart meter installation a pure meter reading solution would not be functionally rich enough. This proposed functionality is required to perform two main additional functions:-

- To respond to price variations and thus to change load profile away from peak demand and towards lower peak;
- To respond to demand variations and to give the grid control of domestic appliances as and when required.

In Ireland, the smart meter is installed at the meeting point of the utility's network and the home, and thus in Ireland it is part of the utilities' network. The exact structure of ownership is different across various countries and states. In Ireland ESB Networks currently owns the meter. As the HAN will be implemented on the 'customer side' of the network (in the home) there are more likely to be different standards and protocols used. There is currently an attempt to develop standards for this, but already different standards such as ZigBee or KNX are emerging. For consistency the smart meter is proposed to be the master of the data and communications between the home and the utility network. This has the benefit of:-

- Only one communications channel needs to be provided to the house;
- The security of the grid and the HAN is not exposed to many communication channels.
- There is no duplication of telecoms infrastructure;
- Only one set of standards will need to be set;
- Information will only need to be sent once and in one format;
- The impact on billing and tariffs will be consolidated into one platform and thus billing and usage reconciliation will be simpler.

There are however some challenges and shortfalls with this proposal which are discussed in the next chapter.

### 3.3.5 Smart meters and intermittent renewable energy

With this solution, consumers could be offered cheap electricity when there is ‘surplus or excess’ wind power on the network. As discussed in the previous chapter, the installed capacity of wind generation in the Irish network by 2020 will be equal to the existing peak load of the grid today.

It is unlikely that consumers would manually adjust their profile on a daily basis to match the wind output as this would be too tedious and likely to be impractical. However, with the solution shown, an integrated Home Area Network (HAN) connected to the grid could automatically create a demand for the wind electricity by turning on the appropriate appliances in peoples’ homes - IBM_a (2008).

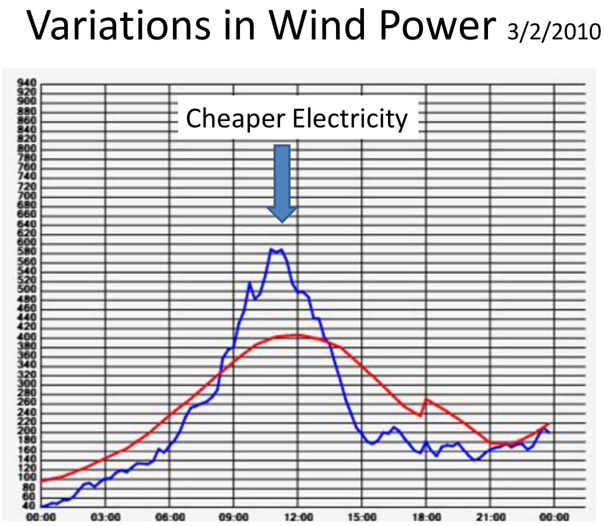


**Figure 3.5: Variations in wind Power: - Source: Eirgrid_c (2010)**

Figure 3.5 above is another example of the variability of wind power over the course of a day. The red line show what wind power was predicted by the network operator in advance. This is only available as a short term forecast and not something that consumers could be expected to respond to. To be able to get consumers to change their behaviour to match this variable and intermittent power would be a significant challenge. The only two options are:-

- The end customer must be informed of the tariffs on the network in advance and then make changes to their house load;
- The home's appliance to be remotely controlled by the grid or by some automated control (HAN).

The acceptance of such control by the grid is discussed in the next chapter. As previously discussed, matching the demand and supply curve is an important requirement of cost effective and environmentally effective grid management. In the past, supply was managed to match demand. As we continue to install increasing amounts of wind generation, there will come a point where it will be of great benefit to consumers to be able to manage demand to match the supply as shown with this solution.

## 3.4 Wattson meter in domestic home

This section outlines what was put in place to test the behavioural side of providing real time information to a home owner on electricity consumption. A Wattson meter was purchased and installed in the author's home in Dun Laoghaire, Co Dublin. The data used here for discussion is from a week in June 2009. Prior to this analysis the author had no idea of the base load or the consumption patterns in his house.

The author found that during this time the meter was turned on in the house and digitally displaying energy consumption, the entire household become more aware of the real time consumption of electricity in the house. This often caused the author's wife and ten year old son to go around the house turning off appliances and lights just to try and get the power consumption as low as possible. This qualitative behaviour analysis was amazing to observe and continues today even as this report is being written up.

### 3.4.1 Capturing the data

With very simple and free software the loads in the house were captured and uploaded and the graphical outputs in this section were generated. While this provided delayed and retrospective usage information on the house it also captured that dynamics of the power usage in the house.

### 3.4.2 The Wattson metering in action

The collection of the data using the Wattson meter in the author's home proved to be a very interesting experiment to watch and participate in. What was totally clear is that human behaviour around energy and cost was greatly impacted by having real-time data on display in the home in a place that was visible to everyone. Lots of data was collected during this process, but only a small amount of data is presented here. A key challenge was to be able to keep track of events in the house and match these with the readings from the meter.

If more time were available the author would have collected data from several homes to understand the profile and activities of other homes.

### 3.5 Survey

This section outlines the purpose of the survey and how it was performed. The objective of the survey was to obtain real data on people's knowledge, insights, attitude and behaviour towards energy and the acceptance of smart meters and home controllers. It was also used to get an understanding of how successfully projects may be implemented in the future and how consumers wish to be communicated regarding their usage and the price of electricity.

The survey was carried out using www.surveymonkey.com which is an online tool. The survey was kept short with only 31 questions so as to ensure a good response rate. The advice received from Behaviour and Attitudes (2009) was to keep the survey to between 20 and 30 questions to ensure a good response rate. The survey was sent to friends, family and business contacts. The author avoided sending it to engineers or people in the energy business to avoid any skews that might occur due to their in-depth knowledge. The link to the survey was sent out using personalised email. Behaviour and Attitudes advised that using personalised emails such as "Dear x" ensures that response rate would be high. The email also asked people to forward the email on to three people.

The author expected about a 5% response rate and was hoping to get 50 respondents to ensure a good sample. The survey was also posted on the author's Facebook page and on his Twitter account to attract further responses. The author estimated that the survey was sent to about 650 people. The social class of the majority of the respondents to the survey were most likely to be ABC1 as defined by the National Readership Survey (NRS) of the UK. However, this cannot be verified. Thus, it would be expected that the general knowledge and awareness of the respondents would be high.

### 3.5.1 Objective of the survey

The objective of the survey was to collect and test the following categories of information:-

- **General information (G)** To collect some background information to understand my sample data. This was not part of the core research but it is helpful in understanding the respondents home size and occupancy;
- **Awareness (A)** H To get and understand the respondent's awareness about electricity bills and usage;
- **Real information (I)** To test exactly how much they know about their usage by asking specific questions;
- **Changing behaviour(C)** To probe and test how open the respondents were to changing behaviour and what returns and rewards they would require;
- **Technical Solution (T)** To gain an insight into how the respondents would like to be communicated with regarding usage and the price of electricity.

The table below shows how the questions were distributed across each of the categories being investigated.

| **Category** | **Number of questions** |
|---|---|
| General Information (G) | **6** |
| Awareness (A) | **7** |
| Real information (I) | **8** |
| Changing behaviour(C) | **5** |
| Technical Solution (T) | **5** |
| Total | **31** |

### 3.5.2 Survey questions

The survey questions are listed in Appendix E. The questions were presented to the respondents in the order they appear. To validate the response to the multiple choice questions, where the answer may not have been known or an opinion was being asked, the survey was set up to present the answers in random order to each person.

### 3.5.3 The consumer survey experience

Setting up the survey on www.surveymonkey.com was a good experience, and while it cost money to execute the survey, the process and results are insightful to examine. In response to the author's email requesting participation in the survey, many of the respondents indicated that they were interested in receiving a copy of the results. These raw results were shared with those who requested it.

## 3.6 Problems and challenges encountered

There were no significant problems encountered during the research part of the project. The real architecture challenges were identified using UML in trying to identify a working model that allows the grid take control of the energy consumption in the home. It took several iterations to finally arrive at the current model.

### 3.6.1 Challenges identified with UML

Challenges with designing the data flow and processes were identified using the UML design tool. This tool focussed the author on considering:-

- What data is required;
- Where the data originates;
- How does the HAN know what loads are available in the home to be turned on/off;
- How is the data transmitted and received;
- Why physical tools or systems could be deployed to make the model work;
- Who pays for the infrastructure.

Using UML highlighted some key problems with designing and rolling out this model. To simply get billing and time of use data from the smart meter to the billing system is relatively straightforward. This really only requires a standard smart meter with a communication layer built on top. However, there is clearly a back end issue with the volume of data collected. Currently there are only four meter readings per year to which daytime or night time tariffs are applied . If the smart meter is to record usage data every half hour that would mean that there is a requirement to process 2*24*365 (17,520) data points yearly for every home. That is 4,380 times the amount of data that is currently collected. Clearly this has an impact on the architecture of the existing systems to store and sort this data.

However the model gets far more complex when demand response is added to the model. The issues that surfaced and were identified are listed below:

- Does the utility company or electricity supplier need a new contract with the customer to be able to turn things on/off and up/down in people homes?
- Will consumers allow this pervasive control in their homes?
- Will new laws or safety standards be required to allow remote control of such a dangerous power as electricity?
- Capturing the data to and from the smart meter is simple as this is under the control of the 'utility company'. However, once control of data is required on the customer side of the meter the landscape is not quite so straightforward and the vast majority of the installations in homes will require a costly retrofit.
- It is possible that people will not pay for their own equipment, and look for subsidy for the equipment;
- Many different types of communications and control prototypes are likely to exist, thus making the final leg of the control process more complicated to implement;
- In order for the grid operator to be able to build a demand response model into his operational plan for the grid he needs to know what loads are available to him in the home and how much 'virtual power' he can access. This is a totally dynamic load that changes with people's lifestyles, time of day, age of life, social background, number of children, working patterns, etc;
- If a demand response instruction was issued to the home what device would validate that the intended request was actually followed in the home. Thus how would the contract with the customer be structured, monitored and managed is a significant challenge for the electricity supplier and the grid operator.

There is a huge reward for finding a solution to these challenges which is a reduction in the peak load for national electricity grids and the more efficient use of renewable energy.

## 3.7 Summary

This chapter outlined the new design that is required to allow smart meters and smart grids to take full advantage of the vast amount of renewable energy that is planned to be installed on the Irish grid. The research that was carried out and the tools that were used and the processes that were followed are explained. The problems and challenges that were encountered are summarised at the end of each section.

UML proved to be a good tool to design the processes and data flows and high level processes of a workable solution. This allowed a structured iterative process to get the final solution documented. What became obvious was that the data required to manage a smart grid is complex and requires new data models, new IT systems and new telecoms infrastructure to the grid for it to take full advantage of renewable energy and the capabilities of a smart grid. The domestic home is also likely to require a costly retro fits to install new electrical circuits that are controllable. Using UML to design this helped flush out the master/slave issues of equipment, processes, data and ownership. This led to the creation of the consolidation tool which is the author's high level design of the new architecture.

The Wattson meter was the only physical measurement of behaviour linked to electricity that was performed. However, the qualitative insights observed during this process surprised the author and indicated some clear evidence and data to show how the maximum benefits from smart meters could be achieved. To collect simple data using the Wattson meter proved to be cumbersome. If a larger data sample were to be performed a more robust model to collect the data would be required in order to collate behaviour and the meter reading together.

The survey was employed to collect quantitative data. Using Survey Monkey proved to be an easy to use tool and the feedback from those who participated was that the survey was easy to follow and they trusted the technology. The service provided good reporting tools and there was no manual collation of the data required. The survey was tested several times before it was sent out to the wider audience.

# 4 Results and findings

## 4.1 Introduction

This chapter focuses on presenting results obtained from implementing the work undertaken in Chapter 3 and analysing it. The Unified Modelling Language (UML) was primary used to give a higher level operational and functional abstraction, and minimise actual encoding issues. It assisted in explicitly detailing the proposed design to a level in which the design could be verified. Section 4.2 analyses the proposed smart metering paradigm and details ways in which the system could be realised in a real system. It shows how load shedding capabilities of the smart meter can be included to improve the economic payback for consumers, the grid operator and electricity generators. Section 4.3 examines the results of the Wattson Meter used to capture data from a domestic setting and summarises some of the changes in operation/performance that can be achieved. It also reviews some of the behavioural changes that were observed that are key to the successful implementation of a smart meter rollout. Section 4.4 focuses on the results of the consumer survey. This fundamental understanding of how the HAN and the Consolation entity would be accepted by the end user is critical to any implementation success. Without any end-user acceptance very few energy saving strategies could be effectively installed or tolerated by users in the domestic market where consumers like control of their own lives. Finally Section 4.5 summarises this chapter.

## 4.2 UML design

The UML provided a structure that allowed the data flows and processes to be modelled. The author's proposed design has two key components to the architecture of the rollout of the smart meter.

- The smart meter is the master of the data and communication that is used to control appliances in peoples home and this is integrated with a Home Area network (HAN) that can take instructions and control domestic electrical loads.

- In order to provide a domestic demand response mechanism that works for both home owners and the grid operator a Cnsolidation tool is required to link together the parties in the energy supply chain.

Having such capabilities available to the network operator is clearly a big step in delivering on a key part of the promised functionality and benefits of a smart grid.

### 4.2.1 Load management Consolidation Tool

The Consolidation Tool is a key entity in the author's design to ensuring that that the information about the domestic homes and the needs and requests from the grid are managed. Hundreds of thousands of homes may sign up to these 'Response' schemes and thus it would neither be possible to have visibility of what load is available nor to be able to issue commands without such a tool.

