CRANFIELD UNIVERSITY

KATIE LI

AN INVESTIGATION INTO THE DEPICTION OF SMART GRID TECHNOLOGY

SCHOOL OF APPLIED SCIENCES
Master Of Science By Research

MSc Thesis
Academic Year: 2011 -2012

Supervisors: Jeffrey Alcock and Ashutosh Tiwari
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This thesis is submitted in partial fulfilment of the requirements for the degree of Master of Science by Research

ABSTRACT

Increasing climate change concerns and depletion of fossil fuels demand greater efficiency in electricity production and consumption. Smart Grid is a vision of an enhanced electricity grid that integrates the electric grid with communication and sensing technologies to improve energy delivery. A number of initiatives have been embarked upon to reach this vision.

Databases of Smart Grid projects are being kept to hallmark the state of development and advise future project design. However, to date, there is no method of comparing projects' results. This means that it is difficult to identify the most successful projects. In addition, details of projects tend to be descriptive and there is no standard method of representing Smart Grid systems. The first Smart Grid technologies are about to be deployed in homes, and yet, there are little research examining how domestic consumers would react to a full set of Smart Grid technology. This is important because the opinions and participation of domestic consumers could lead to the success or failure of the Smart Grid system.

This research aims to device a representation system that enables the comparison of smart grid technology available for the residential consumers in the UK. The objectives are to: (i) review and identify existing representations of home Smart Grid technology; (ii) review and identify the general system representation methods; (iii) develop a representation method that maps and enables the comparison of Smart Grid technology in homes; (iv) validate the design of the representation method with relevant stakeholders. Through a four step methodology these objectives were achieved.

Thirty Smart Grid diagrams taken from journals and conference papers were analysed and categorised into five groups based of the type of communication features they contained. The results from this analysis guided the development of a Smart Grid representation method. Two Smart Grid systems that are available on the market were depicted using the representation method and were used to validate the design through interviewing 10 residential electricity

consumers. As an outcome, this research had delivered a validated representation method that could be used to depict electricity management systems. It could be adopted by energy companies to convey the functions and benefits of Smart Grid technologies to potential customers.

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LIST OF ABBREVIATIONS

AMI	Advanced Metering Infrastructure
BPL	Broadband over Power Lines
EMU	Energy Management Unit
GDP	Gross Domestic Product
GW	Gigawatt
HAN	Home Area Network
HEC	Home Energy Controller
HEM	Home Energy Management System
IHD	In Home Display
PHEV	Plug-in Hybrid Electric Vehicle
PFTTH	Power Fibre To The Home
PLC	Power Line Cable
SEDS	Smart Energy Distribution System
SMCS	Smart Monitoring and Control System
WSN	Wireless Sensor Networks

1.1 INTRODUCTION

Traditionally, the electricity grid was designed to supply energy in one direction (European Commission, 2006). Electricity was generated at the power station and transmitted via the transmission and distribution systems to reach the end-users. Electricity was generated and supplied when it was needed with no consumer participation.

Due to depletion of fossil fuels and concerns in climate change, electricity generation is slowly switching from large power stations to smaller renewable generators (Wolsink, 2012). The smaller generators could be installed in homes and commercial buildings, enabling consumers to also be producers. However, unlike traditional generators that could generate electricity on demand, renewable generators (such as solar panels and wind turbines) relies on the weather and this meant that their energy production could be unpredictable. Hence, a more advanced electricity system is needed to manage electricity demand and supply. The Smart Grid is a vision for such a system.

The Smart Grid vision is evolving and becoming more advanced as new technological solutions became available (World Economic Forum, 2010; Carvallo & Cooper, 2011). Even though the number of initiatives researching in Smart Grid are growing (Giordano et al., 2011), at present, the results of the pilots can only be viewed one and a time and there are no access to comparative data of a large number of pilots (Stromback et al., 2011). Databases that keep record of Smart Grid projects tend to be descriptive. This could make it more difficult to apprehend the functions of different components in a project. Without an effective tool to evaluate current state of development in Smart Grid technologies, future developments could be hindered.

1.2 Research Goals

1.2.1 **Scope**

This project is sponsored by University Centre Milton Keynes and IVHM Centre to investigate how energy companies could introduce Smart Grid technologies for people in their home.

Domestic consumers make up a large proportion of the total electricity consumption. In 2010, in UK, they accounted for 31% of total electricity consumption (DECC, 2011). Domestic consumers would play a crucial role in the development of Smart Grid because, as end-users, their participation could determine the success or failure of the system. For this reason, the scope of this research had addressed Smart Grid technologies (electricity generation, measurement and management devices) situated in the home environment.

1.2.2 **Aim**

The aim of this research is to device a representation system that enables the comparison of smart grid technology available for the residential consumers in the UK.

1.2.3 **Objectives**

This research has the following objectives:

1. To review and identify existing representations of home Smart Grid technology;
2. To review and identify the general system representation methods;
3. To develop a representation method that maps and enables the comparison of Smart Grid technology in homes;
4. To validate the design of the representation method with relevant stakeholders.

1.2.4 **Research Methodology**

This section presents the research methodology (detailed in Figure 1) of this project. The research methodology consists of four phases that are detailed in the following subsections.

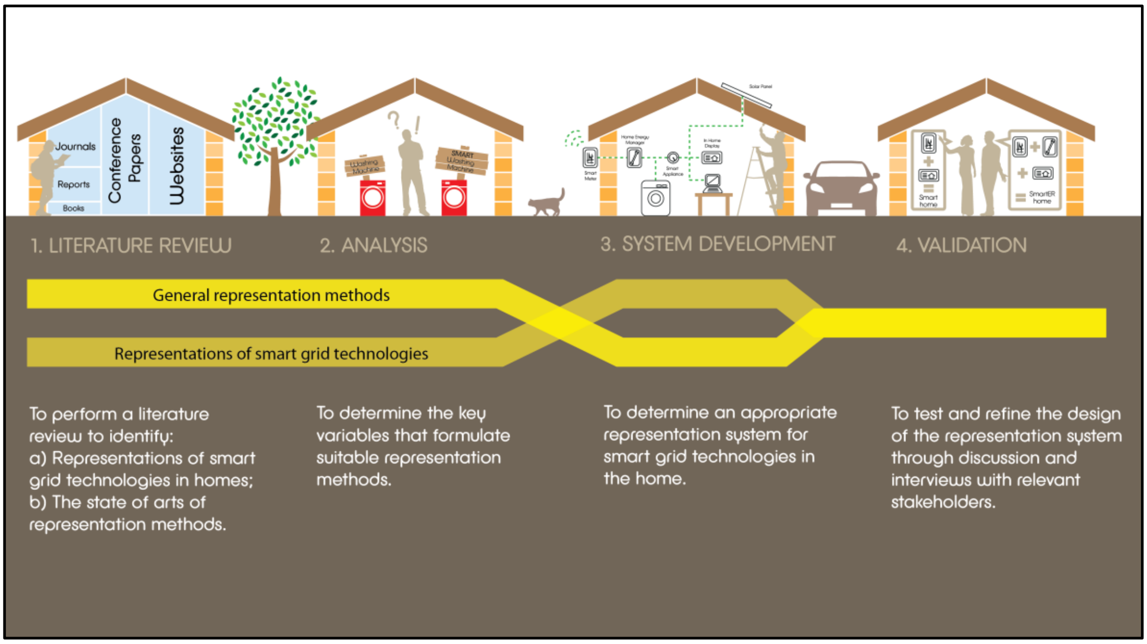


Figure 1 - Research Methodology

1.2.4.1 Phase 1: Literature Review

In the initial phase of this research, a literature review is conducted to identify: (a) representations of Smart Grid technology in homes; (b) the state of arts of representation methods

1.2.4.2 Phase 2: Analysis

In phase 2 there is an analysis of both the general representation methods and smart grid representation diagrams found in the literature. As an outcome, key variables that formulate suitable system representation are identified.

1.2.4.3 Phase 3: System Development

This phase takes the learning from phase 1 and 2 to develop an appropriate representation system for Smart Grid technology in the home.

1.2.4.4 Phase 4: Validation

The final design of the representation system is validated with the relevant stakeholders. To do so, the representation system is used to depict two Smart Grid systems available on the market. The depictions are tested with the 10 electricity consumers through semi-structured interviews. The results are analysed to validate the design and to identify any improvement that could be made.

1.2.5 **Thesis Structure**

This thesis comprises of five chapters. It begins by introducing the aim, objectives, and the scope of this research in Chapter 1. Chapter 2 consists of an initial literature review, where the definition of the Smart Grid and the purpose of this concept is identified. Chapter 3 and 4 are written in journal paper format. Hence both chapters have an individual literature review, methodology, results and discussion. Chapter 3 discusses the state of the arts of Smart Grid representation. Chapter 4 utilises findings from the Chapter 2 and 3 to design and validation a representation method for current electricity management systems. The last chapter provides the findings and the final conclusion of this research.

1.3 Summary

The research scope was outlined detailing the limitation and delimitation of this research. The aim and objectives of this research had been identified in this chapter and the research methodology developed for this project was explained. Finally the structure of the thesis was presented.

2 LITERATURE REVIEW

2.1 Introduction

The concept of Smart Grid have existed for the last two decades (Lo & Ansari, 2012) but there are still different opinions as to what this concept encapsulates (Slootweg et al., 2011). This chapter aims to identify the theories behind the idea of the Smart Grid, how it has been defined, and what it embodies for domestic consumers. This chapter contributes to phase 1 in the overall methodology of the thesis, as shown in Figure 2.

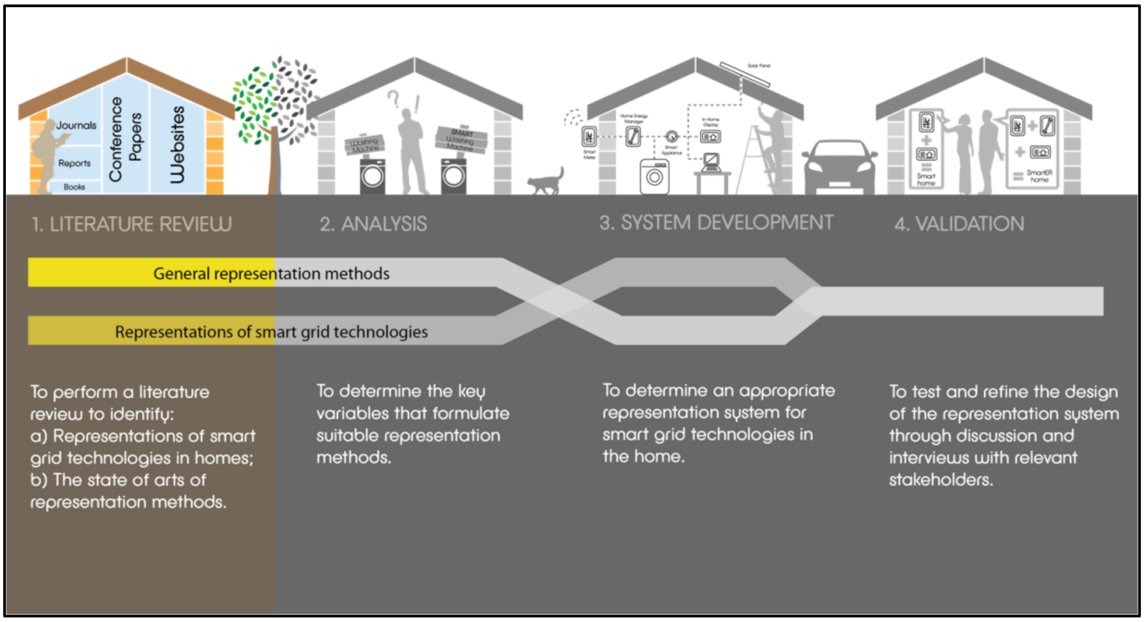


Figure 2 - A figure to show how this chapter contributes to the overall project

2.2 The Need for Smart Grid

This section discusses the reason behind why the Smart Grid is needed. Although a number of reasons can be identified in literature to explain the need of upgrading the electricity grid, they were often briefly explained with no facts or data to illustrate the problem. This section attempts to present and elaborate on the problems to illustrate the overall picture of why the Smart Grid is needed.

2.2.1 **Retiring Generation**

Around 70% of the electricity consumed in the UK is produced by burning fossil fuels in central power stations (DECC, 2012a). Under EU regulations, eight 29GW coal powered generators are due to retire by 2020 and therefore new methods of electricity generation will be needed to replace the amount of electricity produced by these generators (Center for Alternative Technology, 2010).

2.2.2 **Environmental Concerns**

Historically, a number of power plants in the UK had used fossil fuels, such as oil and coal, to generate electricity. However, the depletion of fossil fuels and rising concerns that burning fossil fuel contribute to climate change is resulting in electricity generation to be slowly switching from large power stations to smaller renewable generators (National Grid, 2012a; Wolsink, 2012). The adoption of multiple generating units closer to the consumer can be more energy efficient and reduce carbon emissions. These generators can be placed closer to consumers because they are smaller in scale and the most suitable renewable generation could be sought for depending on the geographical location (Wolsink, 2012).

2.2.3 **Ageing Infrastructure**

The UK's electricity grid is ageing, which is affecting the overall security and reliability of electricity transmission and distribution. There is a need to make the grid more robust and resilient through solutions such as to enable trans-European electricity market and to integrate renewable generations (European Commission, 2006).

2.2.4 **Transmission Losses**

Electricity is lost in transmission from where it is generated to where it isused. In the UK, around 2% of electricity is lost in transmission each year. This is roughly equivalent to a lost in £250 million each year (Ofgem, 2007).

2.2.5 **Rising Prices**

Between 2001 and 2011 the real price of electricity increased by 55% (DECC, 2012d). With rising prices, there is an increasing need to identify ways to reduce electricity consumption and generation.

2.2.6 **Rising Demand**

The increasing trend of consumer electronics is increasing the overall electricity demand (DECC, 2012b). Figure 3 shows a graph of the electricity consumption in UK between 1970 and 2011.

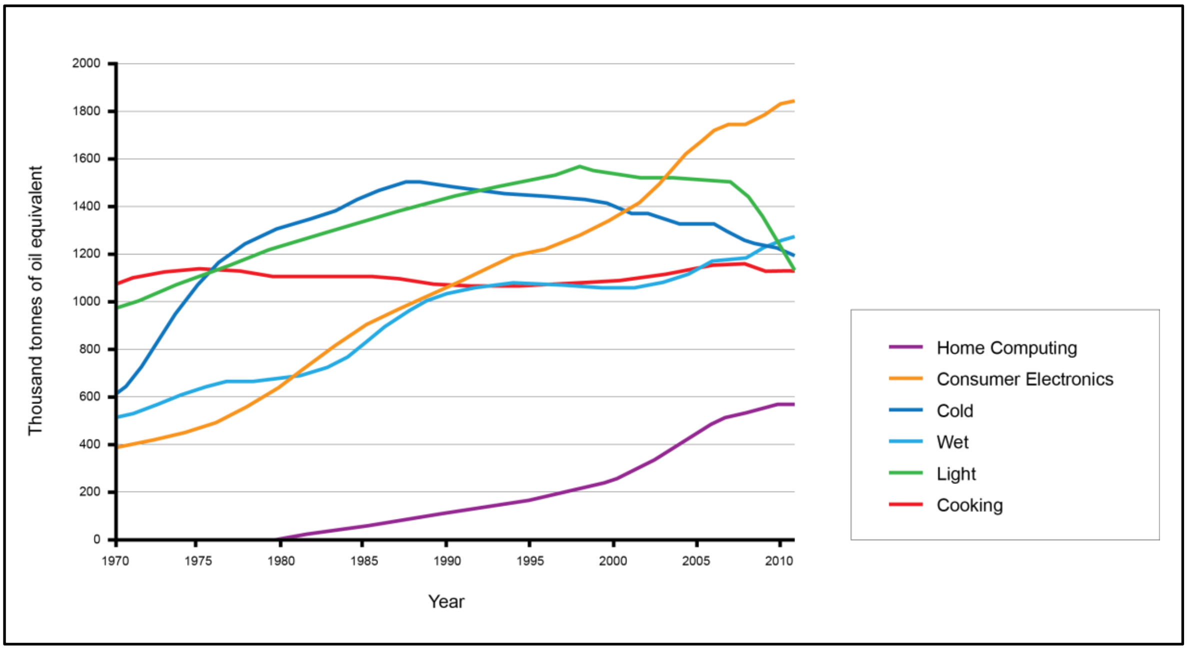


Figure 3 - A graph to show the electricity consumption by household domestic appliance types in UK between 1970 and 2011 (adapted from DECC, 2012b)

From this graph it could be seen that within the last 40 years, electricity consumption in consumer electronics had risen by more than 450% (from 400k to 1840k tonnes of oil equivalent). Home computing and wet appliance can also be seen to have made a significant increase. Electricity consumption has almost trebled from around 500k tonnes of oil equivalent to 1300k. Home computing had risen from 0k tonnes per oil equivalent in 1980 to around 600k in 2011. Although there are decreases of electricity consumption in light and cold appliance, the increase usage in the other areas far exceeds that amount. Hence, with rising electricity consumption there is a need to find new ways to meet the demand.

2.3 Definition of Smart Grid

This section details the evaluation of 12 Smart Grid definitions identified from the literature. Table 1 highlights some of the definitions evaluated and the full list of definitions can be found in Appendix A.

Table 1 - Smart Grid Definitions

Source	**Definition**
U.S. Department of Energy(n.d.)	The Smart Grid is a developing network of transmission lines, equipment, controls and new technologies working together to respond immediately to our 21st Century demand for electricity.
IEEE(2012)	The Smart Grid has come to describe a next-generation electrical power system that is typified by the increased use of communications and information technology in the

	generation, delivery and consumption of electrical energy.
Garrity(2008)	The Smart Grid entails a transformation to an information-enabled and highly interconnected network between electricity consumers and electric suppliers embracing transmission, distribution, and generation.

Based on the evaluation, five key areas were found to be discussed in the Smart Grid definitions. These includes: the overview of Smart Grid, new technologies, new services, new functions, and the benefits. The subsections below details each key area.