Providing domestic information to this tool, to ensure that it is always up to date with the latest status of homes, provides a big challenge for the communications network. In addition, current billing systems only need minimal information for a billing run where the data could be stored on the smart meter for several weeks before it is uploaded in a batch format. However, the Consolidation Tool would require information in 'real time', and needs instructions to be issued in 'real time'. This could provide significant challenges to whatever telecoms solution is chosen without having considered this new architecture. It appears that most current projects have only been configured for batch uploads and not 'real time' control communications.

### 4.2.2 Smart meter as master

Smart meters will be installed in more and more people's homes going forward. A communications channel must be provided to the smart meter for meter reading capabilities. To deliver additional functionality to homeowners such as price changes and demand changes on the network, an additional 'box' the HAN (HAN) is required in the home. For the model to work the smart meter has to receive and provide additional pieces of information to and from the HAN:-

- From the HAN
    - What KW's are available to be turned on/off at any given time? This is passed on to the grid operator through the Consolidation Tool;
    - What KW's were turned on/off in response to this request? This is passed on to the billing system to reward/penalise the customer for their response
- To the HAN
    - Price of electricity – the HAN will then have to respond based on preconfigured usage algorithms
    - What KWs are required to be turned on/off?
    - Is this a green/amber/red request?
    - When this is required and for how long?

There is a lot of functionality and intelligent algorithms that are required on the HAN side of the solution to ensure that the correct loads/appliances are controlled. A simple data signal(input) of KW required and a timeframe would be sufficient to allow the HAN to execute most decisions. Once the actions have been taken the HAN would 'report back' to the smart meter on what actions were taken. As the smart meter records the energy consumed in the home, the response from the HAN including manual interventions, would be identifiable by the smart meter.

Having the smart meter as the master of the HAN, avoids any excessive communications infrastructure that would be required if the HAN was directly communicating with the grid operator. It would also provide a secure mechanism for the communication between the home and the grid.

To remove costs from smart meter rollouts the cost of putting a HAN into people's homes is likely to be borne by the consumer. Thus the smart meter will have to provide a common set of interfaces to the HAN. This ownership model raises questions about the penetration of HAN in homes and ones which requires further research on payback and value for money.

### 4.2.3 Load shedding scenarios

Assuming that the correct technology is deployed, and the regulatory framework is in place, what next needs to be understood is how can significant results be achieved by changeing domestic load profiles. Figure 3.6 below shows various load shedding capacities that would be available to a grid manager. This data is a subset of the peak load for 26th February 2010 taken from Eirgrid's web site. See Appendix I for the full set of data. On this day the peak occurs at 19:30 at 4,446 MW. The model assumes that the grid operator is looking for a 5% reduction in the load from the peak. It is assumed that there are 1.4 million customers. However, not all customers may be signed up for the scheme so various sensitivities are added: 100% take up, 50% and 20%.

| Time | System Demand MW | Network Reduction | % of customer - KW per home | | |
|---|---|---|---|---|---|
| | MWh | 5% | 100% | 50% | 20% |
| 17:15 | 3869 | 193.45 | 0.138 | 0.276 | 0.691 |
| 17:30 | 3952 | 197.6 | 0.141 | 0.282 | 0.706 |
| 17:45 | 4004 | 200.2 | 0.143 | 0.286 | 0.715 |
| 18:00 | 4112 | 205.6 | 0.147 | 0.294 | 0.734 |
| 18:15 | 4248 | 212.4 | 0.152 | 0.303 | 0.759 |
| 18:30 | 4372 | 218.6 | 0.156 | 0.312 | 0.781 |
| 18:45 | 4412 | 220.6 | 0.158 | 0.315 | 0.788 |
| 19:00 | 4411 | 220.55 | 0.158 | 0.315 | 0.788 |
| 19:15 | 4438 | 221.9 | 0.159 | 0.317 | 0.793 |
| 19:30 | 4446 | 222.3 | 0.159 | 0.318 | 0.794 |
| 19:45 | 4391 | 219.55 | 0.157 | 0.314 | 0.784 |
| 20:00 | 4297 | 214.85 | 0.153 | 0.307 | 0.767 |
| 20:15 | 4263 | 213.15 | 0.152 | 0.305 | 0.761 |
| 20:30 | 4191 | 209.55 | 0.150 | 0.299 | 0.748 |
| 20:45 | 4113 | 205.65 | 0.147 | 0.294 | 0.734 |
| 21:00 | 4066 | 203.3 | 0.145 | 0.290 | 0.726 |
| 21:15 | 3984 | 199.2 | 0.142 | 0.285 | 0.711 |

**Figure 3.6: Load shedding capacity model**

If 100% of people had signed up for a reduction scheme, then each home would have to shed on average 159W. However, if only 20% of homes had signed up then 794W would have to be shed per home. A shedding of 159W in a home is only six 50W down lighters or about 10% of the load of a 2 KW immersion water heater. At 794W a more significant yet achievable load would have to be shed. These loads do not have to be just one single appliance but could be the sum of several loads in the home. It would be up to the configuration of the HAN to determine how best to meet the load shedding requests. Different homes will have different capabilities to respond to load shedding, which is a complexity that is stated here but not analysed.

### 4.2.4 Return on investment for the HAN

Today the benefit and payment for the smart meter is likely to be justified based on the two primary savings coming from meter reading costs and a reduction in fraud. Who bears the cost for installing a HAN is not a clearly defined by the market. Figure 3.7 below shows where additional benefits could be recouped from. How these benefits should be allocated is not discussed.

| | | | | | |
|---|---|---|---|---|---|
| Number of Homes (IRE) | 1,400,000 | 1,400,000 | 1,400,000 | 1,400,000 | 1,400,000 |
| Penetration of homes | 25% | 25% | 25% | 25% | 25% |
| Home Installed | 350,000 | 350,000 | 350,000 | 350,000 | 350,000 |
| Power Available to shed KW | 0.5 | 0.7 | 1 | 1.5 | 3 |
| Total Power Shed MW | 175.00 | 245.00 | 350.00 | 525.00 | 1,050.00 |
| Total cost per home | € 350 | € 350 | € 350 | € 350 | € 350 |
| Total cost all homes | € 122,500,000 | € 122,500,000 | € 122,500,000 | € 122,500,000 | € 122,500,000 |
| Cost per MW | € 700,000 | € 500,000 | € 350,000 | € 233,333 | € 116,667 |

**Figure 3.7: Return on investment for the HAN**

Assuming that 25% of the homes in Ireland installed a HAN that was connected to the grid, if the home could shed 0.5(KW) during peak time this would be equivalent to producing a total of 175MW load reduction. Assuming that the cost per home of installing the HAN is €350 then the total capital cost is €122m. Thus the capital cost per MW of load shed would be €700,000/MW. If the load shedding could be increased to 0.7(KW) then the cost per MW of load shed would be €500,000.

This compares favourably with the capital cost of installing a CCGT which is about €800,000 per MW or €1,200,000 per MW for onshore wind farms. While there is some operational cost of running the meters it would only be a fraction of the operating cost (non fuel) of running the CCGT and significantly lower than the cost of operating a wind turbine.

The delivery of such load shedding capabilities would provide significant capital savings on providing additional generation capacity and network build costs. There is the possibility for the electricity suppliers and network operators to bring new incentives and tariffs to the market for customers that wished to participate in such schemes.

### 4.2.5 Load creation for renewable energy

The same calculations can be performed for creating loads in domestic homes in the event of there being significant renewable energy available on the network. This calculation was previously performed for load shedding. While turning off loads is a relatively simple task, turning on additional loads is slightly more complicated. The HAN will need to be configured to identify are loads that can be turned on that would provide an economic benefit for the customer. These loads will typically have some sort of thermal lag or be loads that are pre-programmed to come on in the event of a request from the grid e.g. a washing/drying machine or hot water immersion.

Example of thermal lag loads are likely to be:-

- Traditional space heating including storage heaters;
- Geothermal and under floor heating;
- Hot water heating;
- Electric vehicles. Clearly this is not thermal storage but a truly independent form of energy that can be stored and used at a later time or date.

While few people would choose to use electricity when they do not need it, knowing the dynamics of the home such as:- hot water for showers at 6 am or warm house from 5 pm to 11pm, an intelligent HAN could be programmed to 'watch' the network for events that would match the demand profile of the home and buy electricity at a better price earlier in the day/night yet still provide the home with the same end result.

Specific consumer tariffs would be required to ensure that the consumers receives the benefits of taking power at such times.

## 4.3 Wattson meter results

The data used was for the week commencing Monday 8th June 2009 in a 5 bedroom family home in Cabinteely, Co Dublin. Living in the house are two parents, one Au Pair, and three children: one aged 10, and twins aged 4. The 10 year old was at school until 3 pm and the twins were in a crèche until 12. The author spent the day at home on this day.

Below are the results broken down in to various categories.

- Maximum daily load
- Daily electrical load
- Cost of electricity
- Carbon dioxide created

The graphs that are shown here were generated using a tool that was downloaded from Wattson. This can be found at:- http://www.diykyoto.com/uk. The tool was easy to use but did not provide complex analysis tools to compare day on day or week on week statistics.

### 4.3.1 Maximum daily load

This is the maximum daily load recorded over five minute intervals. To turn this into a relative KWh number the values should be multiplied by 12.

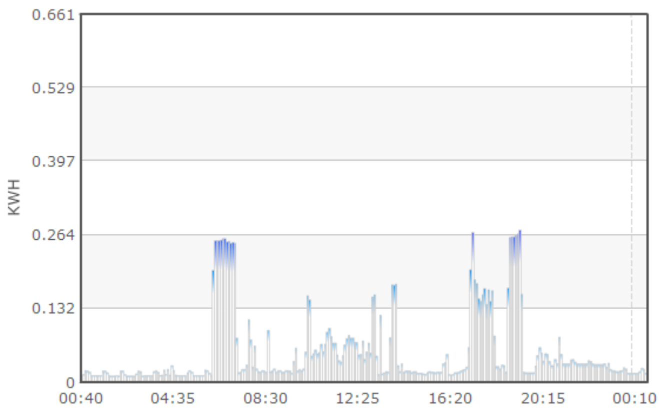


**Figure 3.8:- Five minute interval data**

This data was for Monday 8th June 2009. What the data shows here is:-

- 6 am the morning peak. This is caused by the immersion being turned on by a timer before the occupants of the house get up;
- 7.15 kettles and toasters are on for breakfast;
- 10.45 A mid morning wash turned on and various lights were on;
- 2 pm the clothes dryer is turned on;
- 5.15 the oven is turned on for dinner;
- 8 pm the immersion is turned on again on the timer;
- 8 pm + lights are turned on in the house as well as TV, laptop etc.

What is interesting to observe here is that there is always a base load in the house. At no point and time is there a zero load.

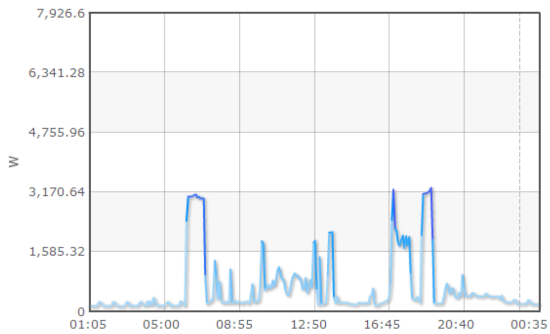


**Figure 3.9: – Wattson Max hourly loads**

Figure 3.9 is for the same data as above in figure 3.8, but shows it by maximum hourly load.

### 4.3.2 Daily electrical load

The graph in figure 3.10 shows the daily consumption of power in the house. On this Thursday and Friday the washing of clothes, cooking and baking were all taking place. Thursday had the greatest load as there were several clothes washes put on and the tumble dryer was used. The family travelled away for Saturday but still the house consumed a significant amount of energy.

While this is not a typical week it does show just how much variation there can be in a domestic house profile.

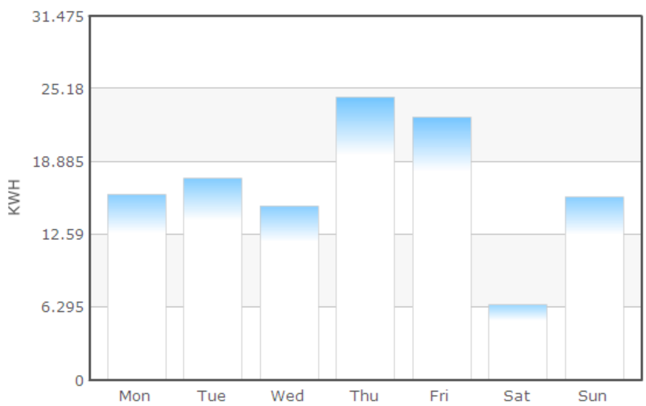


**Figure 3.10: Wattson KWh per week day**

The graph in figure 3.11 below shows the average usage of power over a twenty four hour period. This is at a maximum on Thursday at 1,000 W and lowest on Saturday at 262 W. This is compared with a maximum load in the house of just over 3,000 W at peak times. What this clearly shows is that there is a huge gap between the average and the peak loads in the house. The opportunities for these peaks to be reduced are discussed later.

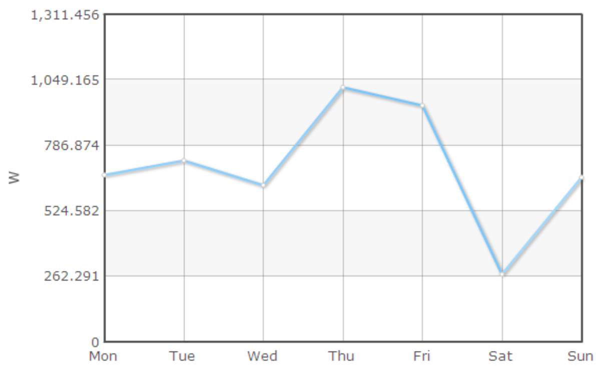


**Figure 3.11: Wattson Average load per day**

### 4.3.3 Cost of electricity

Figure 3.12 is a graph showing the cost in Euros per day for the electricity in the house. This is based on the price of a unit of electricity at 17c flat rate over the course of twenty four hours. This is simple a liner relationship with the KWh used.

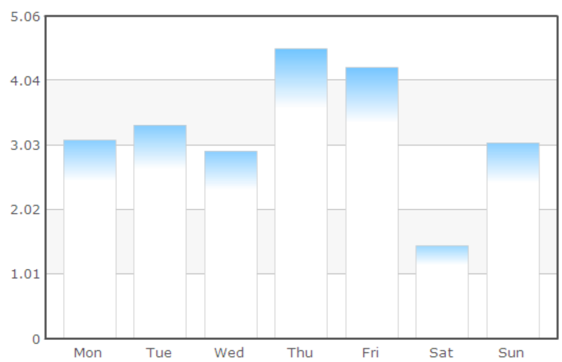


**Figure 3.12 – Wattson Daily cost of electricity**

### 4.3.4 Carbon dioxide created

Assuming the grid electricity produced about 600g per KWh , figure 3.13 shows the $CO_2$ created as a result of the electricity consumed in my home. This too is a liner relationship with the KWh used.

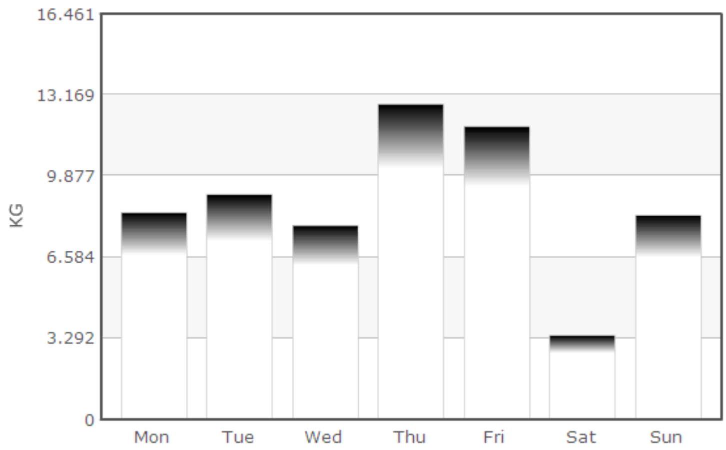


**Figure 3.13: – Wattson Carbon Emissions per day**

To put these emissions in context with transport, at 13kg per day, the electricity used in the home is equivalent to driving a Prius about 125Km per day. (Based on Prius emitting 104g of $CO_2$/Km)

### 4.3.5 Human reaction

The human reaction to having a Wattson meter in the home was very surprising to observe. While the data was collected for only one week, the meter was in place for many months. At first there was great interest in the meter and a lot of attention was given by everyone in the house to the readings that it displayed. After about two to three weeks everyone in the house became less inclined to look at the readings. The meter was then turned off for two weeks and turned on again. On turning on the meter again, the interest levels in the reading were again heightened. While no empirical data was collected for this behaviour these changes were clearly observed.

To test this further it would be of benefit to see how, if incentives were put in place, that the behaviour would change further e.g. ‘If we keep the power reading after 8 pm below 400W everyone in the house gets a reward’. Ultimately this is one of the behavioural changes that smart meters are hoping to deliver. This will clearly have the challenge of keeping the information relevant, and in ‘front of the mind’ of the homeowners.

### 4.3.6 Summary of the Wattson

What the results from the Wattson meter above show is that it is very easy for a homeowner to collect data and to analyse the usage profile in the home. The author found that in his house the entire family started to look at the meter on a regular basis and to see what the electricity consumption was. By doing this many lights and appliances that were not needed were turned off immediately. Because the meter was accessible and easy to read it became part of the activities of the home.

## 4.4 Consumer survey results

There were 106 respondents to the survey, which surpassed the author’s initial expectation of 50. This data has some statistical significance and thus can be treated as a ‘reasonable’ representation of the social class that is was aimed at. This dissertation does not focus on the detail on every question, but more on the key questions and responses relating to smart meters and the attitudes to how smart meter projects might be implemented.

A full copy of the results can be found in appendix F. What is analysed here is the results based on the categories that the questions were asked in.

- General information (G)
- Awareness (A)
- Real information (I)
- Changing behaviour(C)
- How would we do it (T)

### 4.4.1 General Information (G)

This section is for background information and is of no material interest to the research questions. The only observations that can be made on this data are as follows:-

- One in four houses had only two adults living in their home;
- Nearly 50% had only one child living at home;
- Two thirds of homes had somebody at home most days.
    - This is an interesting observation if the timing of energy consumption was to be managed manually in the home during the day;
- 70% felt that their current bills were easy to read;
- Over 70% would change electricity supplier for cheaper electricity while only 10% would change for green electricity;
    - This observation is key, as it shows that the front of mind decision making process is driven by cost and not by green or environmental issues;

The summary of all the input from question 31 is included in Appendix F

### 4.4.2 Awareness (A)

In testing awareness the survey sought to understand how aware the respondents were of their energy usage and their bills.

| **Do you know approximately what your electricity bill (€) per year in your home is?** | | |
|---|---|---|
| **Answer Options** | **Response Percent** | **Response Count** |
| Yes | 35.8% | 38 |
| Reasonable idea | 46.2% | 49 |
| No idea | 15.1% | 16 |
| Don't know | 2.8% | 3 |

It is interesting to note that over 80% of people know or have a reasonable awareness of their bill.

| What do you think is your home's approximate electricity consumption per year Units (kWh)? | | |
|---|---|---|
| **Answer Options** | **Response Percent** | **Response Count** |
| 500 Units | 1.0% | 1 |
| 1,000 Units | 2.9% | 3 |
| 3,000 Units | 12.6% | 13 |
| 10,000 Units | 14.6% | 15 |
| 20,000+ Units | 2.9% | 3 |
| Don't know | 66.0% | 68 |
| | ***skipped question*** | **3** |

66% surveyed responded that they don't know what units they consumed. Interestingly, few questions were skipped in the survey, and this was one of the questions where they was a high level of skipping, perhaps indicating that the answer to the question was clearly unknown. One could assume that in the consumers' mind there is no real link to 'Cost' and actual 'Energy' usage. Yes they understand, 'the more I use the more I pay', but they don't have a link to what energy actually is.

| What do you think is the price of a unit (kWh) of electricity ? | | |
|---|---|---|
| **Answer Options** | **Response Percent** | **Response Count** |
| 5c | 11.3% | 12 |
| 10c | 13.2% | 14 |
| 15c | 45.3% | 48 |
| 25c | 22.6% | 24 |
| 50c | 5.7% | 6 |
| 100c | 1.9% | 2 |
| | ***answered question*** | **106** |

Less than 50% of people knew the price of electricity, while over 10% believed that is was only 5c one third of the actual cost. Linking this answer and the previous one, one could infer that people see electricity as energy that they just need and are not that interested in what the unit cost is other than they pay for what they use. This is very similar to the attitude that people show towards transportation fuel. The price of petrol or diesel is the same price whenever one buys it, and thus it doesn't matter when one buys it. In the home, the same mentality currently applies to electricity. If the consumer has to use the electricity, it really doesn't matter what the price is or when they use it. However, there is another aspect to electricity usage, in that the majority of bills are retrospective, so not only does the consumer not know what they are using, they may not know for several months was the actual cost was.

| **Have you heard of electricity smart meters** | | |
|---|---|---|
| **Answer Options** | **Response Percent** | **Response Count** |
| Yes | 48.1% | 50 |
| No | 51.9% | 54 |

It is surprising to see that less than 50% of people have heard of smart meters even thought this has had much coverage of the smart meters in the media.

### 4.4.3 Real information (I)

As most of the people surveyed were from Dublin the majority of homes were heated by gas. Only 13% were heated by electricity. As 80% of the energy usage in the home is heating and cooking (SEI – Energy in Ireland 2008) there would seem little opportunity for shifting much of the domestic electricity loads with the current mix of energy consumption in domestic homes.

| **Do you use gas or electricity as the primary source of energy to heat your house?** | | |
|---|---|---|
| **Answer Options** | **Response Percent** | **Response Count** |
| Gas | 64.3% | 63 |
| Oil | 22.4% | 22 |
| Electricity | 13.3% | 13 |
| Don't know | 0.0% | 0 |
| Don't know | 0.0% | 0 |
| Other (please specify) | | 10 |
| | ***answered question*** | **98** |

Ten of the respondents use wood chip or an Aga to heat their homes. 25% use electricity and 1% of people used solar to heat their hot water, while only 13% use electricity to heat their homes with electricity. The majority of people, over 80% in both cases, were aware of when the electricity network and their homes use most electricity. However, less than 70% knew which appliances used most electricity. This was not tested by asking further question to see if they could name the appliances.

| **Do you study your electricity bill to understand what your monthly usage and cost is?** | | |
|---|---|---|
| **Answer Options** | **Response Percent** | **Response Count** |
| Yes | 24.5% | 26 |
| No | 27.4% | 29 |
| Occasionally | 44.3% | 47 |
| Rarely | 3.8% | 4 |

Only a quarter of people study their bill on a regular basis to understand their usage. Thus one could assume that there is an acceptance that their 'usage is their usage' and they don't believe that there is any point in tracking how it is used.

### 4.4.4 Changing behaviour(C)

This category of question probes and tests how open the respondents were to changing their behaviour and what returns and rewards they expected. While some of the concepts proposed in the survey may have been alien to the general consumer, there is a clear pattern that people were prepared to change only if they could make savings. However, the changes are more driven by cost than any environmental issues.

| **Would you try to regularly use electricity (washing/drying/ heating water) at different times if it was dearer at peak times and cheaper at off peak times?** | | |
|---|---|---|
| **Answer Options** | **Response Percent** | **Response Count** |
| Yes | 86.8% | 92 |
| No | 7.5% | 8 |
| Don't know | 5.7% | 6 |

| Would you try to regularly use electricity (washing/drying/heating water) at different times if it was better for the environment but still cost the same? | | |
|---|---|---|
| **Answer Options** | **Response Percent** | **Response Count** |
| Yes | 72.6% | 77 |
| No | 11.3% | 12 |
| Don't know | 16.0% | 17 |

As can be seen from the above two responses, 86% would make changes if it was cost driven, but only 72% if it was environmental driven. While there is not a huge gap, the question below is the most startling response that indicates that cost, above all, is the greatest driver in energy consumption and behaviour changes.

| If you switched or are thinking of switching from the ESB as your electricity provider - why would/did you do it? | | |
|---|---|---|
| **Answer Options** | **Response Percent** | **Response Count** |
| Didn't change | 7.5% | 8 |
| Won't change | 5.7% | 6 |
| Cheaper Electricity | 72.6% | 77 |
| Better service | 0.0% | 0 |
| 'Greener' Electricity | 9.4% | 10 |
| Other (please specify) | 4.7% | 5 |

In order for smart meters to be able to control domestic loads in people's homes there will need to be some sort of automated or direct control of appliances by the grid. While clearly this is a concept that would be quite alien to most consumers and perhaps they were cautious when asked if they would allow this to happen in their home - which is indicated in the response below.

| Would you be happy for your electricity supplier to control certain appliances in your home if it had minimal effect on your lifestyle? | | |
|---|---|---|
| **Answer Options** | **Response Percent** | **Response Count** |
| Yes | 39.6% | 42 |
| No | 44.3% | 47 |
| Don't know | 16.0% | 17 |

However, there is a big swing towards 'Yes' from 39% to 51% when the consumer believed that they could be offered cheaper electricity. This significant increase demonstrates that price is the primary driver to change.

| **Would you be happy for your electricity supplier to control appliances in your home if it had minimal effect your lifestyle but offered you cheaper electricity?** | | |
|---|---|---|
| **Answer Options** | **Response Percent** | **Response Count** |
| Yes | 51.9% | 55 |
| No | 31.1% | 33 |
| Don't know | 17.0% | 18 |

This is key insight for the rollout of smart grids and integrating renewable energy into the grid in an economic and consumer friendly manner. In this survey, while presenting quite an alien concept of -'the supplier' controlling appliances, there was a much greater acceptance of this, if there was an incentive for cheaper electricity to be supplied.

When asked if people were interested in comparing their bills to the national average there was a clear desire for this information. 82% were either 'very interested' or 'interested' in this information.

| **Would you be interested to know how your bill compared with the national average?** | | |
|---|---|---|
| **Answer Options** | **Response Percent** | **Response Count** |
| Very interested | 36.8% | 39 |
| Interested | 45.3% | 48 |
| Not really interested | 16.0% | 17 |
| Not at all interested | 1.9% | 2 |

When asked a more specific question regarding having data relevant to their own house and family size, 92% were either 'very interested' or 'interested' in this information. Thus there is a hunger for this information and a desire to understand where they stand on their energy usage.

| Would you be interested to know how your bill compared with a similar house sizes and similar family sizes? | | |
|---|---|---|
| **Answer Options** | **Response Percent** | **Response Count** |
| Very interested | 52.8% | 56 |
| Interested | 39.6% | 42 |
| Not really interested | 7.5% | 8 |
| Not at all interested | 0.0% | 0 |

The final question in the survey asked for ideas and suggestions on further information that would be of benefit. The total results of this are in Appendix F. What can be seen from this is that the questions in the survey have prompted people to think about how they are using electricity and how they might be able to change what they are currently doing. Even though this was at the end of the survey, the majority of people took the time to give feedback to this question.

### 4.4.5 How would we do it (T)

This category of questions in the survey solicits a view on:-

- What information people would like to see?
- How often they would like to see it?
- How they would like it presented to them?
- How much would they spend or invest?