2.3.1 **Overview of Smart Grid**

Broad and varying definitions of the Smart Grid were found in the literature. The Smart Grid is said to be an 'improved', 'modernised', and the 'next generation' version of the present electricity grid. It is also described as a developing network (U.S. Department of Energy, n.d.), an infrastructure that would help to meet today's electricity demand and pave the way for the future (Hughes, 2009). This suggests that the traditional electricity system is somehow insufficient, and yet there is no standard version of what Smart Grid is because the technologies and functions that made up Smart Grid are being developed.

2.3.2 **New Technologies**

In transforming the electricity grid into a Smart Grid, hardware and software would be installed. These could include automation and communication devices as well as sensors and electricity storages.

2.3.3 **New Services**

The new technologies would pave the way for new services such as distributed generation and demand response for the electricity system. New technologies would enable the stakeholder to communicate their actions and behaviours with each other. As a result, consumers could gain feedback on their energy consumption as well as sending and receiving information to and from the electricity supplier.

2.3.4 **New Functions**

A number of new functions would be enabled by the new technologies, including the possibility to monitor, control and manage electricity supply and usage by both the consumer and the electricity provider.

2.3.5 **Benefits**

Subsequent from the new services, increasing consumption awareness and use of smaller, local energy generators would result in the provision of cost effective and environmentally friendlier energy supply. The new technologies would allow grid operators to be more aware of the status of the grid, hence improving their maintenance and providing a more secure electricity supply.

2.3.6 **Summary of the Smart Grid Definitions**

The previous section had found that existing definitions of Smart Grid are made up of descriptions of its overview, new technologies, new services, new functions and the benefits. The Smart Grid definition could be summarised as follows:

> Smart Grid is the concept for a developing electricity power infrastructure. It is envisioned to have an interconnected network that enables bi-directional electricity and communication flow. Software (such as applications) and hardware (such as sensors, computers and automation devices) will be integrated into the electricity grid to improve power transmission efficiency and to support a more secure, reliable, flexible, cost

effective and sustainable energy supply. As a result, consumers will have greater control on their consumption.

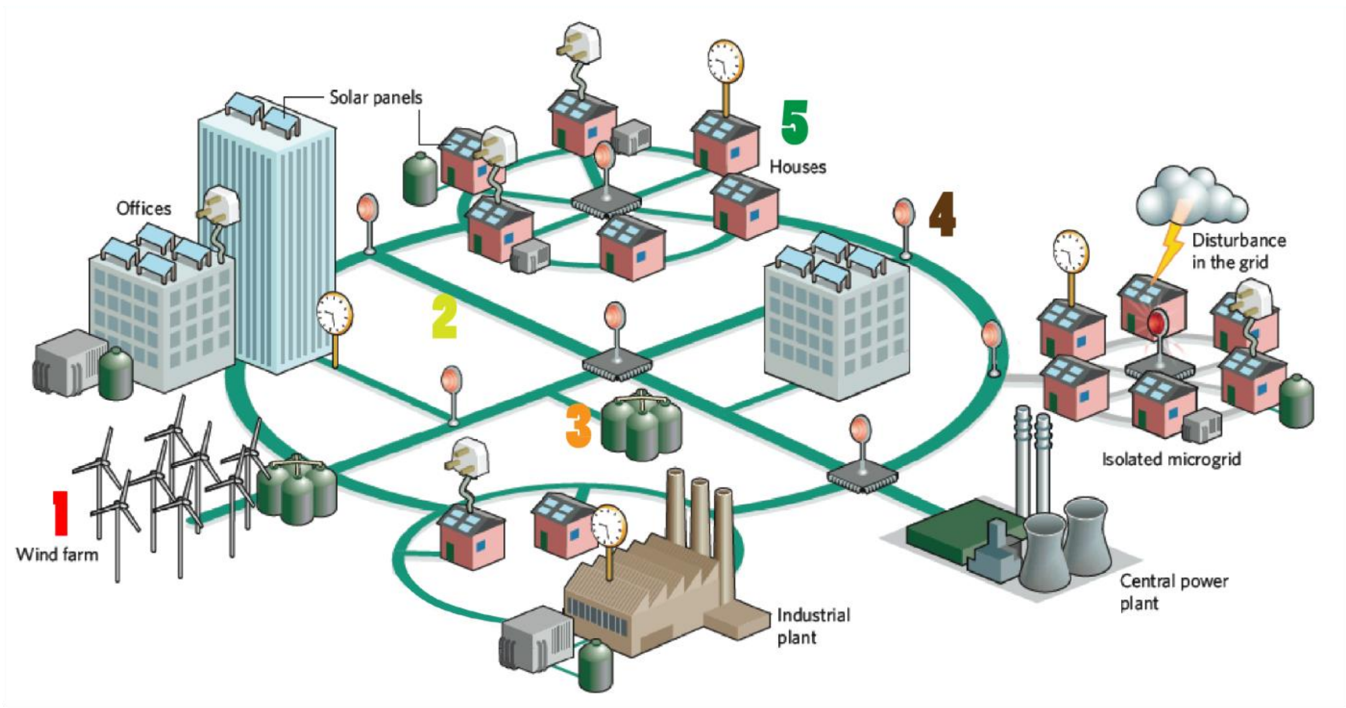
2.4 Smart Grid Technology

In transforming the electricity grid into a Smart Grid, hardware and software would be installed. These could include automation and communication devices as well as sensors and electricity storages.

A diagram showing new Smart Grid Technologies could be seen in Figure 4. One of the key features of Smart Grid is the function to perform two-way communication between the components (World Economic Forum, 2010). This would serve several purposes. It would enable consumers to send and receive data from utilities, allowing end-users to control and manage their electricity usage in real-time (Marris, 2008).

The installation of sensors in the grid facilitates instant detection of fluctuations and disruption. The sensors could communicate to the utilities to report faults and to isolate itself from the grid (World Economic Forum, 2010).

As electricity production is moving from tradition generators to smaller local generators and renewable generation, communication between these components are necessary to ensure electricity demand is being met. Unlike traditional generators that generated electricity on demand, electricity generation from renewable sources is unpredictable. Hence the Smart Grid would require storage devices to store surplus energy for later use. By moving generation capabilities closer to the consumers, transmission costs and losses could also be avoided (Verschueren et al., 2010; Lo & Ansari, 2012).



DECENTRALISED GENERATION 1

Energy from small generators and renewable generation (e.g. solar panels) can reduce the overall demand on tradition generators.

TWO-WAY COMMUNICATION 2

The components of the grid are connected to enable two-way communication.

STORAGE DEVICES 3

Unlike traditional generators that are controlled to generate electricity on demand, energy generation from renewable sources are unpredictable. Storage devices are used to store surplus energy for later use.

SENSORS 4

The sensors in the grid can detect fluctuations and disruptions. This enables utilities to identify where the faults are and for the grid to heal itself.

SMART HOMES 5

The smart home can send and receive data from utilities. The data received allow end-users to control and manage home appliances in real-time.

Figure 4 - The smart grid concept (adapted from Marris, 2008)

2.5 Stages of Smart Grid Technology Deployment

Smart Grid is a term used to describe vision of a future electricity grid system that does not exist yet. As it describes a concept, it could be redefined and reiterated as new technological advancement becomes available to meet this vision. Rather than describing the Smart Grid as one final vision, it had been portrayed with three generations (Carvallo & Cooper, 2011; Flood & Lucero, 2011; Callahan, 2011), correlating with the past, present and future of the Smart Grid development. Each generation of Smart Grid development builds upon the last to reach the final third stage. The three generations could be explained as:

1. *Smart Grid 1.0*

   Wesoff (2011) described Smart Grid 1.0 as the beginning of bi-directional communication. In this generation, Smart Grid development focuses on the smart meter development and had limited applications (Callahan, 2011).
2. *Smart Grid 2.0*

   Smart Grid 2.0 would build on the basic communication infrastructure to support greater variety of applications. In this generation, the basic infrastructure already exists (Carvallo & Cooper, 2011). This generation targeted the operation aspect of the Smart Grid, developing its management automations.
3. *Smart Grid 3.0*

   Smart Grid 3.0 focused on the consumer. Once Smart Grid 2.0 had been accepted, the third generation looks to use the Smart Grid to empower consumers (Callahan, 2011). It would realise benefits, such as peer-to-peer trading and distributed generation (Carvallo & Cooper, 2011).

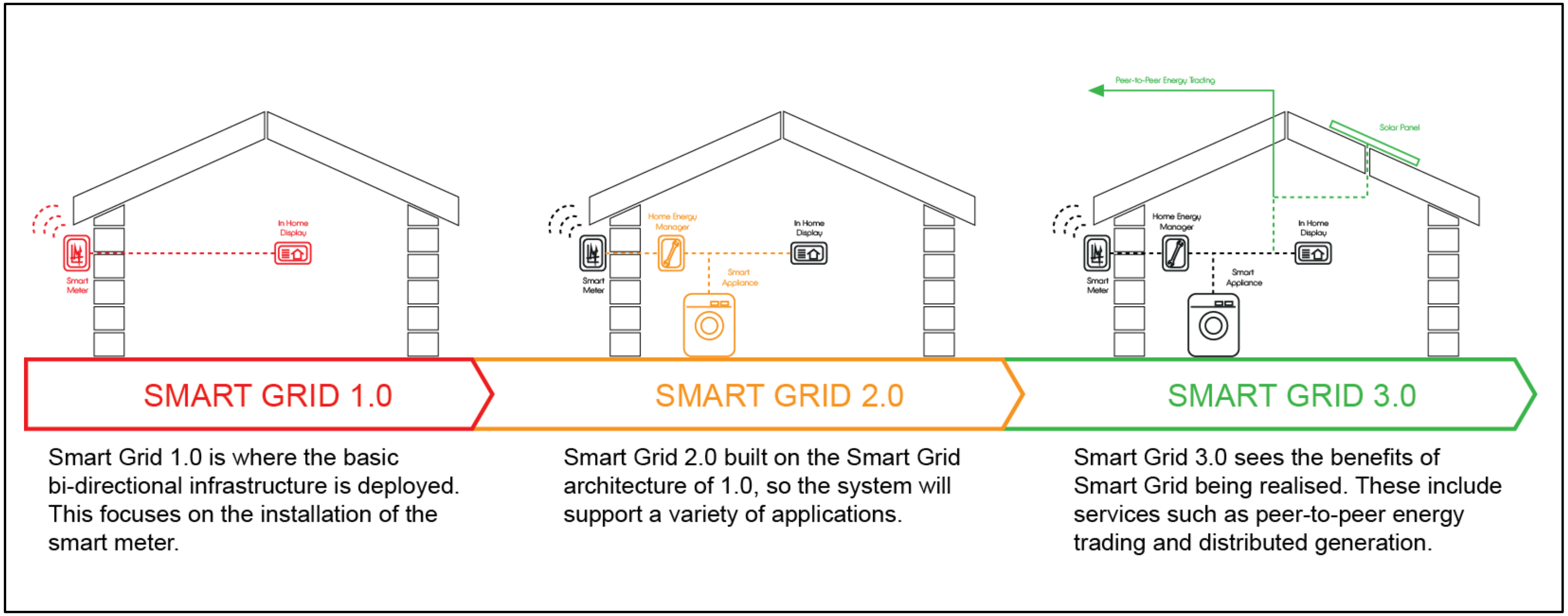


Figure 5 - Stages of smart grid deployment (adapted from Carvallo& Cooper, 2011)

Figure 5 shows how the three stages of Smart Grid development would apply to domestic consumers. In Smart Grid 1.0, the Smart Meter and In-Home Display was installed, this connected the home with the service provider (energy companies). Once the Smart Meter is in place, consumers could install additional devices which to management their electricity consumption in Smart Grid 2.0. Lastly, in Smart Grid 3.0, consumer could install renewable generations and trade electricity with neighbouring houses.

2.6 Summary

There are a number of problems with the currently electricity grid. The UK's electricity infrastructure is ageing, which means that the security of electricity transmission and distribution is threatened. A vast amount of electricity is lost in transmission each year; this was around £250 million in monetary value. News ways of electricity generation is needed because older and less efficient power stations are set to retire. Rising electricity demand means that more electricity must be generated to meet consumer's needs. Historically, fossil fuels were the main sources used for electricity generation. This could no longer be the case as these sources have been exhausted. With rising electricity prices, consumer would need to reduce their consumption to save on costs.

There are many different opinions of what Smart Grid is. From 12 Smart Grid definitions, it was found that Smart Grid definitions generally encompassed five key areas, this included: the overview of Smart Grid, new technologies, new services, new functions, and the benefits.

As Smart Grid describes a vision of the future electricity grid, its definition could change with new technological advancement. The deployment of Smart Grid technology had been described in three stages, where each stage paves the foundation for the next.

A number of new technologies are described in the Smart Grid concept. Five new technologies identified in this chapter include: decentralised generation, two-way communication, storage devices, sensors and the smart home.

3 SMART GRID REPRESENTATIONS

The previous chapter had identified that Smart Grid concept is not well defined because it is a vision of a future electricity system. There is no conclusive vision of the Smart Grid but only descriptive views of what it could be. The direction and progress of the Smart Grid development is determined by investments and technological advancements. This section investigates how Smart Grid is depicted.

3.1 Introduction

Upgrading the electricity grid would be a long and complex process. Over 150 successful smart meter pilots had been completed worldwide, and yet there had been little documentations of the lesson learnt. Utilities and regulators could only see the results of one pilot at a time, and did not have access to comparative data (Stromback et al., 2011).

The study of Giordano et al. (2011) found that it had been difficult to collect data and share knowledge between Smart Grid projects because there is a lack of a common structure in their definitions, terminology, categories and benchmarks.

3.1.1 **Standard Approaches to Designing Representation Systems**

There is little available in the literature on the design of representation systems. Hitchins (2007) suggested that systems could be represented in different ways depending on the user's own understanding and the purpose of representation and it is up to the creator to decide on what is "more useful" for each representation. Hence, in order to deduce what would be *more useful* to depict in a Smart Grid representation system it is important to define the attributes of a Smart Grid system.

3.1.2 **The Smart Grid System and the Communication System**

According to Lo & Ansari (2012), the taxonomy of the Smart Grid is composed of five layers or five different goals (Appendix B): power, communication, control, application, and security. The focus of this research is placed on the communication layer. Communication technologies had been described by World Economic Forum (2010) as foundational technologies that were required in successful Smart Grid pilots. This layer ensures that data are transmitted accurately and effectively between the components of the system. Even though Smart Grid is incorporating communication devices into the electricity grid, it is not the same as a conventional communication system. Table 2 shows in detail the features in a general model of communication system (taken from Frenzel, 2007) and the features of the Smart Grid systems used in this project.

Table 2 - A table to show the features of Smart Grid communication system used in this project and that of a general communication system (adapted from Frenzel, 2007)

General Communication System		**Smart Grid Communication System**	
Feature	Description	Features	Description
Transmitter	The device that send the message	Component	Devices that send and receive messages
Receiver	The device that receives the message		
		Data Flow	The direction in which information are being transferred
Communications Channel	The medium over which the message is sent	Data Channel	The medium over which the message is sent
Information	The information or data being communicated	Data Type	The information or data being communicated
Noise	Random, undesired disturbance that interferes with the transmitted		

	message	

Smart Grid provided two-way communication between its components. Hence, Smart Grid components could be both the transmitter and the receiver. As some component might transmit as well as receiver information, where as other components may just be transmitter or a receiver, the data flow feature is included to represent the direction in which data were sent. Data channel and data type were the same as that a of the general communication system. Although noise would also appear in a Smart Grid communication system, the author has chosen deliberately to omit whilst analysing Smart Grid diagrams. This is because noise is not an integral feature in communication systems, but an effect that could appear. Hence it is unlikely to be visualised in Smart Grid diagrams.

Figure 6 illustrates how some of the features in Smart Grid communication system differ from that of a general communication system. In a general communication system information is sent one way from a transmitter, through the channel and the information is recovered by the receiver. In contrast, information in a Smart Grid communication system can be sent and received both ways.

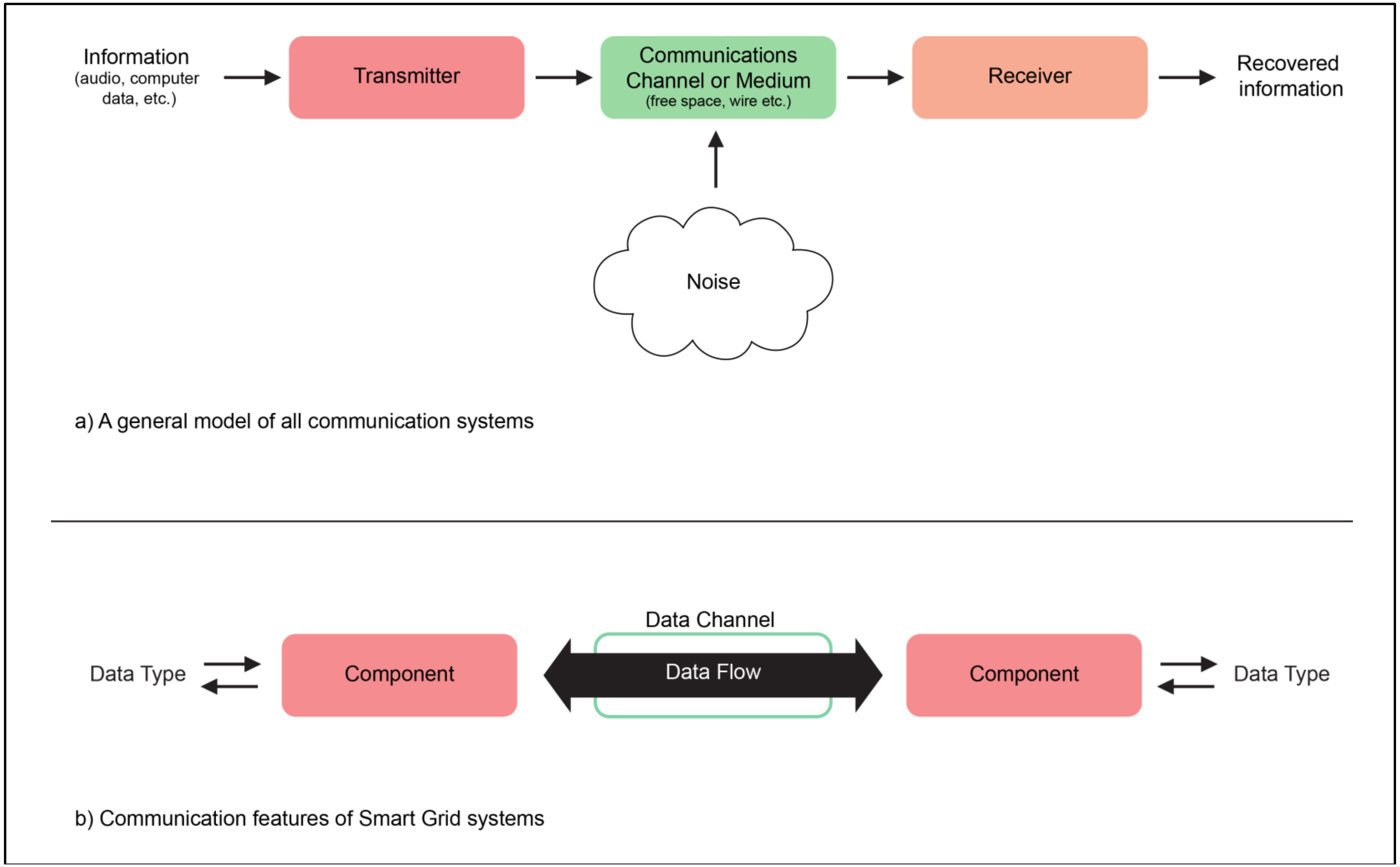


Figure 6 - A diagram to show how some features in a Smart Grid communication system differ from that of a general communication system

3.2 Research Objectives

The aim of this chapter is to determine how Smart Grid systems are being represented. It contributes to phase 1 and 2 in the overall methodology of this project (as shown in Figure 7).

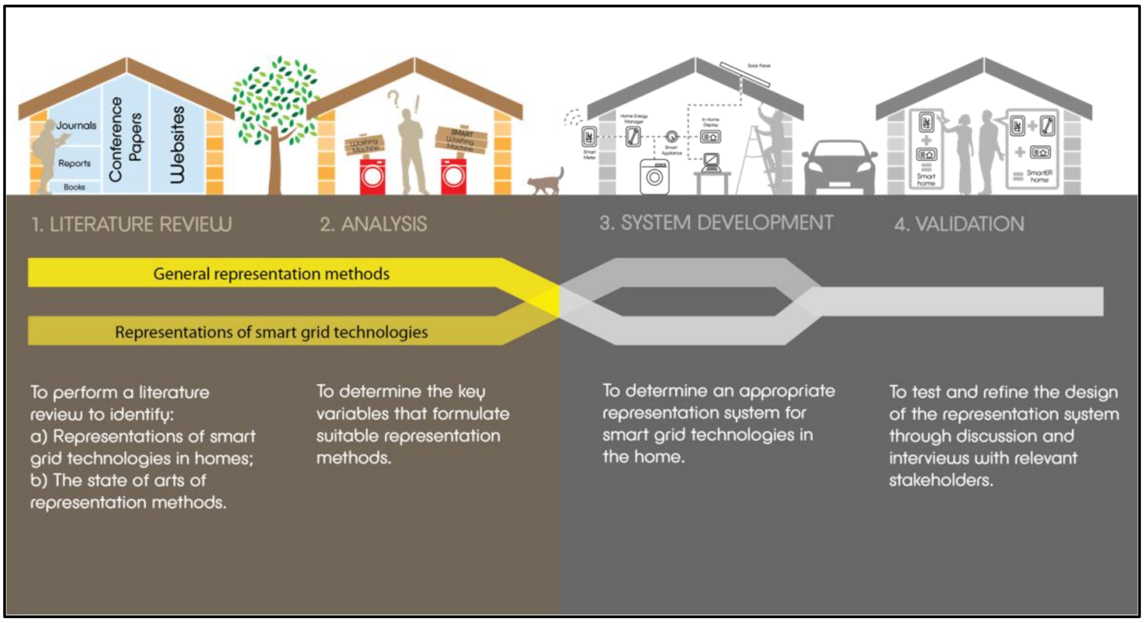


Figure 7 - A diagram to show the stages this chapter is to achieve in the overall research project

This chapter ventures to fulfil the following objectives:

- To identify the general system representation methods;
- To identify existing method of representations Smart Grid systems in the home;

In the introduction (Section 3.1.1), it had already been established that there is no general system representation method. How a system is represented depended on the purpose of representation and what the creator considered as more useful (Hitchins, 2007).

In determining the attributes that are the most useful in representing a Smart Grid system, it was determined that the Smart Grid is made up of five taxonomy layers (a detailed diagram explaining the taxonomy could be found in Appendix B). The focus of this chapter is on the communication layer because it is the most relevant layer to this research and because studying all five layers would be too large a scope for the duration of this research project. The first layer (power) already exists and, therefore, it is not necessary to re-explain what it is. At this stage of the Smart Grid development it is the communication layer that is being adapted in the electricity grid. The other three layers (control application and security) are the layers that will need to be established only after the communication layer is in place.

3.3 Methodology

In the previous section, no established method of representing Smart Grid was found nor was there a standard approach to create a representation system. This methodology is designed to investigate the common characteristics of Smart Grid diagrams. It consists of three key stages. Stage one involves a systematic review of the literature to obtain diagrams showing how the Smart Grid is represented. Based on the communication features in the diagrams, stage two categorises the diagrams into groups. Finally, the last stage evaluates the Smart Grid diagrams based on their system types.

3.3.1 **Literature Search**

The literature search was conducted by using the science, technology and medicine database *SciVerse Scopus*. The year of publication was limited to 2009-2012. This range was chosen to identify the most recent and advance systems. The document type was limited to conference papers, journal articles and books. Keywords used in the searched are shown in Table 3. A number of searches were performed to identify the most relevant literature.

Table 3 - Literature search

	Date	Keywords Search (article title, abstract, keywords)	Results			
			Conference Papers	Articles	Books	Total
S1	2009-2012	Smart, grid	2547	1092	2	3641
S2		Smart, grid Or meter*	2800	1272	2	4074
S3		Smart, grid Or meter*, consumer OR customer	500	232	1	733
S4		Smart, grid Or meter*, consumer OR customer, hous* OR home	133	59	0	172
S5		Smart, grid Or meter*, consumer OR customer, hous* OR home, electric*	87	45	0	132

The first search (S1) resulted with over 3000 literature results. The scope was too wide. It had also identified that another popular term used in Smart Grid technologies was smart meter. Smart meter was described as the link between the homes and the Smart Grid. Hence, from the second search, both terms (smart grid and smart meter) were searched for. In order to limit the scope to Smart Grid technologies used by consumers, the search term of consumer OR customer was introduced in the third search. This was made more specifically as home consumers in the fourth search because consumers in Smart Grid systems could include industrial and commercial consumers. Finally, to ensure that the results identified related to the electricity grid, the last search term electric* was included.

Out of the 132 documents resulted from the literature search, 35 documents could not be procured, and so a total of 97 documents were used. These documents were scanned for representation diagrams. A total of 119 figures were found from 62 documents.

To verify that each diagram fitted within the scope of this chapter, only diagrams containing at least one communication features (detailed in Table 4) were selected. In addition, any repeated diagrams and those of poor graphical quality were discarded. This reduced the total diagrams from 119 to 30.

3.3.2 **Communication Features**

Each of the 30 diagrams was evaluated to establish the background purpose of the illustration. The diagrams were then analysed using the communication features (shown in Table 4).

Table 4 - Communication features of a smart grid system

	Feature	**Definition**
1	Components	A component can be a place (e.g. home, utility, office) or a technological device (e.g. smart meter, home automation systems).
2	Data Flow	The data flow is a communication connection between two or more components.
3	Data Channel	Data channel is the method in which data are transmitted (through wireless or wire-line). The communication standard and protocol must be identified (e.g. ZigBee, PLC, BPL).
4	Data Type	Data type is the information that is being transmitted. This should provide the nature of the data transmitted (e.g. energy used, consumer control).

All diagrams with lines indicating the connection between networks were considered to be diagrams with the data flow feature. However, it should be noted that data may not flow in both directions.

Data channel was considered as either the abstraction layer (actual name and model of communication protocol) or the type of medium (such as if wireless of cables were used). A broad consideration was given because of the variation in the diagrams identified.

3.3.3 **System Types**

The Smart Grid system depicted in each diagram could have different purposes, presents different levels of the system and used varying styles to represent their information. In order to understand the characteristics of these systems, each diagram was analysed using five sets of system types (detailed in Table 5). The sets of system types were originally used by Wu (1994) to categorise manufacturing systems. Diagrams that did not fit in either system type were discarded for that set.

Table 5 - System types found in the manufacturing environment

	System Type	**Definition**
1	Physical	Contain real objects.
	Conceptual	Have no physical existence. This type of system is used to represent an idea or a concept.
2	Open	Interact with their environment (maintain a dynamic relationship with their environment and so can offset entropy.
	Closed	Self-contained under normal conditions (may become chaotic because no other solution can be sought).
3	Stochastic	Systems characterised by random properties.
	Deterministic	Systems that exhibit unique cause and effect relationships between the inputs, and between the initial conditions and the final state.
4	Static	Having structure without activity. The system process will not evolve over time.
	Dynamic	Systems that combines structural components with activity, so the states of these systems will usually change continuously over time.
5	Continuous	A type of dynamic system where the state variable changes continuously over time.
	Discrete	A type of dynamic system where the system variable change in stepwise fashion.

**In system theory, increased entropy means increased disorganisation (Wu, 1994).

Wu (1994) suggests that all systems have some common characteristics even if their content differs. Therefore, the purpose of classifying the Smart Grid systems by types was to establish the characteristics of the systems under investigation. This would subsequently aid the tasks of modelling, analysing and evaluating existing Smart Grid systems. The systems were classified as follows:

- *Set 1 - Conceptual and Physical*
  A system was considered as a Physical system if it consisted of components were tested in pilots or installed in the home environment. Conceptual systems were systems that depicted an idea or a concept.
- *Set 2 - Open and Closed Systems*
  This set identified if a system was Open or Closed in terms of the type of information being transferred. Therefore, a system without data flow was not considered in this set because it is unknown how the information was being transferred. Systems consisting of components from different level of the hierarchy were treated as Open systems.
- *Set 3 - Stochastic and Deterministic*
  Only systems which detailed the type of information feed in and out were classified in this set.
- *Set 4 - Static and Dynamic*
  Similar to Set 3, only systems which detailed the type of information feed in and out were classified in this set.
- *Set 5 - Continuous and Discrete*
  Continuous and Discrete are both dynamic systems, so only systems that have been classified as dynamic in Set 4 could be classified in this set.

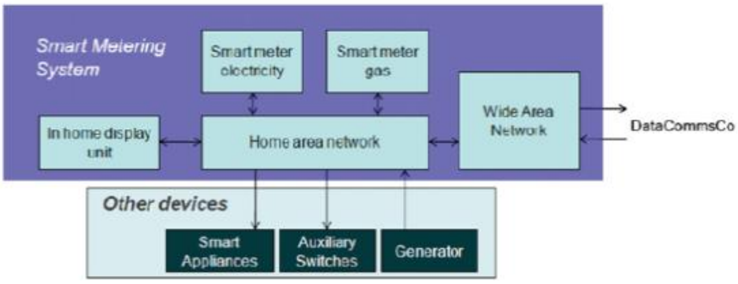
3.4 Results

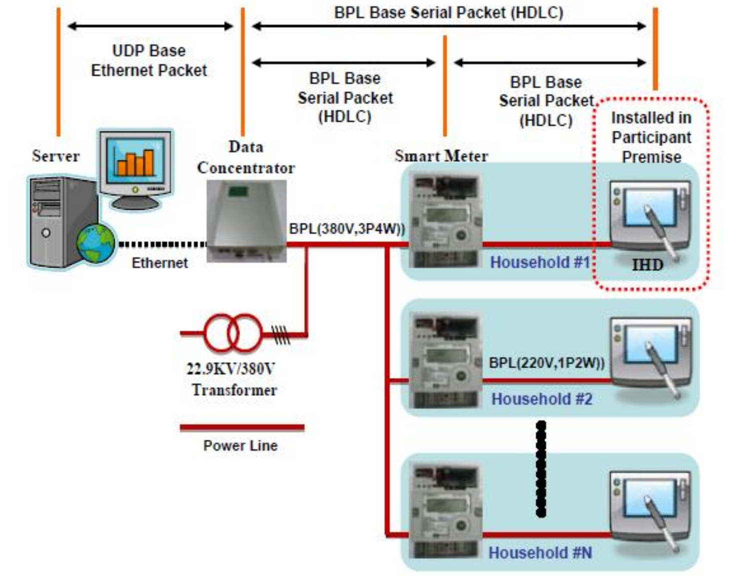
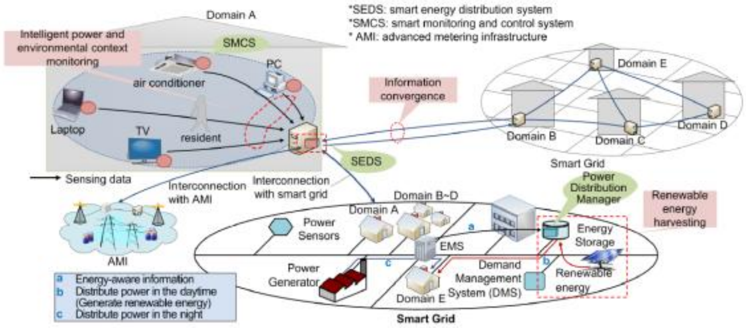
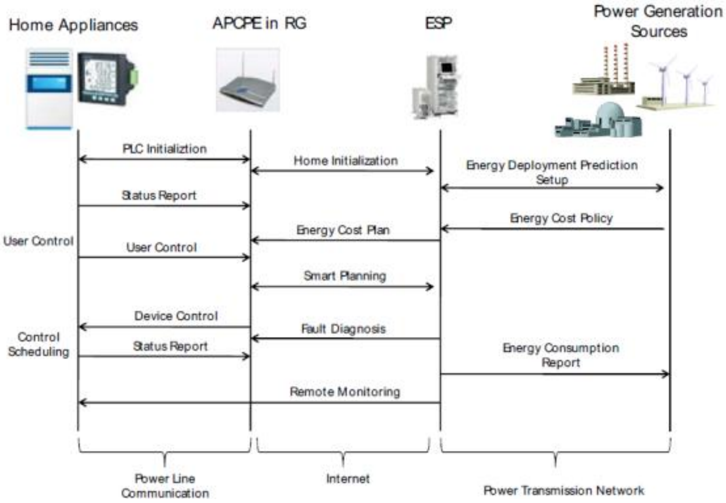
This section provides the analyses of the 30 Smart Grid diagrams found from the literature search, the detail of the 30 diagrams could be seen in Appendix C. Part one of this section details the findings in relation to the communication features of the Smart Grid diagrams, and in part two the characteristics of the diagrams are established.

3.4.1 **Classifying Smart Grid Diagrams**

Table 6 highlights the results of the analysis of 30 Smart Grid diagrams (the full results table can be seen in Appendix C). An illustration and the source are presented to specify the diagram in question and the communication features indicated which features each diagram had.

Table 6 - A table to show examples of how Smart Grid diagrams were classified according to the communication features they contained

Diagram	Component	Data Flow	Data Channel	Data Type
 Source: Frenzel, 2010	X			
 Source: Darby, 2011	X	X		

 Source: Choi et al., 2009	X	X	X	
 Source: Byun et al., 2011	X	X		X
 Source: Son & Moon, 2010	X	X	X	X

3.4.2 **Communication Features**

By summing up the communication features of each of the diagrams in Appendix C, five group categories were identified (Table 7).

Table 7 - A table to show the groups of smart grid diagrams derived from the configuration of communication features

	Communication Feature			
	Component	Data Flow	Data Channel	Data Type
Group 1	X			
Group 2	X	X		
Group 3a	X	X	X	
Group 3b	X	X		X
Group 4	X	X	X	X

The groups were deduced according to the number of communication features each diagram had. Diagrams in group 1 consist of one communication feature, the Component. Diagrams in group 2 has two features, the Component and Data Flow. In group 3, there are two sub-groups, 3a and 3b. Each sub-group has both the Component and Data Flow, but their third feature differed. The final group (group 4) consists of diagrams with all four communication features.

3.4.2.1 The Tally of Diagrams in Each Group

Table 8 shows the quantity of diagrams classified in each group. In the Smart Grid diagrams identified in the literature search, the majority had two communication features (the Component and Data Flow). Only one diagram was found to have all four communication features.

Table 8 - A table showing the diagrams categorised in each group

Group 1	**Group 2**	**Group 3a**	**Group 3b**	**Group 4**
9, 19, 20, 23	1, 2, 3, 4, 7, 8, 12, 14, 18, 21, 22, 24, 26, 27, 28, 29	6, 10, 13, 15, 16	5, 11, 17, 30	25

3.4.2.2 Archetype Models for Depicting Smart Grid Systems

As each group (categorised in Table 8) consists of different configuration of communication features, the manner in which they portrayed this information differed. An archetype model as to how each group depicted the communication features was derived. This could be seen in Table 9.

Diagrams classified in group 1 tend to be very realistic because they consist of only one communication feature (component) which is a physical object. They are mainly used to represent a future system of what Smart Grid could be and not an actual system. The diagrams could represent devices from different levels (linking home devices with components outside the home).

More than half the 30 diagrams found in literature were classified in group 2. In addition to the component feature, the diagrams in this group also illustrate the data flow. As data flow is not a physical object, the visualisation in this group tends to be abstract. Group 2 diagrams tend to be used to represent pilots of Smart Grid technology as well as the overall concept of Smart Grid.

Groups 3a, 3b and 4 all tend to have diagrams that are abstract because, similar to that of group 2, the diagrams consist of abstract communication features (such as the data flow, data channel and data type). They were typically used to should technology pilots and could represent devices in mixed levels. There were less diagrams classified in these three groups combined that in group 2.

3.4.3 **The Key Characteristics of Smart Grid Diagrams**

Thirty Smart Grid diagrams were examined against five sets of system types. The results are shown in Appendix D. The diagrams that could not be classified in a category were left blank.