In the last categories it was observed that a majority of people are open to the concept of using electricity at different times and/or having some sort of automated/grid control of appliances in their home. The response to this question improved when it was incentivised by cost. How these people would like to be communicated with, is investigated further here. It is unlikely in the short term that the price of electricity for domestic homeowners will dynamically change during the course of a day or week. This may change when there is a greater amount of intermittent renewable energy being produced. There is still a desire by 55% of the people who responded to be informed whenever it changed. 23% were happy for it to be provided with their bill, which is what we currently have in place today.

| If the price of electricity changed regularly how often would you like to be informed of the price changes? | | |
|---|---|---|
| **Answer Options** | **Response Percent** | **Response Count** |
| Hourly | 0.9% | 1 |
| Daily | 2.8% | 3 |
| Weekly | 3.8% | 4 |
| Monthly | 12.3% | 13 |
| With my bill | 22.6% | 24 |
| As often as it changed | 54.7% | 58 |
| Other (please specify) | 2.8% | 3 |

40% of people would like to receive it by e mail which indicated that they would like more up to date information of what their costs were.

| How would you like to be informed of the price of electricity? | | |
|---|---|---|
| **Answer Options** | **Response Percent** | **Response Count** |
| Looking at a display on your meter | 6.6% | 7 |
| Receiving a text on your mobile | 8.5% | 9 |
| Provided on a website | 5.7% | 6 |
| Receiving an email | 40.6% | 43 |
| On your bill | 34.9% | 37 |
| Other (please specify) | 3.8% | 4 |

While keen to receive information by other means than just the bill, the vast majority were not that keen to receive the price information more often than weekly or with their bill.

| How often would you like to know how much electricity you are using on a daily basis? | | |
|---|---|---|
| **Answer options** | **Response Percent** | **Response Count** |
| Instantaneously | 12.3% | 13 |
| Daily | 8.5% | 9 |
| Weekly | 21.7% | 23 |
| Monthly | 17.0% | 18 |
| With my bill | 40.6% | 43 |

With smart meters, a big challenge is who pays for the meter and the infrastructure. What can be seen from the following responses, is that if the consumer is being asked to pay, then they would expect that it would pay back in saving in less than three years. If a consumer is being asked to pay for or a HAN, the question which has to be asked is could such savings and returns be achieved with smart meters?

| How much would you be prepared to spend in your home to save €200 on your yearly electricity bills? | | |
|---|---|---|
| **Answer Options** | **Response Percent** | **Response Count** |
| Nothing | 10.4% | 11 |
| Up to €200 | 28.3% | 30 |
| Up to €500 | 35.8% | 38 |
| Up to €1000 | 17.9% | 19 |
| Over €1,000 | 7.5% | 8 |

## 4.5 Summary

This chapter focused on three areas. Firstly, the benefits delivered by implementing a sophisticated smart meter and a HAN rollout to domestic homes. These benefits are available to the grid operator as well as benefits that can be delivered to the consumer. What the author has proposed is an architecture that puts the smart meter as the 'master' in controlling the communications between the grid operator and the domestic home. The calculations showed that there is significant benefit to be gained from being able to load shed and control domestic loads en mass even if only a 25% penetration is achieved.

Secondly, qualitative research gave a great insight into behavioural changes that can occur when a household is presented with data that shows energy usage in real time. This shows that the homeowner has some control over their usage and that behaviour can be changed. However, a simple meter does not allow the householder to make any automated changes to the home's load.

Thirdly, high level insights that were gained from the consumer survey were analysed. The responses show some clear insights to consumers' attitude. It was shown that most people are prepared to make changes, but price is likely to be the driver. While most people are aware of their costs few are aware of usage profile. The respondents indicated that they would like to receive more information and are open to receive this information using new media and not just via traditional paper bills. A surprising outcome of the results was that 52% of people have not heard of smart meters. In general what was found is that there is an acceptance by people that they will have to change and that they are likely to embrace that change. Respondents indicated they were prepared to make an investment to deliver savings in their home but indicated the payback period must be two to three years for it to be appealing.

The inclusion of the Consolidation entity is key to achieve significant results from a smart meter implementation and this was shown, from the observations of both Wattson meter and the results of the consumer survey. The key findings are outlined below.

- The observations from the Wattson meter clearly showed that the some changes to the usage profile in the home could be achieved from purely providing information but this is unlikely to have a lasting effect without some automated control such as a HAN;

- Changes to tariffs will drive usage changes but without automation, the survey showed that people need to be able to understand the usage profiles to make these changes and today. Most people do not fully understand their profiles or what drives them;

- While modest change will occur by changing prices and providing consumers with information, the survey and the 'Wattson observations' showed that people are likely to revert to their previous usage profiles unless some automation is implemented through a HAN.

- It was shown that getting the home owners to respond to complex requests from the networks such as 'demand responses' will not be possible unless the home has automated control and the grid operator is provided with a Consolidation tool to implement these requests.

- The ownership and cost of the HAN and consolidation tool are key to ensuring that the correct solutions are picked so that the consumer, the grid operator, the power generator all benefit from the capital invested in the project.

# 5 Summary and conclusions

## 5.1 Introduction

This final chapter of the thesis begins with section 5.2, which briefly summarises the four previous chapters (Ch 1 to 4). Section 5.3 reviews the fundamental aims and goals as set out in Chapter 1 and explicitly highlights how each aim was achieved. This section also ties together some final associations between the findings and research of smart metering. Section 5.4 examines the fundamental contributions to the body of knowledge of smart metering that this thesis provides. As this research topic is in a continuous state of flux from a technology and implementation perspective, it is important to examine where future research activity should be focused. Section 5.5 offers a direction and order of priority for future research in this area to take place. Finally section 5.6 presents the ultimate and concluding remarks of this chapter and thesis.

## 5.2 Summary of dissertation

This dissertation documented and explored the opportunities, challenges and implications for the rollout of a smart meter and smart grid for the benefits of both the consumer and the grid operator. The authors' key findings of this dissertation is that very little change to the home's load profile will be achieved, without a Home Area Network (HAN) connected to a smart meter to control the home's electrical loads. In addition, without the author's proposed new Consolidation Tool the grid will not have the capabilities to be able to implement many of the controls and savings, both electrical and economic, which are benefits promised from new smart grid rollouts.

Almost all domestic and grid control is currently task based. The author's design successfully shows that one cannot have "energy saving collaboration" without a goal based control strategy where a number of options for controls are offered and prioritised. In section 3.2 the new architecture shows the new components that are required to fulfil the objectives of goal based smart meter rollouts going forward.

## 5.3 Summary by Chapter

In Chapter 1, the goals and objectives of the project were stated and the framework of the energy challenge and technology challenge were stated.

In Chapter 2, the current state of how the electricity network and the billing systems work are documented. This shows the various technical, commercial and regulatory parties that all need to work together for the successful rollout of a project. The details of the functionality of smart meters, were investigated and discussed. The dominant technologies that are in the market were documented and critiqued. This chapter also documented the likely roadmap for renewable energy in Ireland and how renewable energy complements smart meters and vice versa.

In Chapter 3 the author discussed the high level design that was arrived at. Using UML provided the tool to allow the structures and processes to be developed. The research methodology and how the research was carried out and the challenges and issues that arose carrying out this research are outlined.

In Chapter 4 the results of the new design and the benefits to be delivered are quantified. The results of qualitative and quantitative research are discussed and documented and the key insights from the research are highlighted.

## 5.4 Review of aims and objectives of the dissertation

Below is a restatement of the four aims (1 to 4) set out for the research and a summary of how these objectives were met through the course of completing this dissertation.

1. The research and analyses of the key commercial driving factor for the introduction of smart metering by electricity providers. Why will smart meters be installed? Why is this happening now? What are the commercial, technical, energy and environmental reasons for doing it?
    - Section 2.4 discusses the economic benefit to generators in having more control over their ability to despatch renewable energy when it is available;

- It was shown in section 2.6 how the challenges faced by peak loads on electricity grids can be managed better using smart meters;
- Section 2.9 outlines some of the key test projects that were implemented or are currently under way;
- Some of key saving were discussed in section 2.9 which show that the current key commercial drivers are firstly a reduction in meter reading costs and secondly fraud avoidance.
- Section 1.3 discusses that with increasing amounts of electricity usage, coupled with an increase in global carbon emissions, as well as the introduction of intermittent renewable energy, the need from smart energy usage, generation and transmission continues to grow.

2. The accurate categorisation of the functionality that the industry defines as "smart metering" in relation to the different needs of the various parties such as the consumer and electricity providers. What benefits justifies the rollout of a network of smart meters such as automated billing, fraud protection, load shedding, variable tariff implementation or network management?
    - Section 2.8 defines the term 'smart meter' and what benefits they deliver to the parties in the electricity supply chain;
    - Section 2.8 shows that existing smart meters are often just data loggers and are not smart other that they can store electronic data and be read remotely;
    - Section 2.9 shows that existing projects do not have the architecture to support a HAN to deliver the real benefits to the electricity supply chain;
    - Who is likely to pay for smart meter projects and how they will be financed is outlined section 2.11;
    - Section 4.2.4 outlines how the benefits of the smart meter rollout will be delivered to the end customer. The needs of consumer were identified including the need for cheaper electricity as well as more control over domestic loads to match new variable smart meter tariffs;

- Section 4.2.5 calculates how load shedding and new tariffs can be implemented for the benefit of all the parties. It was shown that going forward this is a great opportunity to the grid operator to dispatch large amounts of intermittent renewable energy by being in control of domestic loads.

3. An investigation to examine the current technology available to provide smart metering as defined by the benefits delivered to the various parties. What benefits are delivered to each part and what is likely to be the future goals of smart meters.
   - Section 2.7 and 2.8 look at the current technology and how projects are being implemented today;
   - A review of the current technology was performed in Section 2.9 The high level meter technology that is available to deliver current projects was documented showing that there are many smart meters and communication protocols that could be used to deliver solutions;
   - Section 3.2 and 3.3 reviews how the benefits are delivered to each party;
   - The future goals and benefits delivered are outlined and discussed in section 4.2. How smart meters could be implemented to deliver benefits beyond the primary benefits of existing smart meter projects were identified.
- Section 3.3 show that an architecture that does not have a HAN and a consolidation tool, as proposed by the author, is not likely to deliver on all the benefits possible with a smart meter rollout.

4. The research and analysis of the techniques and approaches to improve the interaction with the home and the smart meter with a view to giving better tariffs to consumers by controlling the house's load and supplying useful feedback to encourage and aid in behavioural changes, both leading to 'load balancing' and 'load shedding'.
   - Section 2.10 reviewed the current consumer interface to smart meters and documented what is planned in an Irish context;

- What the author found in section 4.3 during the Wattson meter research is that changes in consumer behaviour is possible, however it is not likely to be sustainable without some automated control. Without the HAN little change to domestic home loads can be achieved by consumer behaviour alone.
- A new model was proposed and both a new technical architecture and procedural framework was developed for both the home owner and the grid operator which was outlined section 3.2;
- A review of the consumer behavioural response to providing information in the home was documented in section 4.3;
- Section 4.2 showed that the author's proposed 'Consolidation Tool' integrated to the HAN is required for the home and the grid to manage domestic loads effectively and to achieve the best possible solution that gives flexible load management capability;
- Section 4.4 outlined the consumer acceptance of new tariffs and documents their willingness to change, primarily to save money.

Each of the above areas is treated individually and throughout the course of the dissertation. What is clear from the author's research is that the momentum that is behind smart meter projects is significant. The stimuli for these are from a wide range of sources such as environmental, economic and financial stimuli such as those being implemented by the current US administration under Obama.

However, to deliver many of the future functions and benefits (both energy and economic) that can be achieved from smart meters and smart grids, the architecture of smart meter projects need to be future proofed to allow for the integration of tools such as HANs and Consolidations entities.

## 5.5 Addition to the body of knowledge

The primary focus of the research was to gain an understanding of the technical challenges faced and the human acceptance and interaction with smart meters. Identifying what obstacles need to be overcome to ensure that projects are rolled out and that their objectives are met were also discussed. What is demonstrated is that consumer behaviour towards electricity and energy can be changed and this will be most effective through providing timely and easy to use information. What is shown here is that, with today's modern technology, information can be provided through many channels that are now acceptable to modern day consumers. However, what is key for electricity usage is to provide the information in a timely and meaningful manner to enable change.

It is shown that it is unlikely that human behaviour can deliver a significant change in domestic usage patterns, and a technical solution is required to actually control loads. Thus, to deliver such solutions, a more complex infrastructure is required to mediate between the grid operator and the load in the house.

However, there are currently gaps in current architecture that are being deployed on smart meter rollouts.

- There are no clear standard interfaces from smart meters to a HANs to allow two way traffic between the grid operator and the home;
- There is no consolidation of data to allow the grid operator to call on the domestic loads when required.

What has been proposed here are two significant yet seemingly simple amendments to the current infrastructure:-

- An open standard for the smart meter to receive commands from the grid operator and to issues commands to the HAN;
- The retrofit of the home with circuits that can be switched based on the homes profile and algorithms applied to the HAN;
- The implementation of a consolidation platform to provide a gateway between the grid operator and the domestic home through the smart meter and the HAN.

Without such considerations being implemented at the start of smart meter and smart grid projects, it is likely that considerable costs would be incurred in implementing the functionality at a later date.