Table 9 - A table to show the archetype models used for depicting smart grid systems

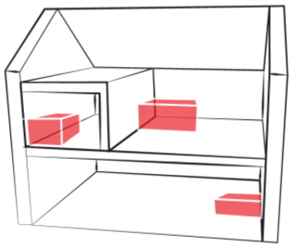
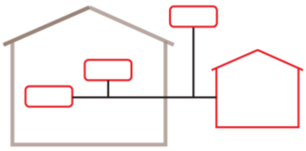
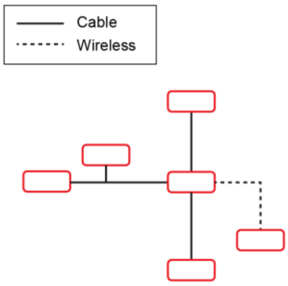
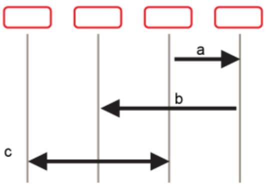
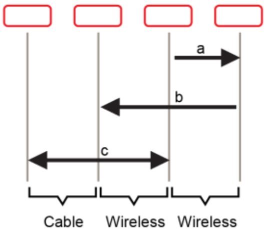
	Diagram	Description
Group 1		- This group of diagrams were used to show the concept of Smart Grid - The diagrams provide representation at device and mixed levels - The visualisation tended to be realistic and life-like
Group 2		- This group of diagrams tended to show technology pilots and the concept of Smart Grid - The diagrams can provide representation in a range of levels - The visualisation tended to be abstract
Group 3a		- This group of diagrams were used to represent technology pilots. - The diagrams tended to provide representation at device level - The visualisation tended to be abstract
Group 3b		- This group tended to show technology pilots - It provided representation at mixed levels - The visualisation tended to be abstract
Group 4		- This group tended to show technology pilots - It provided representation at mixed levels - The visualisation tended to be abstract

Table 10 shows the statistics of Smart Grid diagrams in each set of system types. From the table it could be seen that half the diagrams found were Physical and half were Conceptual. Most of the diagrams (74%) were Open systems. Rarely were there diagrams with all the necessary data contained depicted. All the diagrams found were deterministic systems. The majority of the diagrams (79%) illustrated a Dynamic system. Out these, all were Continuous systems. In some diagrams, the type of information that was being transferred could not be deciphered. However, because it was known that the Smart Grid systems were likely to have variable electricity tariffs, a presumption was made that all the diagrams were Continuous.

Table 10 - A table showing the percentage of smart grid diagrams in each set of system types

			Discarded Diagrams
Set 1	**Physical**	**Conceptual**	0/30
	15 (50%)	15 (50%)	
Set 2	**Open**	**Closed**	11/30
	14 (74%)	5 (26%)	
Set 3	**Stochastic**	**Deterministic**	11/30
	0 (0%)	19 (100%)	
Set 4	**Static**	**Dynamic**	11/30
	4 (21%)	15 (79%)	
Set 5	**Continuous**	**Discrete**	15/30
	15 (100%)	0 (0%)	

3.5 Discussion

This section discusses the findings resulted from the implementation of the methodology. Firstly, an evaluation of the diagrams found in the literature search is performed. Next, it details the results from the analyses of communication features in the Smart Grid diagrams. Lastly, it describes the challenges encountered in classifying the characteristics depicted in Smart Grid diagrams.

3.5.1 **Smart Grid Diagrams**

In the literature search, combinations of search terms were applied in order to locate suitable diagrams that met the scope of this paper. After filtering and discarding unsuitable diagrams, 30 diagrams were found.

Although all 30 diagrams found contained elements of Smart Grid technology for domestic consumers, the diagrams illustrated the Smart Grid system at different levels. Some illustrated devices that made up a system for the home, where as others were illustrating how the home as a whole connected with other places (e.g. distribution elements or storage devices) in the Smart Grid concept.

The diagrams were created for one occasion. The type of symbols or configuration employed vastly differed and were not reused in other diagrams.

3.5.2 **Communication Features**

Out of the five layers that forged the Smart Grid taxonomy, this chapter had chosen to investigate the communication layer. In order to examine the 30 Smart Grid diagrams, communication features that compose Smart Grid systems were deduced from the configuration of a typical communication system.

Five individual groups of Smart Grid diagrams were found. Each diagram groups contained a different configuration of communication features. By analysing the properties of the illustrations, the key elements in each group were identified. This established archetype models (shown in Table 9), which demonstrated the quintessential elements in each group.

Smart Grid diagrams in Group 1 only had one communication feature. Their illustration tended to be life-like because there was less information to convey. In the diagrams with two or more communication features, the illustration tended to be in abstract form. The configuration used in Group 3b and Group 4 was similar; the only difference was the addition of data channel to the bottom of the diagram.

3.5.3 **Challenges in Classifying Smart Grid Diagrams**

Understanding the key characteristics of Smart Grid representations could help the designs of future Smart Grid diagrams. This could potentially remove ambiguity in the depiction of Smart Grid systems and, hence, aid the acceleration of Smart Grid development.

A number of challenges were encountered in classifying the diagrams. The literature, from which the diagrams were extracted, were often consulted to apprehend their design and to clarify uncertainties relating to its communication properties. In addition, some diagrams represented Smart Grid system from a very high level provided very vague information.

From the results, it could be seen that half of the systems classified in Set 1 were Conceptual systems. Since the systems of this type were conceptual and may not exist, the information they present tended to be vague. With little detail provided, a number of diagrams (between 37-50%) could not be classified in subsequent sets.

3.6 Summary

Two objectives were identified in this chapter. The first objective was to identify the general system representation methods. Early on in this research it had been determined that there were only rules in creating representation methods, which was to represent what was most useful. Therefore, the focus of this research was placed on the second objective; to identify existing method of representations Smart Grid systems in the home.

In accomplishing the second, a literature search was first conducted. It made used of specific terms to identified literature that describes Smart Grid technology used by domestic consumers. From these literatures, 30 Smart Grid diagrams were extracted.

A decision was made to focus on the communication layer, and four communications features were identified in a Smart Grid system. These features were used to analyse the 30 Smart Grid diagrams found in the literature search. Based on the number of communication features, five groups were identified. In each group, an archetype model was formulated to show the manner in which the communication features were depicted. The archetype models will be used to guide the design of the representation method the next chapter.

4 SMART GRID REPRESENTATION FOR CONSUMERS

4.1 Introduction

Educating consumers in the Smart Grid technologies development is crucial in gaining their acceptance. Previous studies had found that consumers who understood about Smart Grid technology and their benefits tended to support it (Smart Grid Consumer Collaborative, 2012b) but unfortunately around 90% of UK consumers were still unfamiliar with Smart Grid technology (Zpryme, 2010). Hauttekeete et al. (2010) suggested that domestic consumers were often neglected in the development of the Smart Grid and subsequently, their roles and opinions remained unclear.

In terms of consumer's opinion, the majority of research in the past examined different elements of Smart Grid technology, such as privacy concerns in accepting smart meters (Alabdulkarim & Lukszo, 2011), the perceptions of smart home appliances (Stragier et al., 2010), and the design on feedback provided to consumers(Fischer, 2008; Raw et al., 2011). Rarely were the consumers shown the full set of technology that constituent a smart home environment(Paetz et al., 2012).

4.1.1 **The Consumer Domain**

In the Smart Grid conceptual model described by the National Institute of Standards and Technology (2012), the consumer is one of the seven domains that made up the Smart Grid (Table 11). Figure 8 shows NIST's (2012) vision of the Consumer domain. In this figure it could be seen that the consumer was linked to two other domains, the Service Provider and Distribution. The gateway components which formed a bridge between the Consumer domain and other domains were the Meter and the Energy Service Interface. The Home Area Network connected all the components in this domain including energy management equipment and home appliances as well as components that cross two domains (electric storage and generation devices).

Table 11 - Domains of the smart grid (adapted from NIST, 2012)

Domains	Description
Consumer	The end users of electricity. May also generate, store, and manage the use of energy. Traditionally, three customer types are discussed, each with its own sub-domain: home, commercial/building, and industrial.
Markets	The operators and participants in electricity markets.
Service Provider	The organisations providing services to electrical customers and utilities.
Operations	The managers of the movement of electricity.
Bulk Generation	The generators of electricity in bulk quantities. May also store energy for later distribution.
Transmission	The carriers of bulk electricity over long distances. May also store and generate electricity.
Distribution	The distributors of electricity to and from customers. May also store and generate electricity.

4.1.2 **The Availability of Smart Grid Technology in UK**

In the UK, the first Smart Grid technology (the Smart Meter) is set to be deployed to all homes between 2014 and 2019 (DECC, 2012c). The functions of Smart Grid was defined by DECC & Ofgem (2011) as follows:

> In addition to traditional metering functionality (measuring and registering the amount of energy which passes through it) the Smart Meter is capable of providing additional functionality for example two-way communication allowing it to transmit meter reads and receive data remotely.

As Figure 8 had shown, the Smart Meter would play a key part in that connecting the home to the Smart Grid. However, in evaluating the website of UK's six largest energy company (detailed in Appendix E.1), little information could be found on how this new technology would affect consumers. Smart Meters were not available on the market and there were no options for consumers to install the technology before the set date of deployment.

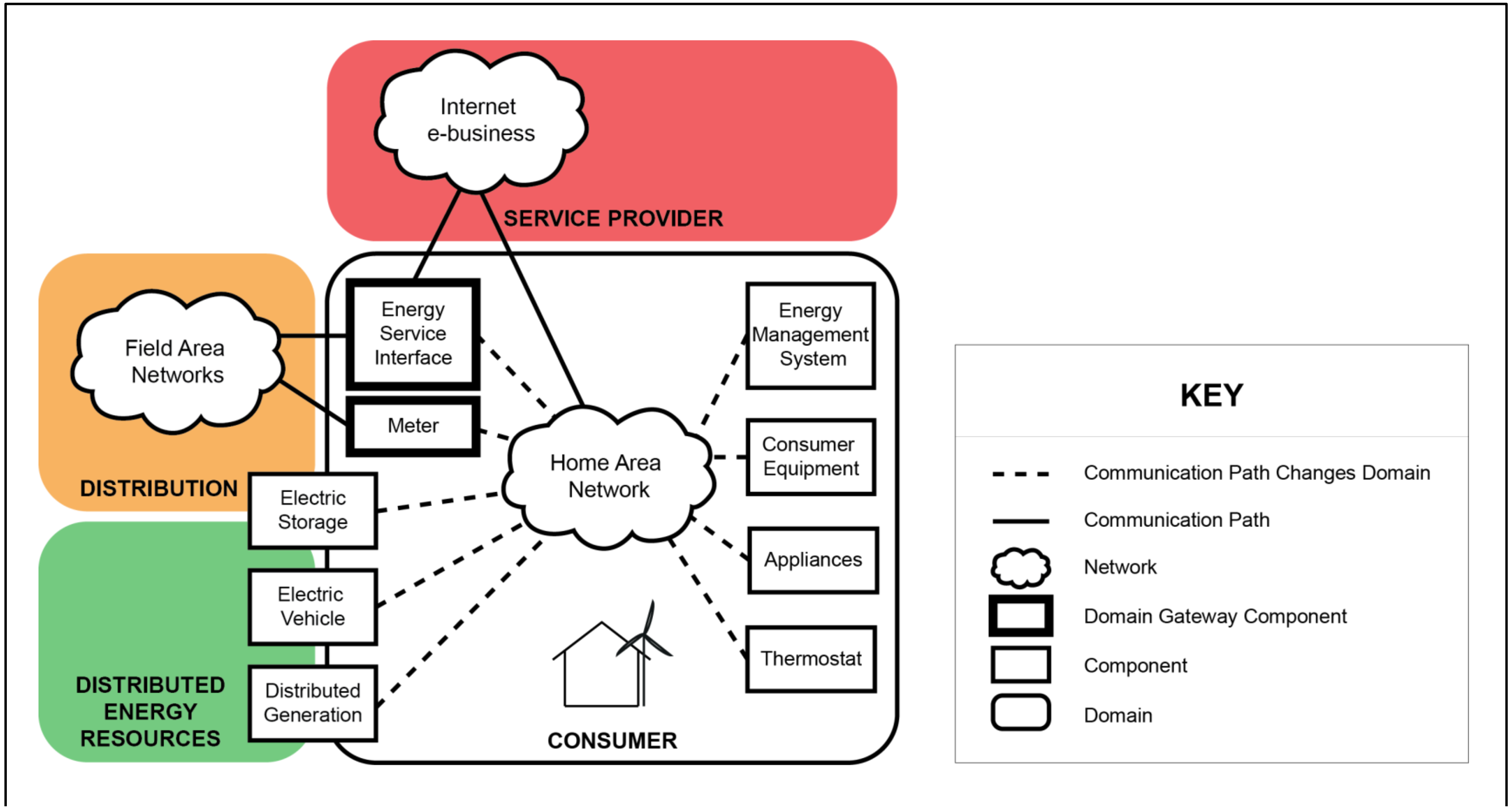


Figure 8 - The consumer domain (adapted from NIST, 2012)

4.2 Research Objectives

Little research had previously looked into consumer's perspective of the Smart Grid development. This chapter aims to identify a suitable method of presenting Smart Grid technology to residential consumers and contributes to phase 3 and 4 in the overall project methodology (Figure 9).

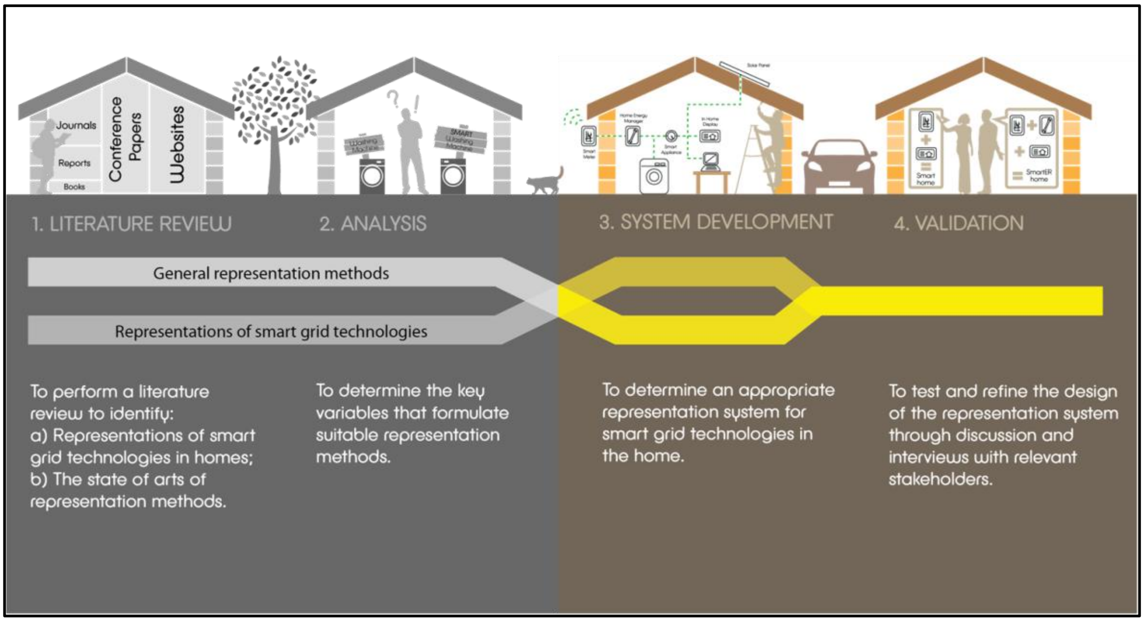


Figure 9 - A figure to show the phase of methodology...

This chapter seeks to fulfil the following objectives:

- To develop a representation method to map Smart Grid technology in homes;
- To validate the design of the representation method with relevant stakeholders.

4.3 Methodology

This methodology is composed of three stages. In the first stage, the background towards the development of the Smart Grid is identified and visualised. The second stage presents the development of the representation method for Smart Grid systems. In addition, this stage also presents how two existing electricity management systems offered to UK consumers were selected and visualised. Finally, an explorative interview is designed to obtain the level of consumers' understanding of the Smart Grid and to validate the design of the visualisation diagrams.

4.3.1 **The Visualisation of the Smart Grid Concept**

The concept of the Smart Grid was explained in two stages. In the first stage, the reasons behind the need for the smart grid were explained. Figure 10 was used to illustrate the conventional electricity grid. This diagram shows the types of problem that exist in the electricity grid today. The second stage of the explanation gives the solutions to the problems. Figure 11 illustrates the concept of the Smart Grid. It highlights emerging technologies and ideas that would play a part in solving the problems of the current electricity grid.

The ideas and development that create the Smart Grid were taken from the literature review of this report (Section 2.3). The illustration were adapted from National Grid (2012b), additional graphics and text were added to the diagrams where necessary.

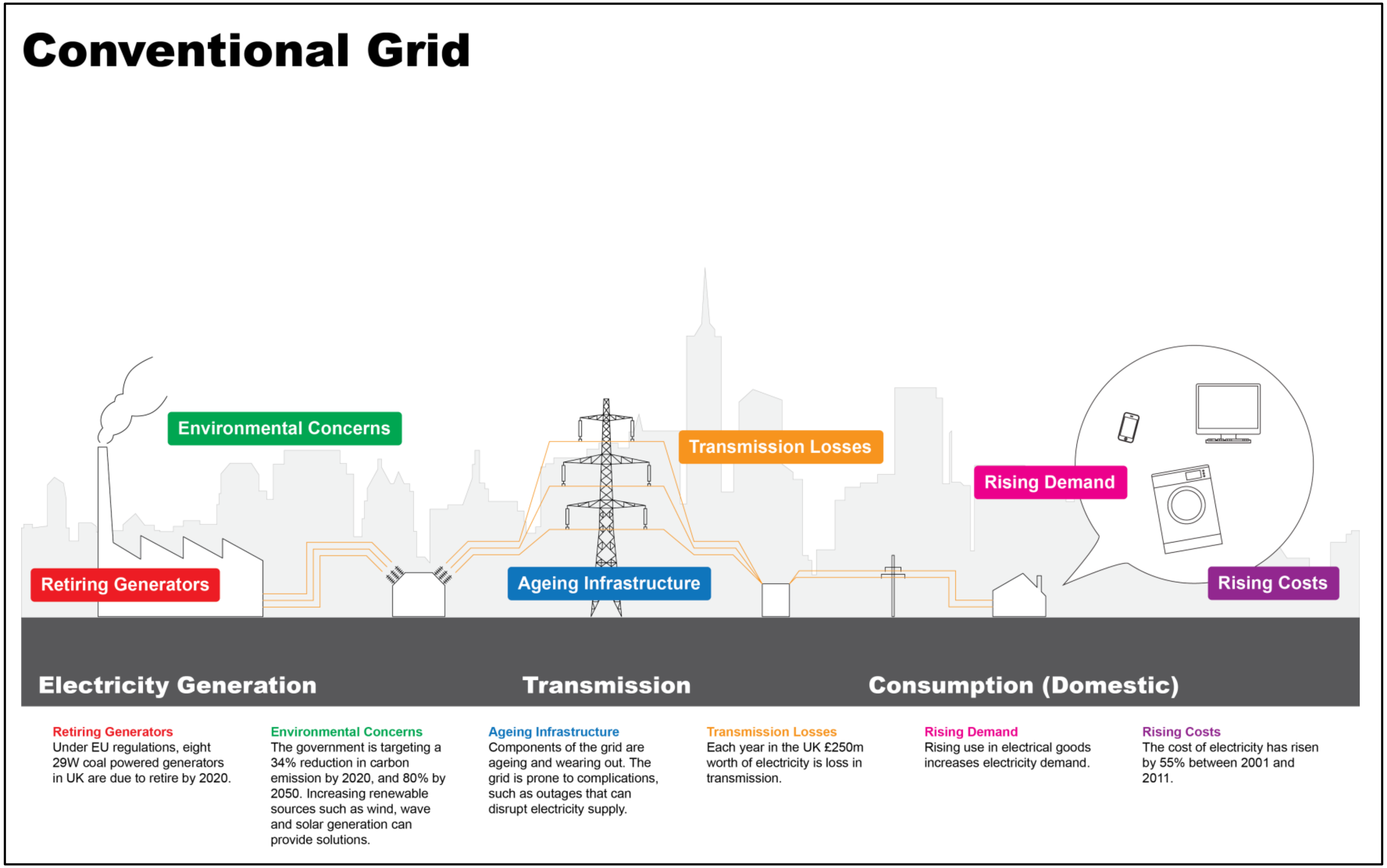


Figure 10 - Visualisation diagram of the conventional electricity grid (adapted from National Grid, 2012b)

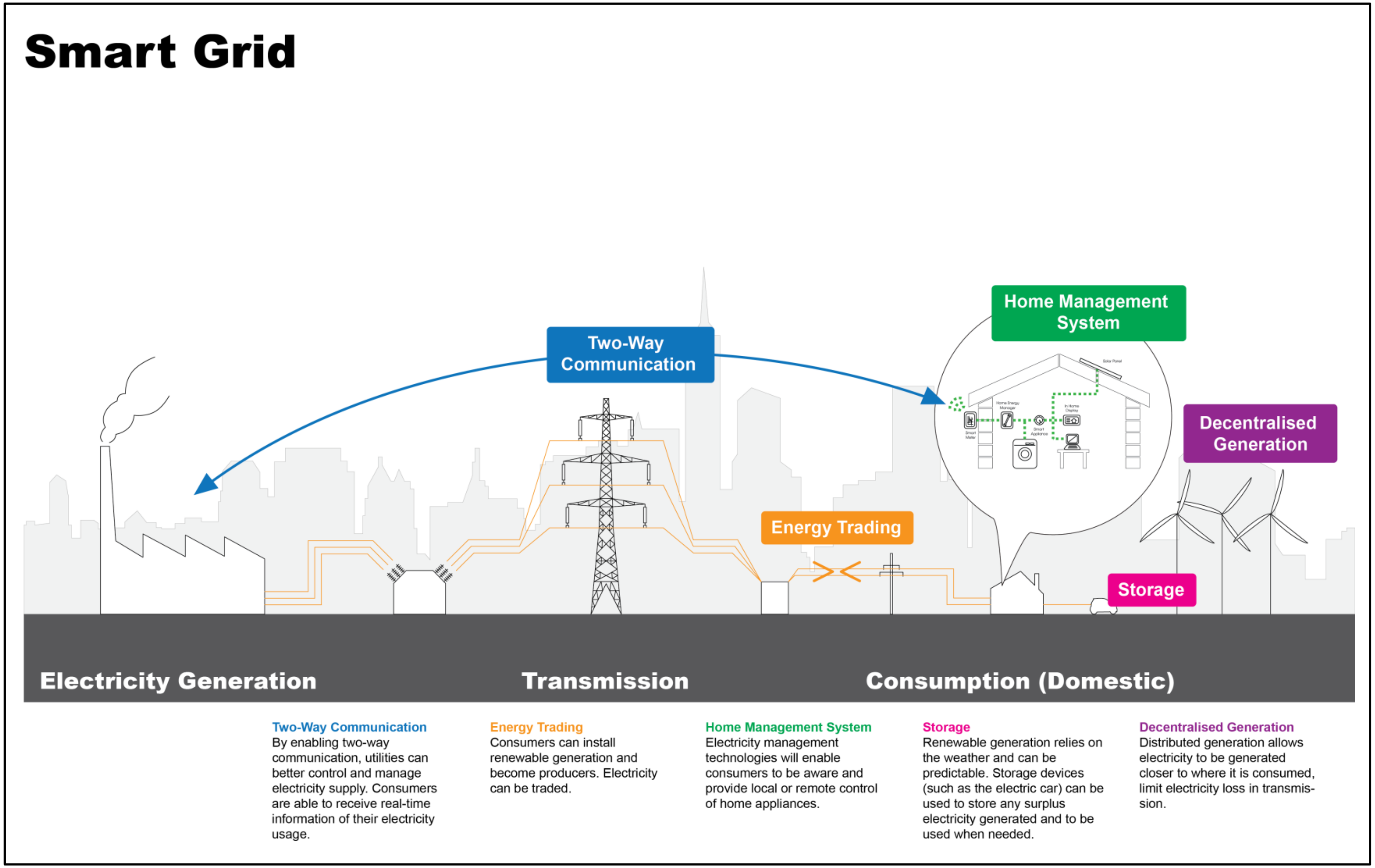


Figure 11 - Visualisation diagram of the smart grid (adapted from National Grid, 2012b)

4.3.2 **Development of a Smart Grid Representation Method**

To develop the representation method, the table of archetype models (Table 9 formulated in Chapter 3) were referred to. Detail of the design features are detailed in the sub-sections below.

4.3.2.1 Home Environment

Similar to the archetype model of Group 1, a life-like drawing of the home (illustrated in Figure 12) was used to act as a backdrop to the management system. This will enable consumer to quickly recognition how any new features may be installed in their home.

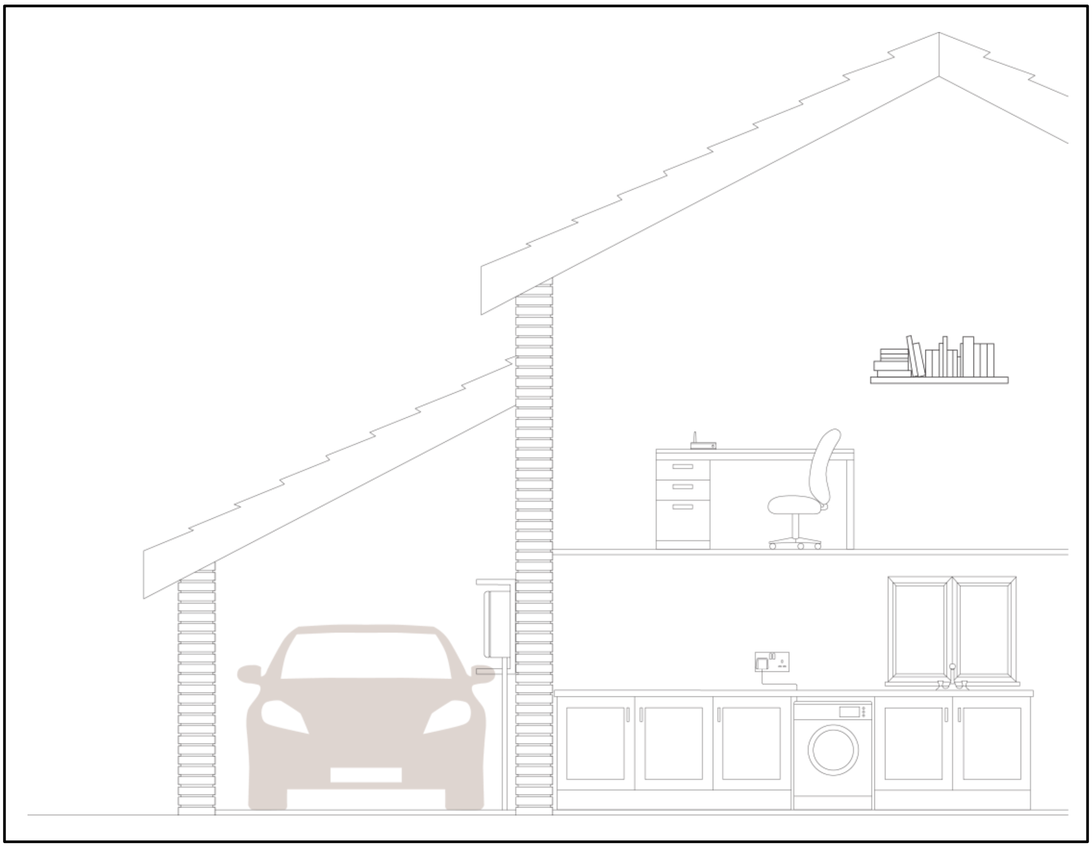


Figure 12 - A diagram to show the simplicity of the home backdrop

Simple and monotone outlines were used to minimise any distraction from the illustration that would be visualised onto the backdrop.

As previously discussed in Section 3.4.2.2, the Smart Grid systems could communicate with features outside the immediate home environment. Figure 13 shows how external factors outside the immediate home environment (such as communication with the electricity company, the use of devices mobile devices) were considered.

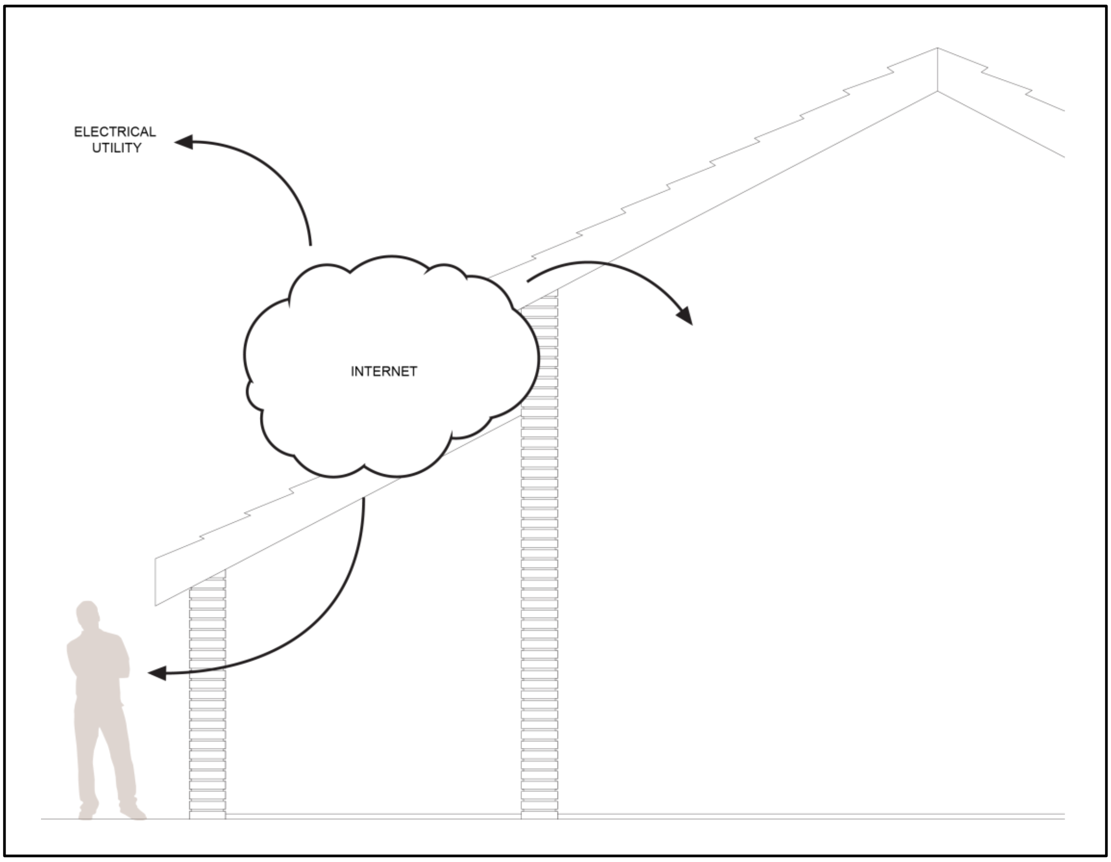


Figure 13 - A diagram to show how factors outside the immediate home environment were represented

The silhouette of the human figure on the far left of Figure 13 represents when the user is outside of the home environment. The electricity company is simply represented by text – “electrical utility”.

4.3.2.2 Data type and Data Flow

The data type and data flow were detailed to visualise the type of information and in which direction they were transferred between the devices. Figure 14 illustrates how these two features were visualised.

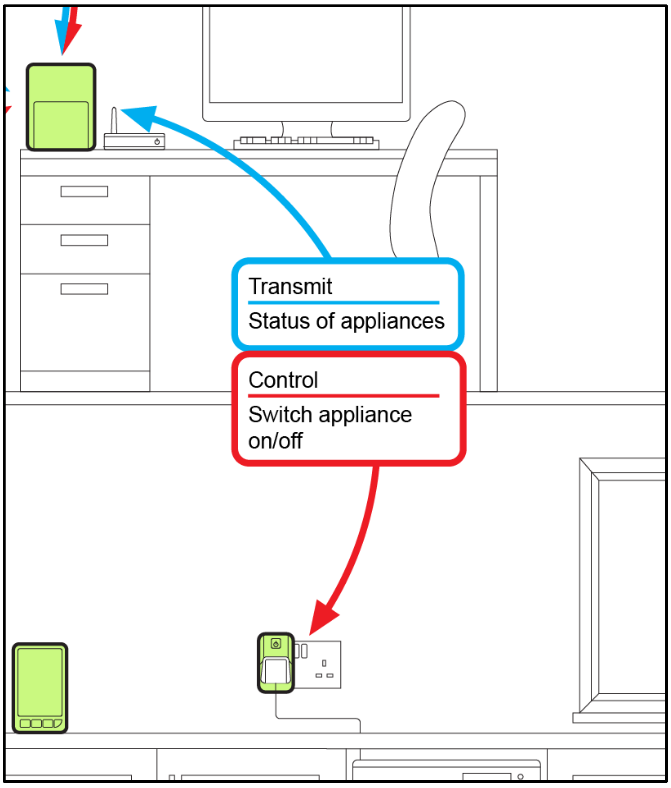


Figure 14 - A diagram to show how data type is represented and the direction in which the data are transmitted

Two colours were used to differentiate the difference between the different types of data being transferred. Blue outlines were used to highlight the data that devices automatically detect. These data are then either transmitted to other devices or presented to the user on a computer screen. Red outlines were used to highlight the data transmitted as a result of a control decision made by a user.

4.3.2.3 New Technologies

The new functions or devices used in the management system were highlighted with light green to differentiate it from the background. This can be seen in Figure 15.

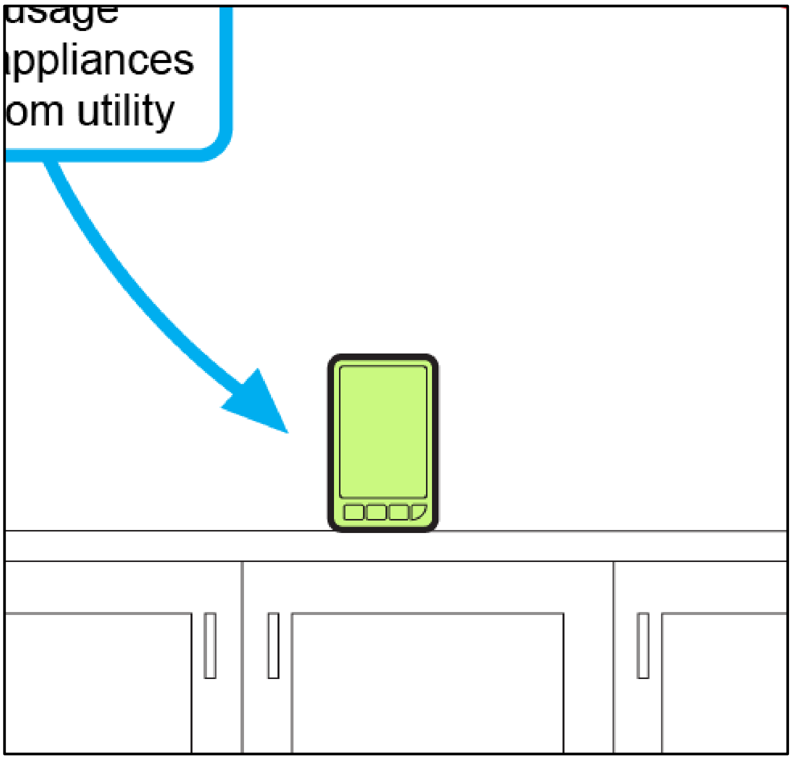


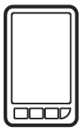
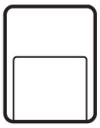
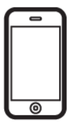
Figure 15 - A diagram to illustrate how new technologies were highlighted to differentiate from the background

Similar to the visualisation of the home environment, the new technologies were also represented realistically so that consumers would be informed of what they look like and how they may be installed in the home.

In Chapter 3 it was found that one problem restricting the sharing of Smart Grid development was in the terminology and definition of Smart Grid technology (Giordano et al., 2011), hence common names were provided for devices with similar functions so that it was easier to understood and compared. A table, such as Table 12, could be used to presents the different device function.

Device one is a sensor/transmitter that captures and transfer data. Device two is display device that provides information. The third device is connection device, its main function is to transfer data from one device to another. The fourth device could access the internet and could potentially send information outside the home. Device five is a smart plug, which can that captures the electrical data of any plugged in device.