There are huge opportunities now to build in the correct functionality into projects that are rolling out smart meters which would greatly reduce the cost of retrofitting at a later date

## 5.6 Recommendations for further research

This is a very fertile area for research at many levels – technical, commercial, human behaviour, regulatory and environmental. The author suggests the following areas for further research should be considered:

- How would the benefits realised from load shedding be accounted for by the grid operator be passed on to the consumer.
- Designing and analysing how electricity suppliers will be able to offer time of use electricity to consumers and what type of tariffs are likely to offered in the future. Will consumers see similar tariffs structures to those offered by the telecoms companies? These new tariffs should be modelled against the price of electricity to see what new tariffs could be rolled out;
- As tariffs will be linked to the growth of renewable energy supply, how will homeowners that are controlled by the grid be rewarded with new tariffs or incentives?
- Design, build and test various applications to evaluate the human interface options of smart meters. This could be in the form of application on mobile phones using iApps (Apple) or various tools on messenger via web or mobile phone.
- Will the smart meter be the channel for communications to the smart meter or will personal broadband either fixed or mobile, provide the most cost effective channel for such a service.
- Modelling of the payback for the meter to include not only the meter reading and fraud avoidance savings, but also to include how other services such as renewable energy tariffs and demand response tariffs can be accounted for.
- How the storage capabilities of electric vehicles could be implemented into the smart grid to provide the buffer for both excess generation and power for demand response requests from the network.

## 5.7 Summary and conclusions

The overall aim of this research was to document the current status of smart metering, with a focus on the Irish infrastructure and the opportunities therein that exist. A key objective was to identify insights, including behavioural, economic, commercial and technical that should be considered in the implementation of any smart meter project going forward. During this research some key insights were uncovered and documented.

It is clear that in general the current architecture of the smart meter projects is missing two key technical components in order to future proof projects going forward. The domestic home needs to have a HAN (Home Area Network) that can be programmed to control domestic loads in homes, based on certain rules and/or alerts and notification from the grid operator. Secondly, in order to fully utilise the resources in domestic homes for load shedding and load balancing, a new ‘Consolidation entity’ is required to provide consolidated visibility and control to the grid operator and to provide each HAN with specific alerts such as price changes and demand response requests. Without both of these new technical components, the ability for the residential market to intelligently adjust to price changes or to consume electricity from large-scale intermittent renewable sources will prove difficult.

The costs of implementing such solutions are significant but the opportunity to improve and increase savings were also shown to significant. However, it is not clear who pays for such solutions going forward or how these savings will be calculated or passed on to the parities in the electricity supply chain, including the consumer.

What is also clear is that there is no ‘one size fits all’ solution in the rollout of smart meters and there is no defined standard for the integration of these tools.

The surveys part of this research showed that consumers are prepared to accept new technology and are keen to understand how it will work. However, the key driver for the acceptance of this technology is not environmental concerns or metrics. What was clear is that consumers want the costs that they incur to be justified and for these costs to have a short payback period. Thus the network operator or supplier, or whomever the party responsible for the infrastructure is, must consider carefully how these costs are justified to the consumer if the consumer has to pay towards their installation.

Much research that could be performed in this area and there are some very exciting and rewarding research projects that could be completed as outlined.

What is clear, is that the challenges faced from climate change and the shortage of fossil fuels, coupled with exponential growth renewable energy generation and thus the intermittent supply of electricity, will create great opportunities for smart meter and smart grid technology to be deployed for the benefit of all parties in the electricity supply chain.

- The End -

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## Definitions and Glossary

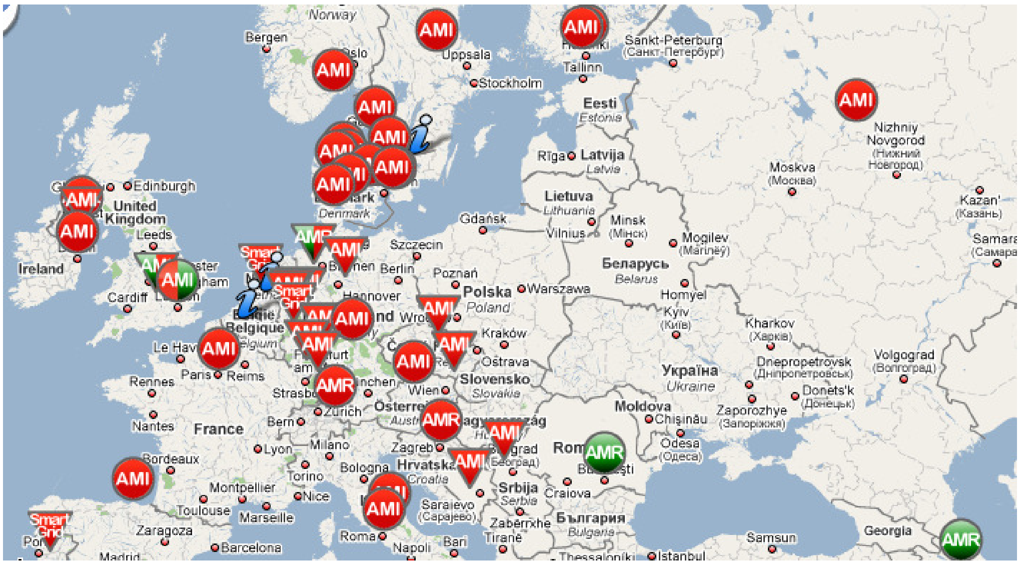
| | |
|---|---|
| 3G | Third Generation – The upgrade to the GMS network |
| CBT | Consumer Based Trial |
| CCGT | Combined Cycle Gas Turbines |
| CER | Commission for Energy Regulation |
| CHP | Combined Heat and Power |
| CT | Current Transformer |
| DSO | Distribution System Operator |
| DUoS | Distribution Use of Service |
| ESB | Electricity Supply Board Ireland |
| GPRS | General Packet Radio System – IP network use on GSM 2G technology |
| Grid (The) | This is the national network of electricity generation and transmission |
| GSM | General System for Mobile |
| HAN | Home Area Network |
| IEA | International Energy Agency |
| IHD | In-home Display |

| | |
|---|---|
| MRSO | Meter Registration System Office |
| MW | Mega Watt |
| MWh | Mega Watt hour |
| NRS | National Readership Survey |
| Pass Through | Tariffs that vary with the price of spot electricity in the SEM |
| PLC | Power Line Communications |
| PSO | Public Service Obligation levy |
| SEAI | Sustainable Energy Association of Ireland formally know as SEI |
| SEI | Sustainable energy Ireland now known as SEAI |
| SEM | Single Electricity Market for RoI and NI |
| SMS | Short Message Service – Also know as 'Text message' |
| Survey Monkey | Online tool to allow surveys to be carried out using. www.surveymonkey.com |
| TSO | Transmission System Operator |
| TUoS | Transmission Use of Service |
| WPDRS | Winter Peak Demand Reduction Scheme |

# Appendix A - Smart meter projects

## Known projects in Europe

There is currently no recognised repository or data source for all the smart meter projects that are under way. All projects are at different stages in their life cycle. Not all projects have the same goals or the same scope. The figure A.1 below gives some indication of the scale of the deployment of this technology.




Key: red = electricity, green = gas, blue = water and triangle = trial or pilot; circle=project.

**Figure A.1: Sample project in Europe - Source Engage (2009)**

## Known Projects in North America

The USA is the largest electricity market in the world and it faces many of the same challengesas the European market. Many high profile projects have been initiated since the announcement of the Federal governments funding of the smart grid initiative.

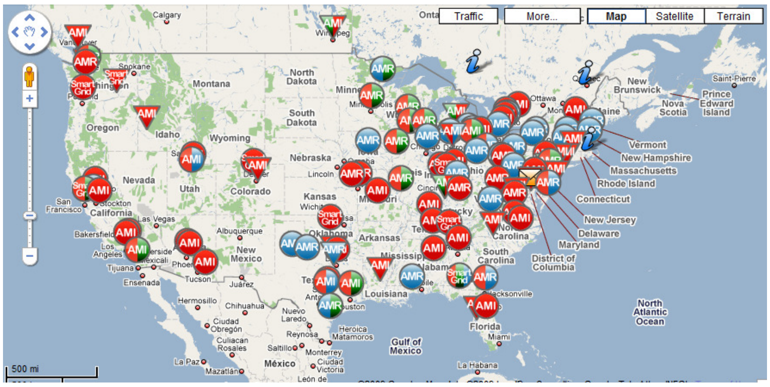



**Figure A.2: Sample Project in North America - Source Engage (2009)**

Key: red = electricity, green = gas, blue = water, triangle = trial or pilot; circle=project.

## Appendix B - User interface design

One of the critical success factors of smart meters without a HAN is the engagement with the consumer to ensure that the correct data is provided in a timely, simple and understandable format. The display of information could be on the smart meter itself like Echelon, a web based application like Google meter, a home area network (HAN) such as EcoBee or on mobile phone as discussed in the previous chapter. Regardless of the form factor, the ability of the consumer to understand the information and to take action based on the information presented is key to a successful outcome.

The author recommends that the "Choice of Display" as compiled by Wood & Newborough (2006) Figure B.1, is a good design methodology to follow when designing an interface to smart meters. The "Motivational Factor" row below is a key consideration outside of any technology solution. This requires careful planning and execution and to keep this relevant to the consumer a consistent communications strategy must also be implemented.

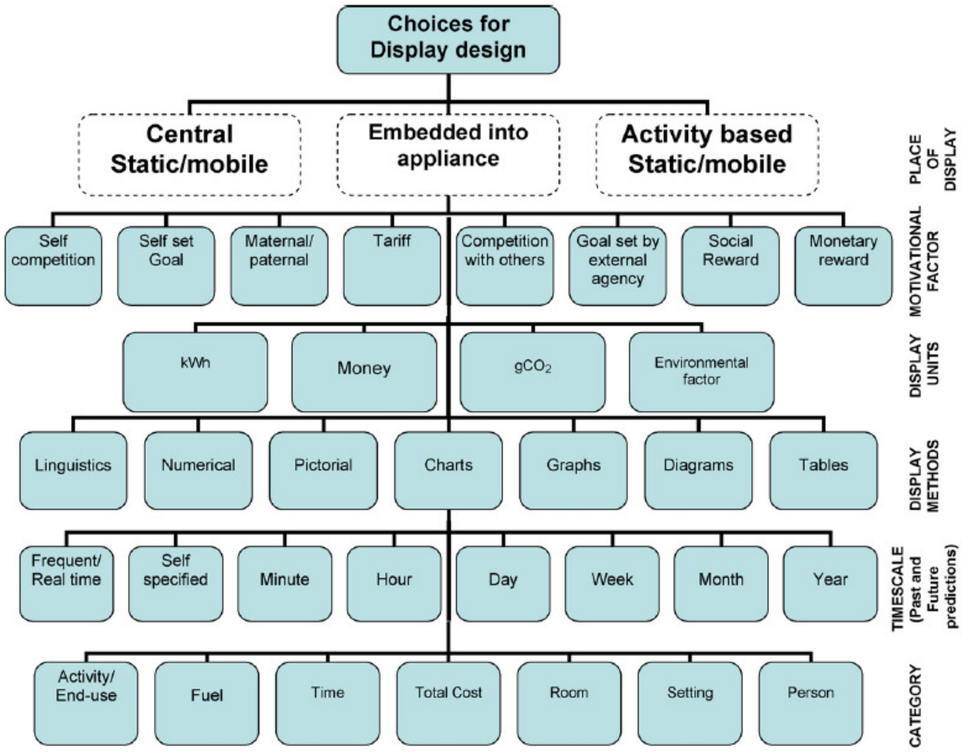



**Figure B.1: Sample Project in North America**

## Appendix C - The communications infrastructure

The simple smart meter requires only very simple communications between the home and the supplier. The meter needs to be able to:

- Be enabled so that power can flow through the meter
- Record the usage by kWh in each predetermined period e.g. half hourly
- Be disabled so that power flow through the meter can be stopped and thus shut off the customer supply.

However, with greater demands put on smart meters the communication demands and options increase. These are discussed under four headings:-

- Communicating with the electricity supplier
- Communicating with the grid

- Communication with the customer
- Communication with the customer's house

A key consideration of such deployments is the security of the customer data and denying unsecure access to the grid. Providing an open network that has access to the grid creates great concerns for utility companies as potential hackers may be able to control peoples homes and get access to their billing data. Of more concern would be that potential hackers would gain access to a utility companies network and be able to disrupt the operation of the network. This would have serious and far reaching consequences for energy supply and indeed national security.

**Communicating with the supplier/MRSO**

In order for a billing cycle to be completed in a timely and accurate manner a communications infrastructure must be in place to each meter. By using GSM (GPRS) or 3G over 99% Vodafone (2009) of homes in Ireland will be covered. All major economies and developing countries are now moving towards this wireless coverage level. Thus there is network already in place to provide the 'meter reading' services provider with a ubiquitous wireless network that will work in most cases. Other technologies such as Wi-Fi, WiMax, Mesh networks, and Powerline data networks are also available. The decision on which network to choose will largely be based on reliability and cost. No analysis is performed here of the likely costs of using the different technologies.

Once the meter has been read by the meter reading service the usage data will be passed on using standard telecoms networks to the electricity supplier. The supplier will generate the invoice based on the contract they have with the customer and that usage profile for the billing period.

## Communicating with the Grid

If the smart grid rollout is ambitious enough to want to control load in people's homes in a secure and structured way, then the communication to and from the grid is a key component of the next generation of smart meter projects.

In most cases the same communication channels that are used to communicate with the supplier can be used to communicate with the grid. As the communication is two way the same network can be piggy backed to transfer the data.

The typical information that the grid will want to have available to it, is what loads are on the network that could be reduced or shut down when there is excess demand on the network. As discussed previously this could be water heaters, storage heaters, refrigeratiors, freezers, electric vehicles etc. Secondly, the grid operator would want to know what loads are available to be turned on in the case of their being excess generation on the network coming from renewable energy sources such as wind.

## Appendix D - Google power meter

Below is a testimonial taken from the Google Blog on it Power meter. What is show is that we the correct information, a certain group of society, will make changes that be deliver real savings.