Table 12 - A table that show how the new technologies could be presented according to their functionality

	Option 2	
Device	**Illustration**	**Description**
1 Sensor and Transmitter		This device connects to the electricity meter. It senses and transmit electricity consumption data to the connection device.
2 Display		The display provides information of electricity usage in real-time. Appliance connected to smart plugs can be viewed and controlled from the display.
3 Connection Device		This device connects the elements of the system, transmitting data and control commands between devices. It communicates with the utility company automatically as long as it has internet access.
4 Internet Accessible Device		Web services provide for users to view their current consumption as well as setting and keeping track of energy reduction targets. Through the utility website and mobile app, smart plugs status can be viewed and controlled remotely.
5 Smart Plug		The smart plug sends the status of the appliance plugged in to the connection device. It can receive commands send wirelessly switching appliance on/off.

4.3.3 **Research Validation**

This section describes the validation process. Two sets of diagrams were developed for a semi-structured interview. The first set of diagrams provided the comparison of the Smart Grid with the conventional electricity grid. The purpose this set of diagrams was used to obtain insights into consumer's current understanding of the Smart Grid. The second set of diagrams utilised the representation method to visualise existing home electricity management systems. The clarity of the diagrams was evaluated by the interviewees. Recommendations on how the representation method could be improved were identified.

4.3.3.1 Semi-Structure Interview Design

A semi-structure interview was designed with both open and closed questions. This style of interview was chosen because the participants' level of understanding of the Smart Grid was unknown. Semi-structured interviews utilises predetermined questions that can be modified and explained to accommodate interviewees with different type of experience (Robson, 2002).

The open questions allowed participants to freely express shades of opinions and offer the research to capture different perspectives and understanding expressed by consumers. Closed questions were also used so that a set of pre-coded answer which could be used for data analyses purposes (Brace, 2004).

The full list of questions for the interview is shown in Appendix F. The first six questions was used to delved into how much consumers current understood about the Smart Grid concept and the clarity of the visualisation diagram. Questions such as "*Have you heard of the term 'Smart Grid' or 'Intelligent Grid' before?"* and *"Do you find anything familiar to you in the description of Smart Grid?"* were used to gain insight into the participants' level of understanding. Figure 10 and Figure 11 were used to aid the explain of the Smart Grid to the participants after question 1b. The author intended to capture the participant's first reaction to Smart Grid before more details were given.

The second part of the interview seek to determine the participants' opinion of the Smart Grid technologies and if validate if the diagrams could be used for comparing different management systems. As there was insufficient information to visualise Smart Metering Systems, a decision was made to depict and test illustrations of existing technologies with similar functions. An online search was performed to identify the energy management products offered by the six largest energy companies (British Gas, EDF, SSE, E.ON, Scottish Power, and Npower) in the UK. The findings could be seen in Appendix E.2. A first attempt to visualise the function of the management products found that a number of products did not have sufficient information. Out of the four products which were visualised (Appendix E.3). The two products with the most available information were chosen for this methodology and visualised using the representation method developed in Section 4.3.2. The end results could be seen in Figure 16 and Figure 17.

Based on Figure 16 and Figure 17, the last five questions of the interview investigated consumers' perspectives on existing electricity management systems and the clarity of the visualisation diagrams. Question such as *"Can you see any benefits in installing either option? Which would you install?"* were used to: (a) gain insight into consumers' knowledge and (b) to validate the design of the representation method.

The reason to limit the validation to UK based Smart Grid systems is partly due to the time constraint of the project, partly because the research project and it sponsors are based in the UK where the resources lie.

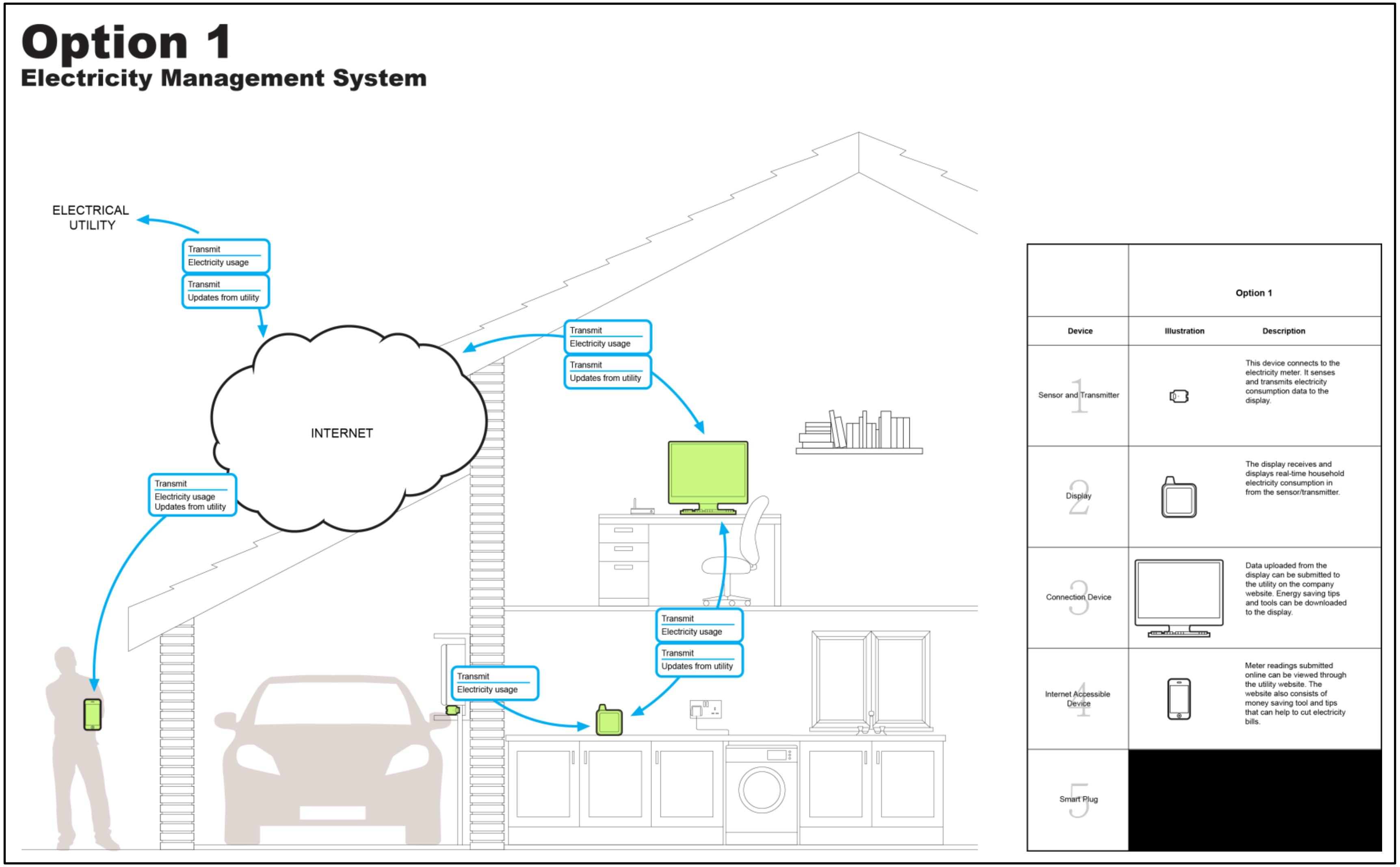
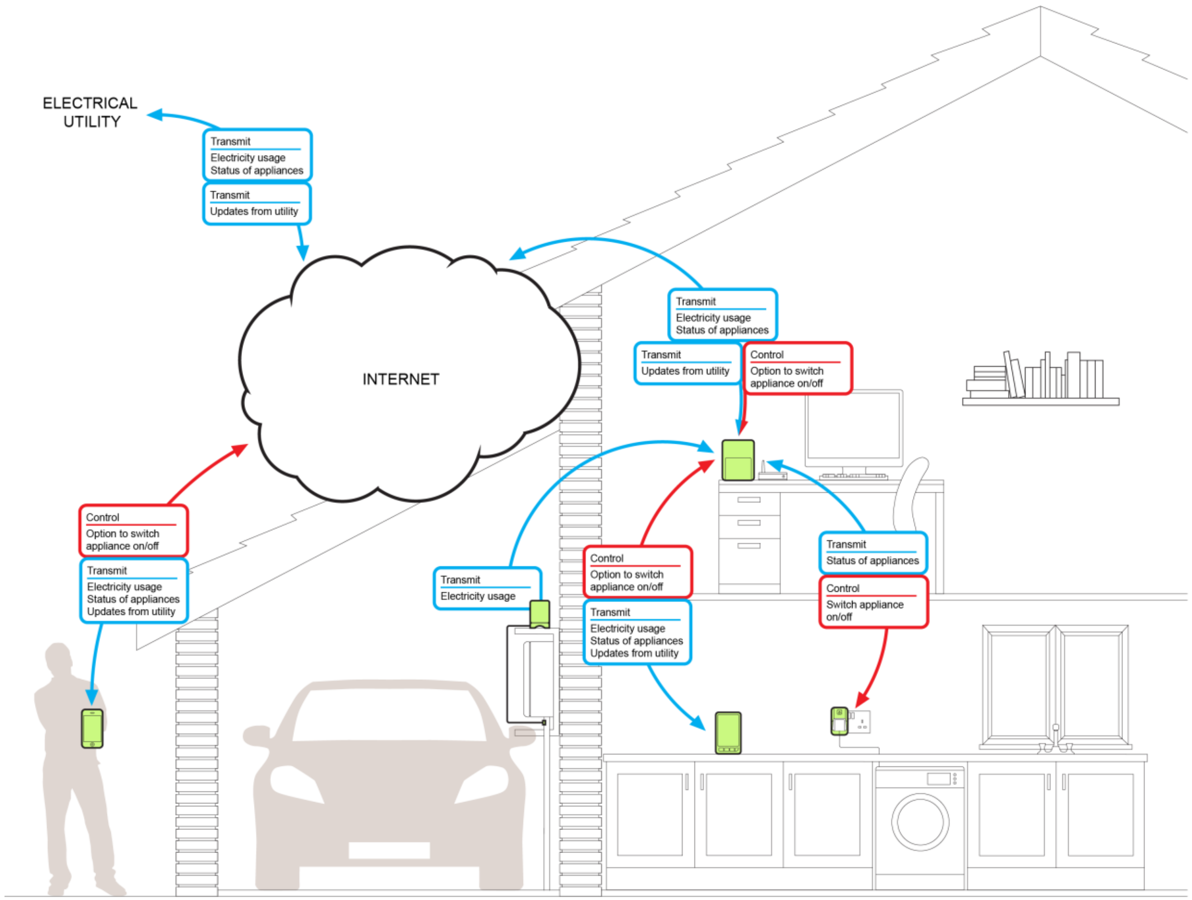


Figure 16 - Visualisation of an electricity management system: option 1

Option 2

Electricity Management System



	Option 2	
Device	Illustration	Description
1 Sensor and Transmitter		This device connects to the electricity meter. It senses and transmit electricity consumption data to the connection device.
2 Display		The display provides information of electricity usage in real-time. Appliance connected to smart plugs can be viewed and controlled from the display.
3 Connection Device		This device connects the elements of the system, transmitting data and control commands between devices. It communicates with the utility company automatically as long as it has internet access.
4 Internet Accessible Device		Web services provide for users to view their current consumption as well as setting and keeping track of energy reduction targets. Through the utility website and mobile app, smart plugs status can be viewed and controlled remotely.
5 Smart Plug		The smart plug sends the status of the appliance plugged in to the connection device. It can receive commands send wirelessly switching appliance on/off.

Figure 17 - Visualisation of an electricity management system: option 2

4.3.3.2 Sample

Ten participants were interviewed individually. Both male and female were interviewed, but overall male were in the majority (6 out of 10).The participants came from a varied age range which spanned across 5 age groups (between 18 and 64 years), and the highest number of participants came from the 25- 34 group. As this was the first research that looked into the representation of the Smart Grid it was expedient to seek feedback from a variety of backgrounds.

All the interviews were conducted face to face and followed the same design. In each case, the interview was recorded and transcribed afterward. Face-to-face interview were chosen because it offered the possibility provide additional explanation and to modify the line of enquiry to following up interesting responses (Robson, 2002).

4.4 Results

This section presents the findings from the implementation of the methodology. Ten participants were interviewed for this research. The interviews were recorded and the results were transcribed and the full results table could be found in Appendix G.

4.4.1 **Knowledge of the Smart Grid**

Question 1a) – "Have you heard of the term 'Smart Grid' or 'Intelligent Grid' before?"

This question was designed to find out how much of the Smart Grid concept consumers were exposed to. Each participant was first asked if they have heard of the term "Smart Grid" or "Intelligent Grid" and then a definition of Smart Grid was explained to them using Figure 10 and Figure 11.It was found that only one participant had not heard of Smart Grid before. After presenting the Smart Grid concept it was found that this same participant had heard of 50% of the Smart

Grid concepts before. In contrast, there were two participants (Participant 2 and Participant 4) who had heard of this term but had no knowledge of the Smart Grid concepts.

Question 1b) – "Do you find anything familiar to you in the description of Smart Grid?"

Table 13 shows the participant's knowledge of the concepts that contributed to the Smart Grid. Although most participants (70%) had knowledge on the Home Management System, it was followed closely by Energy Trading (60%) and the other three concepts (50%).

Table 13 - A table to show the participant's knowledge of the smart grid concepts

Smart Grid Concepts	**Participant**										**Total**
	1	2	3	4	5	6	7	8	9	10	
Two-Way Communication	x				x		x	x		x	5
Energy Trading	x					x	x	x	x	x	6
Home Management System	x		x		x		x	x	x	x	7
Storage	x						x	x	x	x	5
Decentralised Generation	x		x				x	x	x		5

Question 1c) – "In percentage, how much information is new to you?"

There was a large variation of Smart Grid knowledge. As shown in Figure 18, some people knew nothing about the Smart Grid and stated that 100% of the knowledge presented to them was new, whereas others had greater understanding and stated only 0-10% were new knowledge to them. On average, around 46% of the information presented to the consumer were new knowledge.

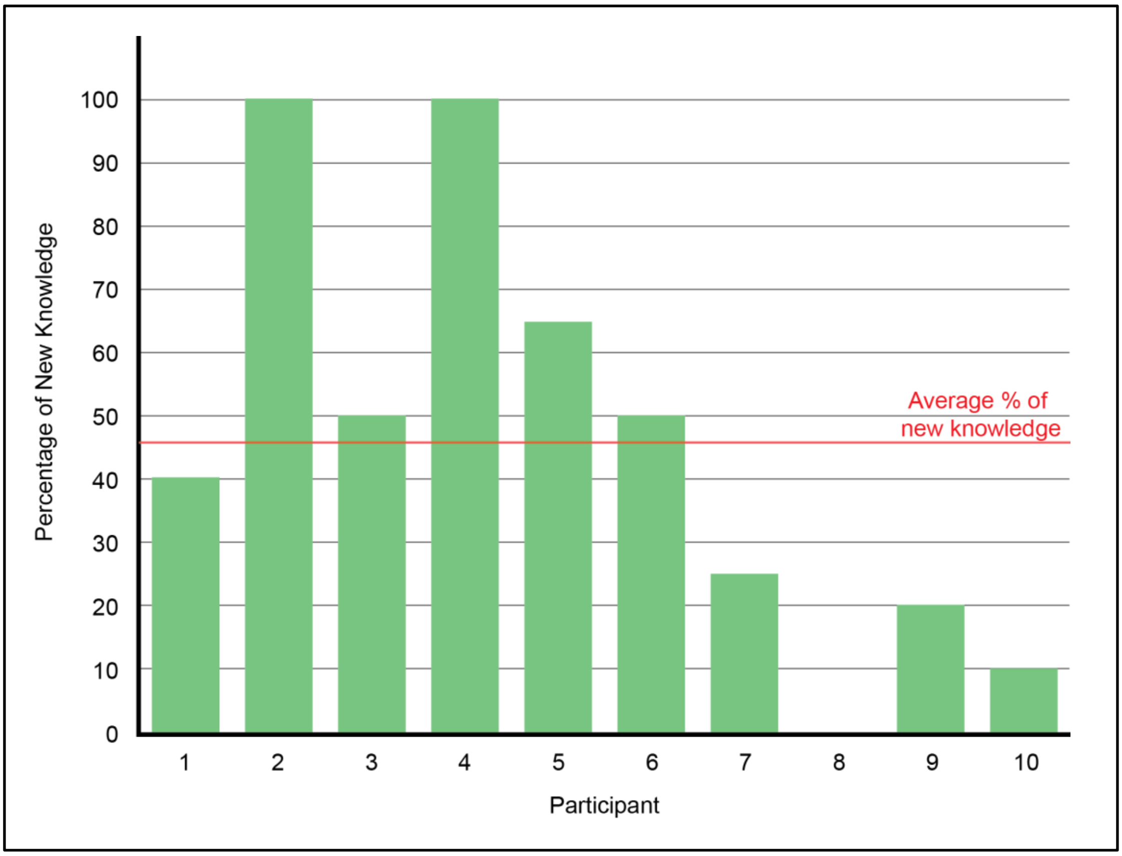


Figure 18 - A graph to show the percentage of new knowledge in the smart grid definition for each participant

4.4.2 **Improvement to Smart Grid Illustration**

Question 1d) - Do you have any question regarding Smart Grid, or is there anything in the diagram that is unclear to you?

This question was designed to find out what type of information consumers wanted to know but was missing from the description or to clarify anything unclear in the visualisation. Table 14 presents the questions or queries found in the interviews.

Table 14 - Consumers' queries derived from the interview process

	Questions / Queries
1	Provide detail on how the home management system functions.
2	Provide more detail on how energy trading functions. Would it require new infrastructures?
3	Provide more detail on how decentralised generation functions. Would it bring pollutions closer the homes if electricity is generated closer? Would more transmission towers be built nearer need to be built amongst houses too?
4	Explain why we need two-way communication. How is a smart meter different from a conventional meter?
5	Provide more detail on the storage. How will electricity be transmitted and stored? What is the capacity and how long can electricity be stored?
6	Provide information on the transmission towers and cables. How will they be improved?
7	Detail how much electricity can be produced by renewable sources.

The majority of the queries involved gaining more knowledge of each of the Smart Grid concepts. There was concern in the idea of decentralised generation. Consumers feared that bringing generation closer to residential areas would bring pollution closer too. In addition, there were doubts in the effectiveness of renewable generation.

4.4.3 **Smart Grid Illustration**

Question 1e) – "Do you find the diagram helpful and have you any suggestions for improvement?"

Feedbacks for improvement are shown in Table 15. They were listed in two categories: Additional Information and, Clarity and Aesthetics. The first category listed the types of information the interviewees wanted to see in the diagram. The second category contained participants' suggestions for improvement.

Table 15 - Feedback for the smart grid diagram

	Additional Information	Clarity and Aesthetics
1		Clarify and label the descriptions at the bottom of the diagram
2		Clarify which part of the diagram 'Ageing Infrastructure' is referring to.
3		Clarify who the consumers are communicating with in the 'Two-Way Communication'.
4	The emphasis should be placed at the Home Management System end. The visualisation of the Transmission part could be omitted.	
5	Clarify the function of Energy Trading. Perhaps include graphics of how electricity may be produced and use different colour to show that electricity is traded from the home.	
6	Provide advices on renewable generation available to consumers. What options are there?	
7	Indicate when the problems are likely to occur (such as retiring generation) and what consumers can do to prepare for it.	
8	The diagram is currently showing the Smart Grid concept at the top-level. Provide further detail.	

4.4.4 **Electricity Management Technology and Services for the Home**

Two electricity management systems available in UK were presented to the participants. They were questioned to find out how much basic knowledge they had on the devices and if they had similar technologies at home.

Question 2a) - "Have you heard of any of these technologies before?"

From the questionnaire, it was found that most consumers had some knowledge of existing electricity management devices. Only 20% of the participants had not heard of any of the management devices at all.

Question 2b) - "Do you have any of such technologies installed in your home?"

Figure 19 shows the results of this question. Out of all the participants who took part in this research, only 50% used some type of electricity management technology or service in their home.

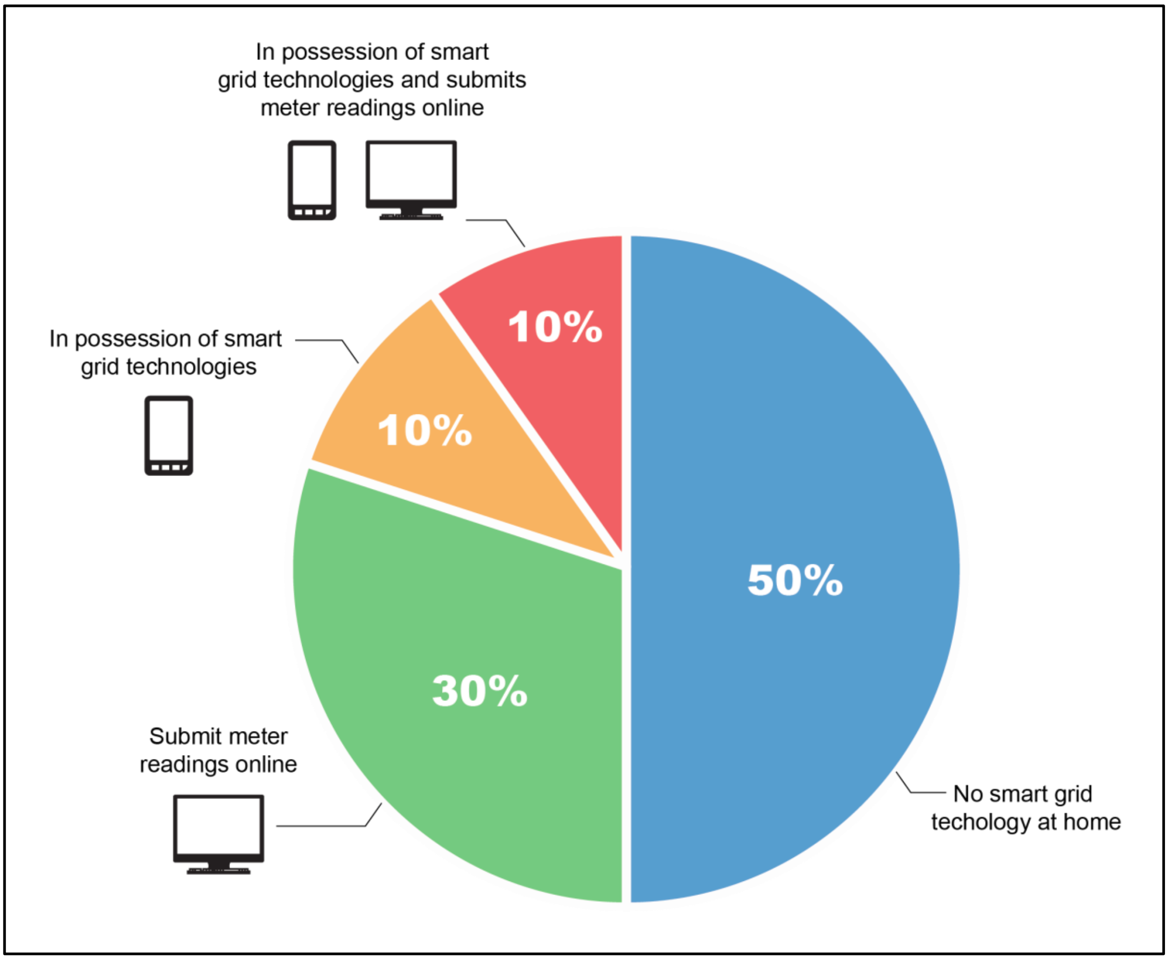


Figure 19 - A pie chart showing the adaptability of smart grid technology and services in the home

Amongst these, 30% discussed using online services to submit their electricity consumption to their electricity supplier. Even though there were 20% of participant with electricity management devices in their home, only 10% used both the devices and the online service.

From the questionnaire, it was found that the technologies used by the two management systems already existed in some home appliances. One participant related to technologies at their home that provide similar functions. For example, option 2 (Figure 17) had a remote control function that allowed consumer to control their appliance using mobile phones. This function was similar to the remote controls used to control television and CD players. In addition, some participants already used devices to manage their electricity appliance, such as the 24-hours mechanical timers. This device facilitates consumers to turn their appliance on at pre-determined times.

4.4.5 **Electricity Management Options**

Question 2c) – "Can you see any benefits in installing either option? Which would you install?"

Two separate management systems (Figure 16 and Figure 17) were shown to consumers to see if they could recognise any benefits these systems might be for them. All participants were opened to the idea of installing either of the systems.

80%of the participants stated that they would install option 2. The main reason given for this was that it has the remote control function, which was absent in option 1. As one participant stated, "If I am going to install something, I want everything (all the available functions)" (Participant 7, male, age 25-34), from this it was clear that the majority wanted to take the full benefit of the system that was available for them.

20% stated that they would install option 1 first and move onto the more complex option 2 if the system worked for them. Complexity of the management system was one factor that influenced the participants' choice. The participants that chose option 1 had not previously used any electricity management devices before, hence they preferred to test simpler of the two options. Participant's lifestyle could also influence their choice. As Participant 10 (female, age 18-24) stated:

> I would install option 1, but I know my partner would want to install option 2 because he is good with electrical devices so he would want more control. Also, he is more concerned about the budget so he will be very happy to use this system.

From this statement it could deduced that consumers might have different priorities in life. For people who were more concern about their budget, option 2 may suit them where as other people would be content with the basic functions.

4.4.6 **Management System Illustration**

Question 2d) – "How clear are the diagrams to you and what can be improved?"

Table 16 presents the feedback for the diagrams in Figure 16 and Figure 17. It shows the feedback in the same categories as Table 15.

Table 16 - Feedback for the electricity management system diagram

<table>
<tr><th></th><th>Additional Information</th><th>Clarity and Aesthetics</th></tr>
<tr><td>1</td><td></td><td>Indicate where the system begins to guide consumers studying the diagram.</td></tr>
<tr><td>2</td><td></td><td>Make the background of the diagram more colourful so it appears more realistic and distinguishes the new devices. Enlarge the text describing the new devices so it is easier to read.</td></tr>
<tr><td>3</td><td colspan="2">Distinguish which devices require the internet.</td></tr>
<tr><td>4</td><td colspan="2">Clarify the functions of the internet and minimise the size of the graphic to reduce its prominence.</td></tr>
<tr><td>5</td><td colspan="2">Remove the boxes or repetitive information and replace it with simple data flow outlines.</td></tr>
<tr><td>6</td><td colspan="2">Provide detail of all household appliances that can be connected the system.</td></tr>
<tr><td>7</td><td>List the benefits of the system.</td><td></td></tr>
</table>

8	Provide detail on whether the system can be connected to renewable generation.	
9	Provide different visualisations of the system to acquire more accurate feedback on its clarity.	
10	Illustrate the type of information that can be viewed and on which device it can be viewed.	

4.4.7 **Clarity**

Question 1f) – "How many marks out of 10 would you give for clarity?"

Question 2e) – "How many marks out of 10 would you give for clarity?"

Question 1f and 2e asked participants to rate the diagrams depending how clear the visualisation was to them. Figure 20 shows the average and range of scores that was giving to the two types of diagram.

The average score for the Smart Grid diagram (8.5/10) was higher than that of the electricity management diagram (8.2/10). The Smart Grid diagram received more consistent rating with scores between 8 and 9, whereas the rating for the electricity management system varied a lot more with scores between 6 and 10.

Even though both visualisation diagram received relatively high scores, participants did find it difficult to rate the diagrams because as Participant 8 (female, age 55-64) stated, "there is no other diagram to compare your diagram to" (Participant 8, female, age 55-64). There were no other diagrams available to base the scores on.

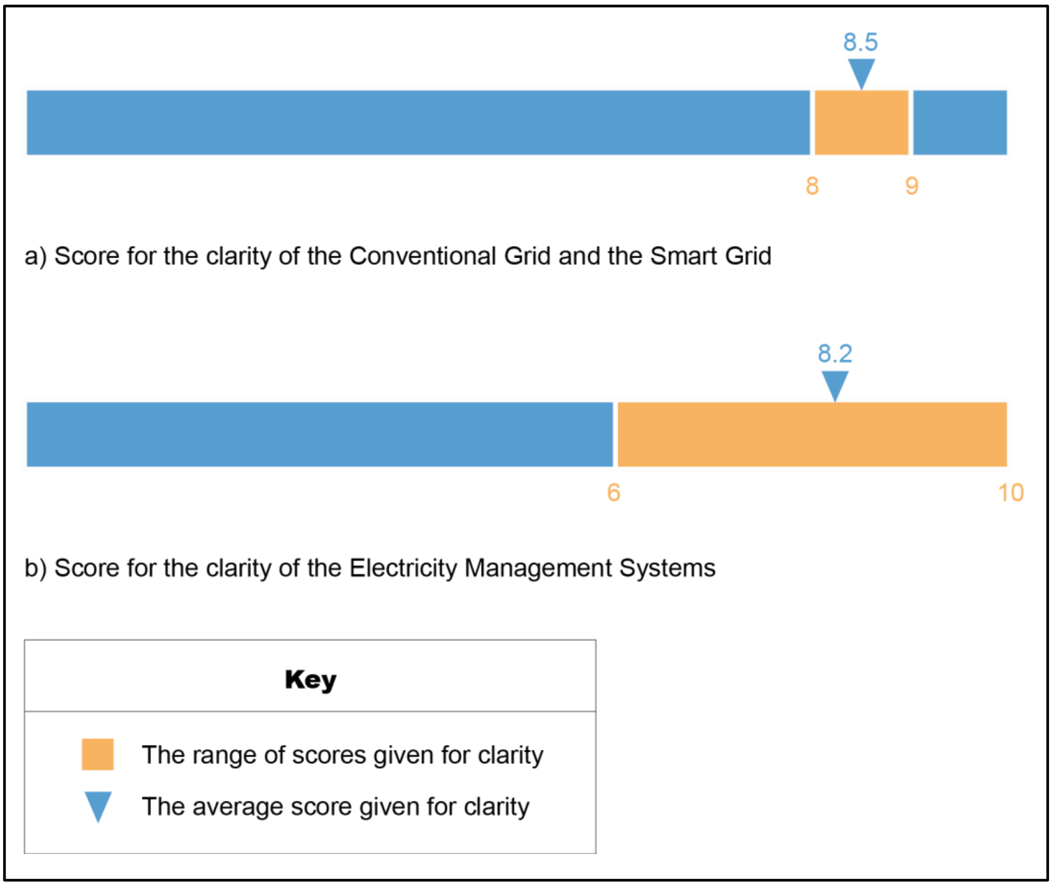


Figure 20 - Scores for the two types of diagrams

4.5 Discussion

This section reports the interpretation of the research process and the understanding of the findings. Firstly, it presents the design approach behind the two types of diagram (Smart Grid and electricity management system) and secondly, it evaluates the findings from the validation interview.

4.5.1 **Visualisation of the Smart Grid Concept**

Previous studies had shown that that consumers with knowledge of the Smart Grid and smart meters tended to support it, but at the moment too few people understand the Smart Grid technology and its benefits. The Smart Grid Consumer Collaborative (2012a) suggests a strong approach to build support for the Smart Grid was to weave together the arrays of benefit and told as a single story to consumers.

In an attempt to establish support for the Smart Grid, two visualisation diagrams were produced to build up the overall vision of Smart Grid. The first diagram (Figure 10) introduced the background of the Smart Grid concept, and second diagram (Figure 11) depicted the new technologies and services in development.

4.5.2 **Visualisation of Smart Grid Technology for the Home**

In the UK, Smart Meters and In-Home Displays are being trialled and would not be deployed until 2014. Although there had been many research and developments in Smart Grid technology, actual products available to consumers were limited. Thus, rather than visualising the smart metering system that does not exist with vague details, this research made use of available electricity management systems with similar functions.

Through online research on the six largest energy companies in UK, existing electricity management products were identified. However, much of the system descriptions had insufficient information, which made it difficult to depict. For this reason, the two electricity management systems with the most available information were chosen and visualised. A mixture of online sources was used, including explanations from the energy company's website, online videos, and images.

In fulfilling the aim of this chapter, a representation system was designed to map different electricity management systems and enabled comparisons of the systems. Since previous research had identified that 90% of people interview in the UK were unfamiliar with Smart Grid technology (Zpryme, 2010), it was especially important that the system provided lucid representation to successfully conveys the functions of the electricity management systems. Due to time limitation only one representation system was designed and tested.

Further research should utilise the feedback from the interviews to refine the design proposal.

4.5.3 **The Design of the Validation Interview**

The visualisations (Figure 10 and Figure 11) of the Smart Grid concept were used to examine consumers' understanding of the Smart Grid. The explanation of the Smart Grid concept was introduced in the first part of the validation interview to ensure all participants understood the background to the purpose of the energy management systems. This allowed the participants to make judgement on the design of the two visualisation systems.

4.5.4 **Knowledge of Smart Grid and Energy Management Systems**

With the date of smart metering deployment looming closer in the UK, it was encouraging to find that the majority of domestic consumers (90%) had heard of the term *Smart Grid* or *Intelligent Grid*, and on average, consumers were familiar with 54% of the key ideas behind Smart Grid.

There were large variations in the knowledge of the concepts. Some consumers had full knowledge of all the concepts whereas others had none. It was also found that even though consumers may not have heard of term *Smart Grid* or *Intelligent Grid* specifically, they could be aware of the developments relating to it.

There were mixed reactions as to the benefits of the Smart Grid. On one hand consumers stated that they would like to see greater use of renewable generation which helped to create a more resistant electricity grid. On the other hand there were concerns with the practicality of storage devices and pollution issues relating to decentralised generation.

4.5.5 **Validation of the Visual Diagrams**

This research did not present smart grid technology (such as the Smart Meter and In-Home Display) to consumers, but similar and more basic electricity management systems. Nevertheless, from this research it was found that all the participants were open to install new electricity management devices in their home. Out of the two options presented to them, the majority chose to install the more complex option because it enabled more functions and could submit data automatically.

Even though participants were opened to new form of technologies of the home and they could see the benefits in using management systems, there were concerns relating to the safety of personal data. Doubts were also raised over the cost of the new technology in comparison to actually savings that could be made.

One difficulty encountered in the research was to decide on the type of information consumer would like to see regarding home electricity management systems and how to present it. As no research had previously been conducted regarding this topic, the final design presented information related to the communication layer. Although relatively high scores were received for the depictions, consumers expressed that they would prefer to see a simpler diagram with less data. The diagram should clarify how the system integrates with their home appliances and the benefits it could provide to their lifestyle.

The validation of the design proposal was conducted through one-to-one interviews with domestic consumers. Even though both the Smart Grid and electricity manage system diagrams received high scores for their clarity, the results were unfair because the researcher had given verbal explanations throughout each interview. Hence further research should test the comprehension of the representation diagrams without external influences.

4.6 Summary

Recognising the functions and purpose of Smart Grid technology could influence consumers' acceptance and for them to make knowledgeable decisions in future investments. In attempting to improve consumers' comprehend of the available Smart Grid technology, this chapter had set out to establish a suitable method of representing Smart Grid technology to residential consumers.

In fulfilling this aim, two objects were met. The first objective was to develop a representation method to map Smart Grid technology in homes. An evaluation of the six largest energy companies in the UK had identified seven electricity management systems on the market. Out of these, the two systems with the most comprehensive descriptions were chosen and visualised. A decision was made to focus on the visualisation of electricity management systems offered by energy companies rather than the smart metering system. This was because little information was available on smart metering systems in the UK and they were not available to consumers until 2014. In contrast, there was more information on the electricity management systems which were readily available in the market.

The second was to validate the design of the representation method with relevant stakeholders. The validation was performed in the form of an interview with domestic electricity consumers. Findings from previous studies had identified an obstacle that was hindering the acceptance of Smart Grid technology was found to be the lack of knowledge. Hence, the background of the Smart Grid Concept was also visualised and presented at the start of the interview. This ensured that each the participant had sound knowledge of the Smart Grid and, therefore, their judge on the visualisation diagrams was not affected by the lack of knowledge.

A total of 10 participants were interviewed in the validation process. As no previous research had delved into the depiction of Smart Grid systems, a number of open questions were used to explore consumers' perspectives. Closed questions were also used to position the level of Smart Grid knowledge and the clarity of the visual diagrams.