*"I put the sound system, DVD player and VCR on power strips. I learned that my computer wasn't sleeping properly, and started putting it on standby when not in use. I cleaned the coils in my refrigerator (which hadn't been cleaned in 15 years! Yikes!). Before I made these changes, my baseline load was around 360 W, afterwards, it was slightly under 200 W - this will save me about $150 / year."*

*"The dishwasher turned out to be a big energy hog. We now wait to load it fully before starting it. Or, if it's just a couple of dishes, we wash them by hand. When we turned on our space heater, we were amazed by its power consumption. It definitely gives one a perspective on a true cost of using a $20 space heater."*

*"My apartment is in the basement near the building's shared washer and dryer. After installing Google PowerMeter, I saw very large spikes that I could not correlate with any of my activities. Eventually I realised that my electric meter included the building's washer and dryer - I was paying for all the laundry done in my building! Without Google PowerMeter, I never would have figured this out."*

*"I saw the huge spikes caused by washer/dryer use, so now I make sure each wash load is full. I also noticed spikes when the home heater would turn on even when we weren't home, so I made slight adjustments to the timer to better align with our schedule. It's amazing that taking such simple steps has reduced our energy consumption by more than 10%."*

http://blog.google.org/search/label/PowerMeter

# Appendix E – List of survey questions

| No | Cat | Question | Options on how to answer each question. |
|---|---|---|---|
| 1. | G | How many adults live in your home? | 1<br>2<br>3<br>4+ |
| 2. | G | How many children under the age of 16 live in your home? | 0<br>1<br>2<br>3<br>4+ |
| 3. | A | Do you know approximately what your electricity bill (€) per year in your home is? | Yes<br>Reasonable idea<br>No idea<br>Don't know |
| 4. | G | During the week, is there someone in your home during the day? | Most days<br>Some days<br>Rarely<br>Never |
| 5. | A | What do you think is your home's approximate electricity consumption per year Units (kWh)? | 500 Units<br>1,000 Units<br>3,000 Units<br>10,000 Units<br>20,000+ Units<br>Don't know |
| 6. | I | Do you use gas or electricity as the primary source of energy to heat your house? | Gas<br>Electricity<br>Don't know |
| 7. | I | Do you use gas, oil, electricity, solar as the primary source of energy to heat your hot water? | Gas<br>Oil<br>Electricity<br>Solar<br>Don't know<br>Other please specify |
| 8. | I | What time of day you use most electricity in your home? | 06:00-09:00 Morning<br>12:00-15:00 Lunchtime<br>17:00 – 20:00 Evening<br>20:00 – 23:00 Night |
| 9. | I | What time of day is the maximum demand for power on the electricity network? | 06:00-09:00 Morning<br>12:00-15:00 Lunchtime<br>17:00 – 20:00 Evening<br>20:00 – 23:00 Night |
| 10. | I | Do you know what appliances in your home use the most electricity? | Yes/No |
| 11. | I | Do you have night rate electricity? | Yes |

| No | Cat | Question | Options on how to answer each question. |
|---|---|---|---|
| | | | No<br>Don't know |
| 12. | I | If you have night rate electricity do you use timers to turn on and off appliances other than electrical storage heaters? | Yes<br>No<br>Don't know |
| 13. | T | If the price of Electricity changed regularly how often would you like to be informed of the price changes? | Hourly<br>Daily<br>Weekly<br>Monthly<br>With my Bill<br>As often as it changed |
| 14. | T | How would you like to be informed of the price of electricity? | Looking at a display on your meter?<br>Receiving a text on your mobile?<br>Provided on a website?<br>Receiving an email?<br>On your bill<br>Other? |
| 15. | T | How often would you like to know how much electricity you are using on a daily basis? | Instantaneously<br>Daily<br>Weekly<br>Monthly<br>With my Bill |
| 16. | A | Do you turn off lights when you are not in a room for 15 minutes? | Always<br>Sometimes<br>Most times<br>Never |
| 17. | C | Would you try to regularly use electricity (washing/drying/ heating water) at different times if it was dearer at peak times and cheaper at off peak times? | Yes<br>No<br>Don't know |
| 18. | C | Would you try to regularly use electricity (washing/drying/heating water) at different times if it was better for the environment but still cost the same? | Yes<br>No<br>Don't know |
| 19. | C | Would you be happy for the grid (ESB) to control certain appliances in your home if it had minimal effect on your lifestyle? | y/n<br>Don't know |
| 20. | C | Would you be happy for your electricity supplier to control appliances in your home if it had minimal effect your lifestyle but offered you cheaper electricity? | Yes<br>No<br>Don't know |
| 21. | A | What do you think the price of a unit (kWh) of electricity is? | 5c<br>10c<br>15c<br>25c<br>50c |
| 22. | T | How much would you be prepared to spend in your home to save €200 on your yearly electricity bills? | Nothing<br>Up to €200<br>Up to €500<br>Up to €1000 |

| No | Cat | Question | Options on how to answer each question. |
|---|---|---|---|
| | | | Over €1,000 |
| 23. | C/T | Would you be interested to know how your bill compared with the national average? | Very interested<br>Interested<br>Not really interested<br>Not at all interested |
| 24. | C/T | Would you be interested to know how your bill compared with a similar house sizes and similar family sizes? | Very interested<br>Interested<br>No really interested<br>Not at all interested |
| 25. | G | Is your current electricity bill easy to understand? | Yes<br>No |
| 26. | I | Do you study your electricity bill to understand what your monthly usage and cost is? | Yes<br>No<br>Occasionally<br>Rarely |
| 27. | G | If you switched or are thinking of switching from the ESB as you electricity provider - why would/did you do it? | Didn't change<br>Won't change<br>Cheaper Electricity<br>Better service<br>'Greener' Electricity<br>Other |
| 28. | A | Have you heard of electricity Smart Meters | Yes<br>No |
| 29. | A | Do you know what an electricity smart meter does? | Select many<br>Is called smart because it does smart things with electricity?<br>Is call smart because it is electronic?<br>Allows for remote reading of your meter.<br>Is can bill you for your electricity based on when you used it.<br>Is required to change electricity supplier |
| 30. | A | What would be the biggest driver for you reducing your electricity usage? | Cost<br>Environmental issues<br>Other |
| 31. | G | What other information would be of benefit to you on your bill regarding your electricity usage, cost, carbon footprint etc? | Free text to be entered |

# Appendix F - Survey responses

| No | Questions | | |
|---|---|---|---|
| 1 | **How many adults live in your home?** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | 1 | 7.5% | 8 |
| | 2 | 73.6% | 78 |
| | 3 | 11.3% | 12 |
| | 4 | 1.9% | 2 |
| | 5+ | 5.7% | 6 |
| | | ***answered question*** | **106** |
| | | ***skipped question*** | **0** |
| | | | |
| 2 | **How many adults live in your home?** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | 1 | 7.5% | 8 |
| | 2 | 73.6% | 78 |
| | 3 | 11.3% | 12 |
| | 4 | 1.9% | 2 |
| | 5+ | 5.7% | 6 |
| | | ***answered question*** | **106** |
| | | ***skipped question*** | **0** |
| | | | |
| 3 | **Do you know approximately what your electricity bill(€) per year in your home is?** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | Yes | 35.8% | 38 |
| | Reasonable idea | 46.2% | 49 |
| | No idea | 15.1% | 16 |
| | Don't know | 2.8% | 3 |
| | | ***answered question*** | **106** |
| | | ***skipped question*** | **0** |
| | | | |

| No | Questions | | |
|---|---|---|---|
| 4 | **During the week, is there someone in your home during the day?** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | Most days | 62.5% | 65 |
| | Some days | 18.3% | 19 |
| | Rarely | 12.5% | 13 |
| | Never | 6.7% | 7 |
| | | ***answered question*** | **104** |
| | | ***skipped question*** | **2** |
| 5 | **What do you think is your home's approximate electricity consumption per year Units (kWh)?** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | 500 Units | 1.0% | 1 |
| | 1,000 Units | 2.9% | 3 |
| | 3,000 Units | 12.6% | 13 |
| | 10,000 Units | 14.6% | 15 |
| | 20,000+ Units | 2.9% | 3 |
| | Don't know | 66.0% | 68 |
| | | ***answered question*** | **103** |
| | | ***skipped question*** | **3** |
| | | | |
| 6 | **Do you use gas or electricity as the primary source of energy to heat your house?** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | Gas | 64.3% | 63 |
| | Oil | 22.4% | 22 |
| | Electricity | 13.3% | 13 |
| | Don't know | 0.0% | 0 |
| | Other (please specify) | | 10 |
| | | ***answered question*** | **98** |
| | | ***skipped question*** | **8** |
| | | | |

| No | Questions | | |
|---|---|---|---|
| 7 | **Do you use gas, oil, electricity, solar as the primary source of energy to heat your hot water?** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | Gas | 50.9% | 54 |
| | Oil | 17.0% | 18 |
| | Electricity | 25.5% | 27 |
| | Solar | 0.9% | 1 |
| | Don't know | 0.0% | 0 |
| | Other (please specify) | 5.7% | 6 |
| | | ***answered question*** | **106** |
| | | ***skipped question*** | **0** |
| | | | |
| 8 | **What time of day you use most electricity in your home?** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | 06:00-09:00 Morning | 1.9% | 2 |
| | 12:00-15:00 Lunchtime | 0.9% | 1 |
| | 17:00 – 20:00 Evening | 84.0% | 89 |
| | 20:00 – 23:00 Night | 13.2% | 14 |
| | | ***answered question*** | **106** |
| | | ***skipped question*** | **0** |
| | | | |
| 9 | **What time of day is the maximum demand for power on the electricity network?** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | 06:00-09:00 Morning | 10.4% | 11 |
| | 12:00-15:00 Lunchtime | 4.7% | 5 |
| | 17:00 – 20:00 Evening | 83.0% | 88 |
| | 20:00 – 23:00 Night | 1.9% | 2 |
| | | ***answered question*** | **106** |
| | | ***skipped question*** | **0** |
| | | | |
| 10 | **Do you know what appliances in your home use the most electricity?** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | Yes | 67.6% | 71 |
| | No | 32.4% | 34 |
| | | ***answered question*** | **105** |
| | | ***skipped question*** | **1** |
| | | | |

| No | Questions | | |
|---|---|---|---|
| 11 | **Do you have night rate electricity?** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | Yes | 21.0% | 22 |
| | No | 63.8% | 67 |
| | Don't know | 15.2% | 16 |
| | | ***answered question*** | **105** |
| | | ***skipped question*** | **1** |
| | | | |
| 12 | **If you have Night Rate electricity do you use timers to turn on and off appliances other than electrical storage heaters?** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | Yes | 10.5% | 10 |
| | No | 22.1% | 21 |
| | Don't know | 4.2% | 4 |
| | Don't have Night Rate electricity | 63.2% | 60 |
| | | ***answered question*** | **95** |
| | | ***skipped question*** | **11** |
| | | | |
| 13 | **If the price of Electricity changed regularly how often would you like to be informed of the price changes?** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | Hourly | 0.9% | 1 |
| | Daily | 2.8% | 3 |
| | Weekly | 3.8% | 4 |
| | Monthly | 12.3% | 13 |
| | With mybBill | 22.6% | 24 |
| | As often as it changed | 54.7% | 58 |
| | Other (please specify) | 2.8% | 3 |
| | | ***answered question*** | **106** |
| | | ***skipped question*** | **0** |
| | | | |

| No | Questions | | |
|---|---|---|---|
| 14 | **How would you like to be informed of the price of electricity?** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | Looking at a display on your meter | 6.6% | 7 |
| | Receiving a text on your mobile | 8.5% | 9 |
| | Provided on a website | 5.7% | 6 |
| | Receiving an email | 40.6% | 43 |
| | On your bill | 34.9% | 37 |
| | Other (please specify) | 3.8% | 4 |
| | | ***answered question*** | **106** |
| | | ***skipped question*** | **0** |
| | | | |
| 15 | **How often would you like to know how much electricity you are using on a daily basis?** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | Instantaneously | 12.3% | 13 |
| | Daily | 8.5% | 9 |
| | Weekly | 21.7% | 23 |
| | Monthly | 17.0% | 18 |
| | With my Bill | 40.6% | 43 |
| | | ***answered question*** | **106** |
| | | ***skipped question*** | **0** |
| | | | |
| 16 | **Do you turn off lights when you are not in a room for 15 minutes?** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | Always | 31.1% | 33 |
| | Sometimes | 33.0% | 35 |
| | Most times | 33.0% | 35 |
| | Never | 2.8% | 3 |
| | | ***answered question*** | **106** |
| | | ***skipped question*** | **0** |
| | | | |

| No | Questions | | |
|---|---|---|---|
| 17 | **Would you try to regularly use electricity (washing/drying/ heating water) at different times if it was dearer at peak times and cheaper at off peak times?** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | Yes | 86.8% | 92 |
| | No | 7.5% | 8 |
| | Don't know | 5.7% | 6 |
| | | ***answered question*** | **106** |
| | | ***skipped question*** | **0** |
| | | | |
| 18 | **Would you try to regularly use electricity(washing/drying/heating water) at different times if it was better for the environment but still cost the same?** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | Yes | 72.6% | 77 |
| | No | 11.3% | 12 |
| | Don't know | 16.0% | 17 |
| | | ***answered question*** | **106** |
| | | ***skipped question*** | **0** |
| | | | |
| 19 | **Would you be happy for your electricity supplier to control certain appliances in your home if it had minimal effect on your lifestyle?** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | Yes | 39.6% | 42 |
| | No | 44.3% | 47 |
| | Don't know | 16.0% | 17 |
| | | ***answered question*** | **106** |
| | | ***skipped question*** | **0** |
| | | | |
| 20 | **Would you be happy for your electricity supplier to control appliances in your home if it had minimal effect your lifestyle but offered you cheaper electricity?** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | Yes | 51.9% | 55 |
| | No | 31.1% | 33 |
| | Don't know | 17.0% | 18 |
| | | ***answered question*** | **106** |
| | | ***skipped question*** | **0** |
| | | | |

| No | Questions | | |
|---|---|---|---|
| 21 | **What do you think the price of a unit (kWh) of electricity is?** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | 5c | 11.3% | 12 |
| | 10c | 13.2% | 14 |
| | 15c | 45.3% | 48 |
| | 25c | 22.6% | 24 |
| | 50c | 5.7% | 6 |
| | 100c | 1.9% | 2 |
| | | ***answered question*** | **106** |
| | | ***skipped question*** | **0** |
| | | | |
| 22 | **How much would you be prepared to spend in your home to save €200 on your yearly electricity bills?** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | Nothing | 10.4% | 11 |
| | Up to €200 | 28.3% | 30 |
| | Up to €500 | 35.8% | 38 |
| | Up to €1000 | 17.9% | 19 |
| | Over €1,000 | 7.5% | 8 |
| | | ***answered question*** | **106** |
| | | ***skipped question*** | **0** |
| | | | |
| 23 | **Would you be interested to know how your bill compared with the national average?** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | Very interested | 36.8% | 39 |
| | Interested | 45.3% | 48 |
| | Not really interested | 16.0% | 17 |
| | Not at all interested | 1.9% | 2 |
| | | ***answered question*** | **106** |
| | | ***skipped question*** | **0** |
| | | | |

| No | Questions | | |
|---|---|---|---|
| 24 | **Would you be interested to know how your bill compared with a similar house sizes and similar family sizes?** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | Very interested | 52.8% | 56 |
| | Interested | 39.6% | 42 |
| | Not really interested | 7.5% | 8 |
| | Not at all interested | 0.0% | 0 |
| | ***answered question*** | | **106** |
| | ***skipped question*** | | **0** |
| | | | |
| 25 | **Is your current electricity bill easy to understand?** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | Yes | 70.8% | 75 |
| | No | 29.2% | 31 |
| | ***answered question*** | | **106** |
| | ***skipped question*** | | **0** |
| | | | |
| 26 | **Do you study your electricity bill to understand what your monthly usage and cost is?** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | Yes | 24.5% | 26 |
| | No | 27.4% | 29 |
| | Occasionally | 44.3% | 47 |
| | Rarely | 3.8% | 4 |
| | ***answered question*** | | **106** |
| | ***skipped question*** | | **0** |
| | | | |
| 27 | **If you switched or are thinking of switching from the ESB as your electricity provider - why would/did you do it?** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | Didn’t change | 7.5% | 8 |
| | Won’t change | 5.7% | 6 |
| | Cheaper Electricity | 72.6% | 77 |
| | Better service | 0.0% | 0 |
| | ‘Greener’ Electricity | 9.4% | 10 |
| | Other (please specify) | 4.7% | 5 |
| | ***answered question*** | | **106** |
| | ***skipped question*** | | **0** |
| | | | |

| No | Questions | | |
|---|---|---|---|
| 28 | **Have you heard of electricity Smart Meters** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | Yes | 48.1% | 50 |
| | No | 51.9% | 54 |
| | | ***answered question*** | **104** |
| | | ***skipped question*** | **2** |
| | | | |
| 29 | **Do you know what an electricity smart meter does/is?** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | Is called smart because it does smart things with electricity | 17.9% | 19 |
| | Is call smart because it is electronic | 1.9% | 2 |
| | It was created for the smart economy | 2.8% | 3 |
| | Allows for remote reading of your meter. | 31.1% | 33 |
| | It can bill you for your electricity based on time of use. | 36.8% | 39 |
| | Is required to change electricity supplier | 0.0% | 0 |
| | Other (please specify) | 21.7% | 23 |
| | | ***answered question*** | **106** |
| | | ***skipped question*** | **0** |
| | | | |
| 30 | **What would be the biggest driver for you reducing your electricity usage?** | | |
| | **Answer Options** | **Response Percent** | **Response Count** |
| | Cost | 81.1% | 86 |
| | Environmental issues | 12.3% | 13 |
| | Other (please specify) | 6.6% | 7 |
| | | ***answered question*** | **106** |
| | | ***skipped question*** | **0** |

## Question 31 Answers

These are unedited answers and no attempts has been made to edit or censor them.. The views expressed here are not that of the author not do they intend to represent any party.

| Number | Response Date | Response Text |
|---|---|---|

| | | |
|---|---|---|
| 1 | Feb 3, 2010 10:29 PM | Time of use of electricity (in 4 hour blocks) |
| 2 | Feb 3, 2010 10:41 PM | year on year comparison |
| 3 | Feb 3, 2010 10:42 PM | None |
| 4 | Feb 3, 2010 11:11 PM | how i could reduce the usage or cost |
| 5 | Feb 3, 2010 11:14 PM | Comparison of night/day rate with flat rate |
| 6 | Feb 3, 2010 11:17 PM | reduced price |
| 7 | Feb 3, 2010 11:23 PM | . |
| 8 | Feb 3, 2010 11:42 PM | Average consumption over time period |
| 9 | Feb 4, 2010 12:24 AM | make allowance for electricity sold to the national grid by domestic consumers. |
| 10 | Feb 4, 2010 1:00 AM | units per week, so you can guage usage per week and set targets for your household. |
| 11 | Feb 4, 2010 6:38 AM | trend info. notable variations from mean |
| 12 | Feb 4, 2010 7:37 AM | How it is generated |
| 13 | Feb 4, 2010 7:54 AM | indicate which appliances use most energy |
| 14 | Feb 4, 2010 8:09 AM | / |
| 15 | Feb 4, 2010 8:22 AM | CarbonfFootprint |
| 16 | Feb 4, 2010 8:29 AM | carbon equivalent |
| 17 | Feb 4, 2010 8:36 AM | Any or all of those |
| 18 | Feb 4, 2010 8:42 AM | carbon footprint. |
| 19 | Feb 4, 2010 8:47 AM | Dont know |
| 20 | Feb 4, 2010 8:53 AM | Next meter reading date specified |
| 21 | Feb 4, 2010 8:55 AM | carbon footprint |
| 22 | Feb 4, 2010 9:02 AM | Diagram showing usage over 24 hours |
| 23 | Feb 4, 2010 9:19 AM | fuel used to generate the electricity and time of usage |
| 24 | Feb 4, 2010 9:22 AM | none |
| 25 | Feb 4, 2010 9:25 AM | Nothing |
| 26 | Feb 4, 2010 9:30 AM | cost compared to home of simialr size and usage |
| 27 | Feb 4, 2010 9:31 AM | Tips to reduce usage and reduce cost. |
| 28 | Feb 4, 2010 9:34 AM | NA |
| 29 | Feb 4, 2010 9:41 AM | a graphic way of understanding what I use versus what i should use |
| 30 | Feb 4, 2010 9:43 AM | I'd like net cost/month to jump out at me. |
| 31 | Feb 4, 2010 9:46 AM | Answer to Question 2 should be no' children' |
| 32 | Feb 4, 2010 9:47 AM | . |
| 33 | Feb 4, 2010 9:49 AM | better awareness of consumption |
| 34 | Feb 4, 2010 9:50 AM | Lotto numbers |
| 35 | Feb 4, 2010 9:50 AM | Seasonal adjustment comparator to last year |
| 36 | Feb 4, 2010 9:54 AM | none |
| 37 | Feb 4, 2010 9:56 AM | Recommendations for usage reduction in my home - as per BER reports. |
| 38 | Feb 4, 2010 9:56 AM | how to reduce the cost on a monthly basis |
| 39 | Feb 4, 2010 9:56 AM | n/a |
| 40 | Feb 4, 2010 10:14 AM | Peak time of day for our electricity cost/usage, if any pattern. Clear statement of unit cost of electricity, with clear highlighting of how it changes at night, and at what time. I have a vague idea that it switches to a lower rate at 7pm but I am not sure about this. |

| | | |
|---|---|---|
| 41 | Feb 4, 2010 10:15 AM | no idea |
| 42 | Feb 4, 2010 10:28 AM | Would like info on average cost of getting a standard house to a B energy rating and the average savings generated |
| 43 | Feb 4, 2010 10:29 AM | None |
| 44 | Feb 4, 2010 10:30 AM | carbon footprint, breakdown of costs showing appliances that are most costly |
| 45 | Feb 4, 2010 10:31 AM | Q2 = zero but not in your option |
| 46 | Feb 4, 2010 10:33 AM | When 'The Greens' are gonig to be F****D OUT ! |
| 47 | Feb 4, 2010 10:40 AM | Usage by time of day |
| 48 | Feb 4, 2010 10:44 AM | Nothing |
| 49 | Feb 4, 2010 10:44 AM | None |
| 50 | Feb 4, 2010 10:54 AM | nothing |
| 51 | Feb 4, 2010 10:54 AM | which socket used most electricity and at what time |
| 52 | Feb 4, 2010 11:08 AM | Co2 |
| 53 | Feb 4, 2010 11:28 AM | alternatives |
| 54 | Feb 4, 2010 11:33 AM | How much higher or lower my bill is compared to previous bills, when I used the most electricity. |
| 55 | Feb 4, 2010 11:33 AM | N/A |
| 56 | Feb 4, 2010 11:34 AM | Peak usage against cost, and comparision to using it at off-peak times |
| 57 | Feb 4, 2010 11:39 AM | Carbon Footprint |
| 58 | Feb 4, 2010 11:39 AM | current cost |
| 59 | Feb 4, 2010 11:39 AM | Ways to reduce the bill |
| 60 | Feb 4, 2010 11:45 AM | carbon footprint. |
| 61 | Feb 4, 2010 11:46 AM | dont knoq |
| 62 | Feb 4, 2010 11:54 AM | carbon footprint would be interesting (haven't looked at our bill in months) |
| 63 | Feb 4, 2010 12:05 PM | Carbon footprint, On peak/off peak usage per day (graph) |
| 64 | Feb 4, 2010 12:39 PM | n/a |
| 65 | Feb 4, 2010 12:51 PM | why wer'e paying levies on an essential service |
| 66 | Feb 4, 2010 1:10 PM | I don't think there is much information on my carbon footprint on my bill. That would be interesting! I'd like to see or have access to a usage calculator that I could compare my use against different price plans (night time, etc.). |
| 67 | Feb 4, 2010 1:37 PM | How to reduce my usage |
| 68 | Feb 4, 2010 2:10 PM | I answered 1 for the children question 2 but we don't have any under 16 and there was no option for this. I haven't a clue what the cost pKW is Q.21. - so I chose a random - invalid response |
| 69 | Feb 4, 2010 2:42 PM | Which plugs/lights were using the most electricity |
| 70 | Feb 4, 2010 2:56 PM | cost by time of day and appliance |
| 71 | Feb 4, 2010 3:06 PM | price and co2 footprint comparison from competitive suppliers |
| 72 | Feb 4, 2010 3:10 PM | cost make-up |
| 73 | Feb 4, 2010 3:12 PM | x |
| 74 | Feb 4, 2010 3:18 PM | Simpllier understanding of the actual cost of ones supply and the unit costs at different times of the |

| | | |
|---|---|---|
| 75 | Feb 4, 2010 3:36 PM | day cheapest - dearest: cost savings if applying different usage patterns i,e using electricity at peak versus off peak |
| 76 | Feb 4, 2010 3:50 PM | over or under average for the size of my family and house |
| 77 | Feb 4, 2010 4:16 PM | Re Q2 - there are no children under 16 living in my house. |
| 78 | Feb 4, 2010 5:24 PM | Whether off-peak usage is better for the environment than peak usage |
| 79 | Feb 4, 2010 6:17 PM | Cost, Carbon Footprint |
| 80 | Feb 4, 2010 6:20 PM | I would like the ESB to state that the bill is for kilowatt hours used and not "units" even though "units" are KWHours |
| 81 | Feb 4, 2010 6:25 PM | carbon footprint |
| 82 | Feb 4, 2010 9:42 PM | CO2 usage |
| 83 | Feb 4, 2010 9:57 PM | which appliance has cost most in the month |
| 84 | Feb 4, 2010 10:10 PM | Comparisons as mentioned above (national avg, etc.) |
| 85 | Feb 4, 2010 10:28 PM | cost |
| 86 | Feb 4, 2010 11:39 PM | nothing |
| 87 | Feb 4, 2010 11:52 PM | Suggestions on how I could save money based on my useage on this bill |
| 88 | Feb 5, 2010 12:38 AM | Xxx |
| 89 | Feb 5, 2010 9:01 AM | carbon footprint |
| 90 | Feb 5, 2010 9:03 AM | savings |
| 91 | Feb 5, 2010 9:28 AM | nil |
| 92 | Feb 5, 2010 9:39 AM | n/a |
| 93 | Feb 5, 2010 9:46 AM | info on the carbon footprint from our usage |
| 94 | Feb 5, 2010 10:23 AM | Hard to say when I give it little thought -perhaps to highlight how one could be more efficient and how one compares to houses of similar size/family size |
| 95 | Feb 5, 2010 11:57 AM | All three things mentioned along with when we use the most electricity on a daily basis |
| 96 | Feb 5, 2010 2:52 PM | what appliances have used most electricity ie a breakdown |
| 97 | Feb 5, 2010 3:12 PM | n/a |
| 98 | Feb 5, 2010 3:16 PM | none |
| 99 | Feb 5, 2010 3:32 PM | What appliance/function is used most |
| 100 | Feb 5, 2010 4:00 PM | time of peak demand in my home(Avg). Hints for reducing |
| 101 | Feb 5, 2010 4:04 PM | Nothing |
| 102 | Feb 5, 2010 4:10 PM | carbon footprint |
| 103 | Feb 5, 2010 4:39 PM | Short succinct points - hate getting booklets that I dont have time to read |
| 104 | Feb 5, 2010 5:58 PM | time pattern when most electricity was used |
| 105 | Feb 5, 2010 7:51 PM | time/place of highest usage |

# Appendix G - Supplier of the components of the architecture

Below is a list of the supplier of the smart grid architecture.

**Exhibit 10 – Selected Smart Grid Vendors**

| Advanced Metering | Demand Response | Backend Systems (Data Mgmt) | Network Systems |
|---|---|---|---|
| Itron (public) | Advanced Telemetry | eMeter | Arkion Systems |
| Landis+Gyr | Ameresco | Itron (public) | Current Group |
| ESCO (public) | EnerNOC (public) | Oracle (public) | Datamatic |
| Elster | Comverge (public) | SAP (public) | DCSI |
| Sensus | CPower | OSIsoft | Echelon |
| Neptune | GridPoint | GridPoint | Eka Systems |
| GE Energy (publ.) | Honeywell | Ecologic Analytics | Google PowerMeter |
| Badger | Nighthawk Systems | | Silver Spring Netw. |
| MasterMeter | PowerSecure Int. | | SmartSynch |
| | Trilliant Networks | | Trilliant Networks |
| | | | Tantalus Systems |
| | | | Tendril Networks |

| Wide Area Measurement Systems | Grid Automation Software | Resource Integration | Energy Storage |
|---|---|---|---|
| Doubletree Systems | GE (public) | GridPoint | A123 Systems |
| Macrodyne Inc. | GridPoint | IBM (public) | Altair Nanotech. |
| PowerWorld | | Ice Energy | NGK Insulators |
| | | | Ice Energy |

Source http://www.smartgridnews.com/artman/publish/Technologies_Metering/

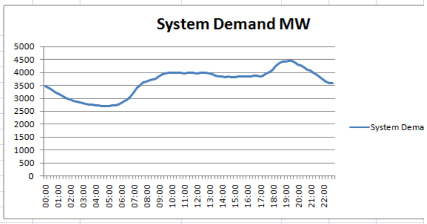
# Appendix H - Cost of Metering

Below are some indicative costings based on the information that was available through public sources.

| | | | | |
|---|---|---|---|---|
| **Cost of Meter Reading** | | | | Source |
| Number of Meters | = | 1,400,000 | Homes | CSO Fact |
| Time per meter | = | 3 | minutes | ESBNetworks - Meter reading group |
| Reads per year | | 4 | | ESB Networks |
| Meter Reading hours per year | = | 280,000 | Hours | |
| Cost per hour | | € 40 | | IBEC |
| Cost per year / Man on the street | | € 11,200,000 | | |
| Back office cost of processing per meter read | | € 1 | | |
| Cost of reads | | € 5,600,000 | | |
| **Cost of Fraud** | | | | |
| Number of Meters | = | 1,400,000 | | |
| Average Buill size | = | 980 | SEI - Energy In Ireland | |
| Total Bill | = | €1,372,000,000 | | |
| Bad Debt as % of total | = | 0.70% | ESRI US Utility statistic | |
| Total cost of Bad debt | | €9,604,000 | | |
| Total Annual costs recouped from Smart meter Project | | €15,204,000 | | |
| Project viewed as 20 Year Project | | €14,343,414.03 | | |
| Meter reads per year | | | | |
| https://www.esb.ie/esbcustomersupply/residential/your_account/our_reading_policy.jsp | | | | |

# Appendix I – Load capacity calculations

| 26-Feb-10 | Time | System Demand MW | 5% | 100% | 50% | 20% |
|---|---|---|---|---|---|---|
| | 00:00 | 3473 | 173.65 | 0.124 | 0.248 | 0.620 |
| | 00:15 | 3406 | 170.3 | 0.122 | 0.243 | 0.608 |
| | 00:30 | 3323 | 166.15 | 0.119 | 0.237 | 0.593 |
| | 00:45 | 3226 | 161.3 | 0.115 | 0.230 | 0.576 |
| | 01:00 | 3172 | 158.6 | 0.113 | 0.227 | 0.566 |
| | 01:15 | 3104 | 155.2 | 0.111 | 0.222 | 0.554 |
| | 01:30 | 3022 | 151.1 | 0.108 | 0.216 | 0.540 |
| | 01:45 | 2974 | 148.7 | 0.106 | 0.212 | 0.531 |
| | 02:00 | 2928 | 146.4 | 0.105 | 0.209 | 0.523 |
| | 02:15 | 2877 | 143.85 | 0.103 | 0.206 | 0.514 |
| | 02:30 | 2843 | 142.15 | 0.102 | 0.203 | 0.508 |
| | 02:45 | 2818 | 140.9 | 0.101 | 0.201 | 0.503 |
| | 03:00 | 2790 | 139.5 | 0.100 | 0.199 | 0.498 |
| | 03:15 | 2771 | 138.55 | 0.099 | 0.198 | 0.495 |
| | 03:30 | 2742 | 137.1 | 0.098 | 0.196 | 0.490 |
| | 03:45 | 2744 | 137.2 | 0.098 | 0.196 | 0.490 |
| | 04:00 | 2716 | 135.8 | 0.097 | 0.194 | 0.485 |
| | 04:15 | 2713 | 135.65 | 0.097 | 0.194 | 0.484 |
| | 04:30 | 2683 | 134.15 | 0.096 | 0.192 | 0.479 |
| | 04:45 | 2680 | 134 | 0.096 | 0.191 | 0.479 |
| | 05:00 | 2683 | 134.15 | 0.096 | 0.192 | 0.479 |
| | 05:15 | 2707 | 135.35 | 0.097 | 0.193 | 0.483 |
| | 05:30 | 2718 | 135.9 | 0.097 | 0.194 | 0.485 |
| | 05:45 | 2737 | 136.85 | 0.098 | 0.196 | 0.489 |
| | 06:00 | 2790 | 139.5 | 0.100 | 0.199 | 0.498 |
| | 06:15 | 2870 | 143.5 | 0.103 | 0.205 | 0.513 |
| | 06:30 | 2942 | 147.1 | 0.105 | 0.210 | 0.525 |
| | 06:45 | 3046 | 152.3 | 0.109 | 0.218 | 0.544 |
| | 07:00 | 3191 | 159.55 | 0.114 | 0.228 | 0.570 |
| | 07:15 | 3396 | 169.8 | 0.121 | 0.243 | 0.606 |
| | 07:30 | 3492 | 174.6 | 0.125 | 0.249 | 0.624 |
| | 07:45 | 3613 | 180.65 | 0.129 | 0.258 | 0.645 |
| | 08:00 | 3647 | 182.35 | 0.130 | 0.261 | 0.651 |
| | 08:15 | 3700 | 185 | 0.132 | 0.264 | 0.661 |
| | 08:30 | 3721 | 186.05 | 0.133 | 0.266 | 0.664 |
| | 08:45 | 3754 | 187.7 | 0.134 | 0.268 | 0.670 |
| | 09:00 | 3831 | 191.55 | 0.137 | 0.274 | 0.684 |
| | 09:15 | 3924 | 196.2 | 0.140 | 0.280 | 0.701 |
| | 09:30 | 3965 | 198.25 | 0.142 | 0.283 | 0.708 |
| | 09:45 | 3969 | 198.45 | 0.142 | 0.284 | 0.709 |
| | 10:00 | 3979 | 198.95 | 0.142 | 0.284 | 0.711 |
| | 10:15 | 3983 | 199.15 | 0.142 | 0.285 | 0.711 |
| | 10:30 | 3991 | 199.55 | 0.143 | 0.285 | 0.713 |
| | 10:45 | 3982 | 199.1 | 0.142 | 0.284 | 0.711 |
| | 11:00 | 3944 | 197.2 | 0.141 | 0.282 | 0.704 |
| | 11:15 | 3983 | 199.15 | 0.142 | 0.285 | 0.711 |
| | 11:30 | 3984 | 199.2 | 0.142 | 0.285 | 0.711 |
| | 11:45 | 3978 | 198.9 | 0.142 | 0.284 | 0.710 |
| | 12:00 | 3966 | 198.3 | 0.142 | 0.283 | 0.708 |
| | 12:15 | 3984 | 199.2 | 0.142 | 0.285 | 0.711 |
| | 12:30 | 3986 | 199.3 | 0.142 | 0.285 | 0.712 |
| | 12:45 | 3978 | 198.9 | 0.142 | 0.284 | 0.710 |
| | 13:00 | 3965 | 198.25 | 0.142 | 0.283 | 0.708 |
| | 13:15 | 3919 | 195.95 | 0.140 | 0.280 | 0.700 |
| | 13:30 | 3874 | 193.7 | 0.138 | 0.277 | 0.692 |
| | 13:45 | 3828 | 191.4 | 0.137 | 0.273 | 0.684 |
| | 14:00 | 3827 | 191.35 | 0.137 | 0.273 | 0.683 |
| | 14:15 | 3822 | 191.1 | 0.137 | 0.273 | 0.683 |
| | 14:30 | 3825 | 191.25 | 0.137 | 0.273 | 0.683 |
| | 14:45 | 3800 | 190 | 0.136 | 0.271 | 0.679 |
| | 15:00 | 3818 | 190.9 | 0.136 | 0.273 | 0.682 |
| | 15:15 | 3827 | 191.35 | 0.137 | 0.273 | 0.683 |
| | 15:30 | 3831 | 191.55 | 0.137 | 0.274 | 0.684 |
| | 15:45 | 3838 | 191.9 | 0.137 | 0.274 | 0.685 |
| | 16:00 | 3825 | 191.25 | 0.137 | 0.273 | 0.683 |
| | 16:15 | 3840 | 192 | 0.137 | 0.274 | 0.686 |
| | 16:30 | 3865 | 193.25 | 0.138 | 0.276 | 0.690 |
| | 16:45 | 3867 | 193.35 | 0.138 | 0.276 | 0.691 |
| | 17:00 | 3837 | 191.85 | 0.137 | 0.274 | 0.685 |
| | 17:15 | 3869 | 193.45 | 0.138 | 0.276 | 0.691 |
| | 17:30 | 3952 | 197.6 | 0.141 | 0.282 | 0.706 |
| | 17:45 | 4004 | 200.2 | 0.143 | 0.286 | 0.715 |
| | 18:00 | 4112 | 205.6 | 0.147 | 0.294 | 0.734 |
| | 18:15 | 4248 | 212.4 | 0.152 | 0.303 | 0.759 |
| | 18:30 | 4372 | 218.6 | 0.156 | 0.312 | 0.781 |
| | 18:45 | 4412 | 220.6 | 0.158 | 0.315 | 0.788 |
| | 19:00 | 4411 | 220.55 | 0.158 | 0.315 | 0.788 |
| | 19:15 | 4438 | 221.9 | 0.159 | 0.317 | 0.793 |
| | 19:30 | 4446 | 222.3 | 0.159 | 0.318 | 0.794 |
| | 19:45 | 4391 | 219.55 | 0.157 | 0.314 | 0.784 |
| | 20:00 | 4297 | 214.85 | 0.153 | 0.307 | 0.767 |
| | 20:15 | 4263 | 213.15 | 0.152 | 0.305 | 0.761 |
| | 20:30 | 4191 | 209.55 | 0.150 | 0.299 | 0.748 |
| | 20:45 | 4113 | 205.65 | 0.147 | 0.294 | 0.734 |
| | 21:00 | 4066 | 203.3 | 0.145 | 0.290 | 0.726 |
| | 21:15 | 3984 | 199.2 | 0.142 | 0.285 | 0.711 |
| | 21:30 | 3890 | 194.5 | 0.139 | 0.278 | 0.695 |
| | 21:45 | 3809 | 190.45 | 0.136 | 0.272 | 0.680 |
| | 22:00 | 3735 | 186.75 | 0.133 | 0.267 | 0.667 |
| | 22:15 | 3635 | 181.75 | 0.130 | 0.260 | 0.649 |
| | 22:30 | 3589 | 179.45 | 0.128 | 0.256 | 0.641 |
| | 22:45 | 3577 | 178.85 | 0.128 | 0.256 | 0.639 |
| | 23:00 | 3565 | 178.25 | 0.127 | 0.255 | 0.637 |
| | 23:15 | 3553 | 177.65 | 0.127 | 0.254 | 0.634 |
| | 23:30 | 3541 | 177.05 | 0.126 | 0.253 | 0.632 |
| | 23:45 | 3529 | 176.45 | 0.126 | 0.252 | 0.630 |




| Time | System Demand MW | Network Reduction | % of customer - KW per home | | |
|---|---|---|---|---|---|
| | MWh | 5% | 100% | 50% | 20% |
| 17:15 | 3869 | 193.45 | 0.138 | 0.276 | 0.691 |
| 17:30 | 3952 | 197.6 | 0.141 | 0.282 | 0.706 |
| 17:45 | 4004 | 200.2 | 0.143 | 0.286 | 0.715 |
| 18:00 | 4112 | 205.6 | 0.147 | 0.294 | 0.734 |
| 18:15 | 4248 | 212.4 | 0.152 | 0.303 | 0.759 |
| 18:30 | 4372 | 218.6 | 0.156 | 0.312 | 0.781 |
| 18:45 | 4412 | 220.6 | 0.158 | 0.315 | 0.788 |
| 19:00 | 4411 | 220.55 | 0.158 | 0.315 | 0.788 |
| 19:15 | 4438 | 221.9 | 0.159 | 0.317 | 0.793 |
| 19:30 | 4446 | 222.3 | 0.159 | 0.318 | 0.794 |
| 19:45 | 4391 | 219.55 | 0.157 | 0.314 | 0.784 |
| 20:00 | 4297 | 214.85 | 0.153 | 0.307 | 0.767 |
| 20:15 | 4263 | 213.15 | 0.152 | 0.305 | 0.761 |
| 20:30 | 4191 | 209.55 | 0.150 | 0.299 | 0.748 |
| 20:45 | 4113 | 205.65 | 0.147 | 0.294 | 0.734 |
| 21:00 | 4066 | 203.3 | 0.145 | 0.290 | 0.726 |
| 21:15 | 3984 | 199.2 | 0.142 | 0.285 | 0.711 |