Although most people had heard about Smart Grid but actual knowledge of what it was largely varied. Two electricity management systems were presented to each participant. Option 1 was more basic and had less functions and option2 was more complex with addition functions. Surprisingly, all the people interviewed were open to installing one of the systems. Using the diagrams, the participants were able to identify benefits of using an electricity management system in them home and they were able to select the system that fitted with their lifestyle.

The visualisation diagrams were successful because high scores were received. However, only one representation method was tested and hence the results could not be compared. The feedback suggested that there were rooms for improvement. A number of concerns were raised, such as the value of the electricity system compared to cost savings and there were request for additional details for a number of features.

5 CONCLUSIONS

5.1 Introduction

This chapter will summarise the research study by presenting the key findings, contribution to knowledge, limitations and the conclusion.

5.2 Key Findings

Smart Grid is a loose term that is used to describe the changing technologies being developed and deployed to aid consumers manages their electricity consumption. In order to gain support of the home consumers so that they could be deployed and used successfully it is important for electricity companies to communicate appropriately with their consumers. This research has developed and validated a visualisation framework based on interviews with electricity consumers. Findings of this research are summarised as follows.

5.2.1 **Literature Review**

An initial literature review was conducted investigation what Smart Grid is, why it is needed and why it encompassed. The following findings were identified:

- **Reasons for Smart Grid:** There are a number of reasons why a Smart Grid is needed, including: an ageing electricity grid, considerable electricity losses in transmission, retiring power generators, rising electricity demand, and rising electricity prices.

- **Smart Grid definition:** There are different definitions of what Smart Grid is. An analysis of 12 Smart Grid definitions found the followings were covered: an overview of Smart Grid, new technologies, new services, new functions, and the benefits.

- **Stages of Smart Grid deployment:** The deployment of Smart Grid technology had been described in three stages, where each stage paves the foundation for the next.
- **Smart Grid technologies:** Five Smart Grid technologies were identified to be introduced to improve the current electricity grid, this includes: decentralised generation, two-way communication, storage devices, sensors and the smart home.

5.2.2 **Analysing Existing Smart Grid Representation**

In an attempt to investigate the representation of Smart Grid systems, visual diagrams of the Smart Grid were studied. Through the literature search a number of suitable Smart Grid diagrams were identified. These were analysed with communication features of a Smart Grid system. The diagrams showed different configuration of Smart Grid features and they were categorised into five groups. An archetype model representing how each group depicted the Smart Grid was developed. The characteristics were evaluated using five sets of system types. This had identified that Conceptual systems tend to be vague because it depicts ideas that may not exist. There was insufficient information on the diagrams to derive whether it is showing an idea or technologies that were in existence.

5.2.3 **Representation Method Development**

A representation method was developed. It is for visualising home Smart Grid technologies to inform domestic consumers of available options. The advantages of the representation method are as follows:

- Two diagrams (one showing the existing electricity grid and the other of the vision of Smart Grid) were developed in aid of explaining why consumers might want to install Smart Grid technologies in their home.

- A realistic illustration of the Smart Grid technologies and where they locate in a home were used. This would consumers to visualise how they would operate the Smart Grid technologies in a home environment.

- A key was provided to further inform consumers of functions of the different technologies. Similar technologies were labelled under the same term so they could be more easily understood.

- Data type and data flow were illustrated so that consumers could identified what type of information were collected and where they were sent. Colours were used to differentiate whether information were sent to or from the device.

5.2.4 **Validation of the Representation Method**

Through interviewing 10 UK consumers the representation method was validated and the following knowledge was obtained:

- An evaluation of the six largest energy companies in the UK found that there are seven electricity management systems on the market. The two systems with the most comprehensive descriptions were chosen and visualised using the representation method

- The visualisation diagrams were successful the participants were able to identify advantage and disadvantage of using an electricity management system in them home. In addition, participants were able to explain why the reasons behind for chosen one of the two options that were presented to them.

- The feedback from the participants suggested that there were rooms for improvement. A number of concerns were raised, such as the value of the electricity system compared to cost savings and there were request for additional details for a number of features.

5.3 Contribution

The main contribution to knowledge is the framework to depict Smart Grid systems for domestic homes. In detail, the following contributions are most relevant:

- **Smart Grid definitions:** Based on the existing Smart Grid definitions and the understanding of where we are in their development, the meaning of the 'Smart Grid' was refined and explained in detail.

- **Method to analyse Smart Grid systems:** A categorisation methodology to understand the components of a Smart Grid system in terms of communication features.

- **Understanding of consumers' perceptions:** Insight into consumers' perspectives of Smart Grid and the electricity management systems were obtained.

- **Framework to depict Smart Grid systems:** A representation method of electricity management systems had been formulated. This representation method had provided an approach in which Smart Grid technology for the home could be mapped and communicated to consumers.

5.4 Limitations

A number of limitations could be identified in the research:

- **The source of Smart Grid visualisations:** Due to time limitation of this research only one database was used for the literature search in Chapter 3. Future research could make use of additional research databases or websites to obtain a fuller picture of the Smart Grid development.

However, care should be taken in obtaining the visual diagrams in order to maintain the quality and rigor of the research.

- **The search for Smart Grid visualisations:** General search terms were used to gather a snapshot of the current Smart development. As no previous research in this topic was conducted, a decision was made against using more specified search terms. It was also difficult to identify there was a lack of standard definitions and terminology for Smart Grid Systems.

- **The analysis of Smart Grid visualisation:** Due to time limitation, only the communication layer of the Smart Grid was investigated. Future research could look at the other layers of the Smart Grid taxonomy to improve consumer's knowledge of the other aspects that is relevant to a Smart Grid system.

- **The end design:** There has been no prior analysis in the representation of Smart Grid systems. Hence it was not possible to compare and contrast the results regarding the design of the representation system with the work of others.

- **Validation population:** If the methodology was applied again, the interview should be applied to a bigger population, especially testing with older people (aged 65 plus). This would give more a richer and more accurate account of UK consumers' perspectives.

5.5 Conclusion

This research has developed a framework for depicting Smart Grid systems in the home. It was necessary to proposed suitable information to consumers so that they understand what the systems consisted of. It provides a visual representation of the system that non-technical experts, such as the ordinary consumers, could comprehend quickly and effortlessly. The results of the research can be summarised as follows:

- The current state of Smart Gird development had been analysed and incorporated into the design of the representation method.
- A representation method to guide how home Smart Grid technologies could be visually represented to communication their functions to domestic consumers.
- Through the validation of the representation method, initial insights into consumer’s opinion of the available Smart Grid technology and feedback on how the representation method could be improved.

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APPENDICES

Appendix A - Smart Grid Definitions

	Source	Definition
1	European Technology Platform for Electricity Networks of the Future(2012)	An electricity network that can intelligently integrate the behaviour and actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies.
2	Hertzog(2011)	The Smart Grid is a bi-directional electric and communications network that improves the reliability, security, and efficiency of the electric system for small- to large-scale generation, transmission, distribution, and storage. It includes software and hardware applications for dynamic, integrated, and interoperable optimisation of electric system operations, maintenance, and planning; distributed energy resources interconnection and integration; and feedback and controls at the consumer level.
3	U.S. Department of Energy(n.d.)	The Smart Grid is a developing network of transmission lines, equipment, controls and new technologies working together to respond immediately to our 21st Century demand for electricity.
4	IEEE(2012)	The Smart Grid has come to describe a next-generation electrical power system that is

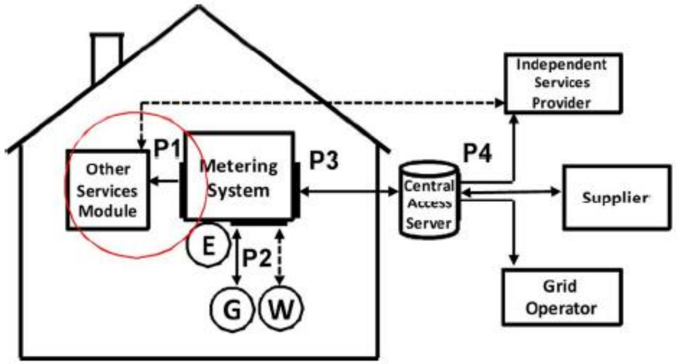
		typified by the increased use of communications and information technology in the generation, delivery and consumption of electrical energy.
5	Garrity(2008)	The Smart Grid entails a transformation to an information-enabled and highly interconnected network between electricity consumers and electric suppliers embracing transmission, distribution, and generation.
6	Hughes (2009)	The core foundation of the Smart Grid is an enabling infrastructure that allows today's need to be met as well as providing a foundation for future applications that our grandchildren will be able to build upon.
7	Polonestsky & Wolf(2009)	Smart Grid will make the nation's power transmission system more efficient, encourage renewable energy sources, and give consumers better control over their electricity usage and costs.
8	Marsan (2009)	Smart Grid is a multibillion dollar modernisation of the electricity grid that involves supporting real-time, two-way digital communications between electric utilities and their increasingly energy-conscious customers.
9	Hart(2008)	Smart Grid is a collection of next generation power delivery concepts that includes new power delivery components, control and monitoring throughout the power grid and

		more informed customer options.
10	Boyer & Mcbride (2009)	Smart Grid is a modern, improved, resilient, and reliable electric grid that provides for environmental stewardship, is secure, cost effective, and is a predominant driver to economic stability and/or development.
11	IESO (2009)	Smart Grid is a modern electric system. It uses sensors, monitoring, communications, automation and computers to improve the flexibility, security, reliability, efficiency, and safety of the electricity system.
12	Harris (2009)	Smart Grid is an infrastructure that puts the emphasis on active rather than passive control.

Appendix B - The Taxonomy of a Smart Grid

Layers	Defintion
Power	This layer consists of smart power generation, generation, conversion, transport, storage and consumption.
Communication	This layer ensures accurate and effective data transmission.
Control	This layer consists of smart sensors and actuators for data collection and conveyance, sensing and control.
Application	This layer supports decision intelligence with the aid of information technologies for various smart grid applications.
Security	This layer assures data confidentiality, integrity, authentication, availability and non-repudiation.

Appendix C - Results Table

	Diagram	Background	Description	Communication Features			
				Component	Data Flow	Data Channel	Data Type
1	 Source: Benzi et al., 2011	Benzi et al. (2011) found that, presently, smart meter interfaces are designed to support the utilities' supervisory role rather than supporting consumers' needs.	This diagram illustrates the standard smart metering solution proposed in The Netherlands. Port 1-4 represents the interfaces where data are exchanged.	X	X		

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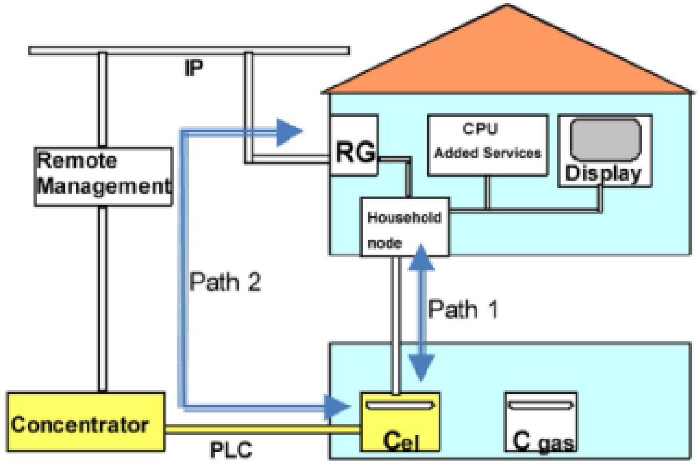
<td>2</td>
<td>

<table>
<tr><td colspan="2">Legenda</td></tr>
<tr><td>Cel</td><td>Electricity Counter</td></tr>
<tr><td>RG</td><td>Residential Gateway</td></tr>
<tr><td>CPU (Added services)</td><td>CPU based devices for added value services based on meter data</td></tr>
<tr><td>Cgas</td><td>Gas Counter or similar</td></tr>
<tr><td>PLC</td><td>Powerline</td></tr>
<tr><td>IP</td><td>Line TCP/IP – Web</td></tr>
</table>
Source: Benzi et al., 2011</td>
<td></td>
<td>This diagram illustrates two paths for data transmission between the consumer's home and the smart meter. From these two paths, four communication solutions were identified.</td>
<td>X</td>
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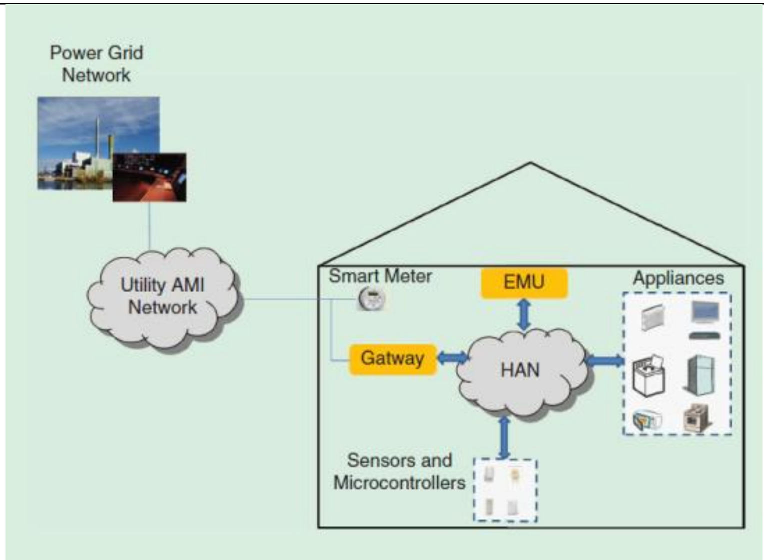
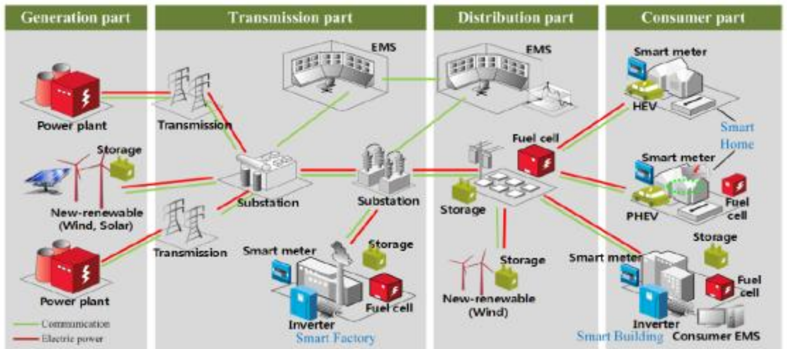
<tr><td>3</td><td>

Source: Bouhafs et al., 2012</td><td>In their article, Bouhafs et al. (2012) studied the communication challenges that must be fulfilled in order to realise the smart grid. Sub-systems making up the Smart Grid were analysed, this included distributed generation, AMI, home energy management system (HEMS) and PHEV technology.</td><td>This diagram shows the overview of a home energy management system (HEMS).</td><td>X</td><td>X</td><td></td><td></td></tr>
<tr><td>4</td><td>

Source: Byun et al., 2011</td><td>Byun et al. (2011) proposed the smart energy distribution and management system (SEDMS). This system forms dynamic patterns by monitoring a consumer’s power consumption,</td><td>In introducing the purpose of this system, this diagram was used to illustrate the overview of the Smart Grid concept.</td><td>X</td><td>X</td><td></td><td></td></tr>
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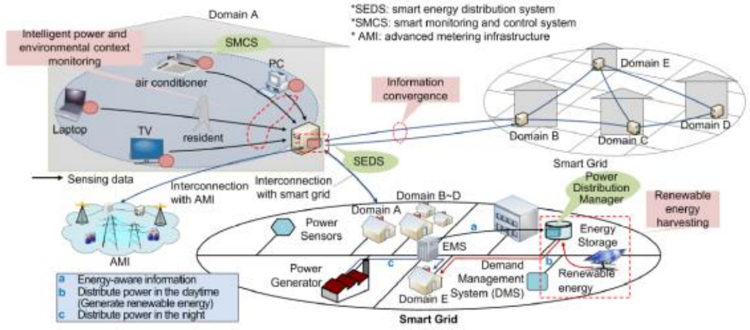
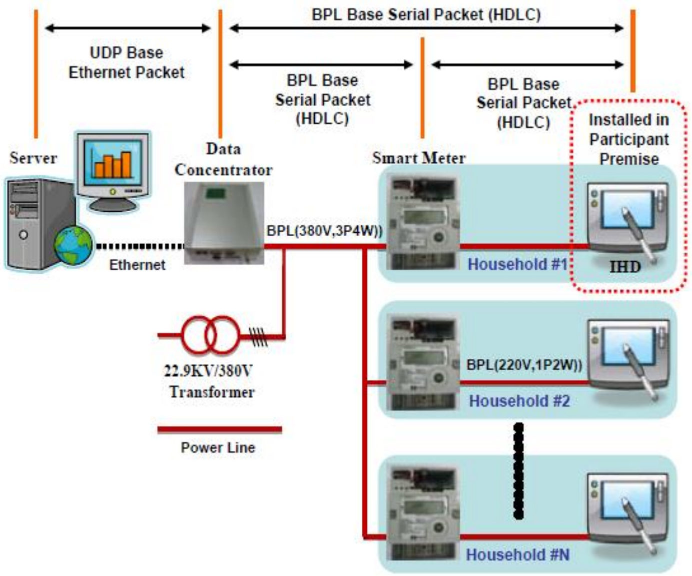
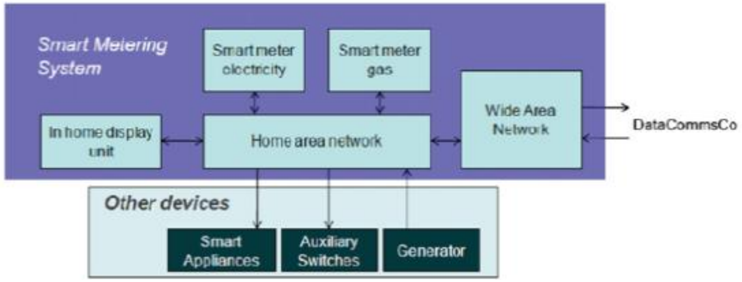
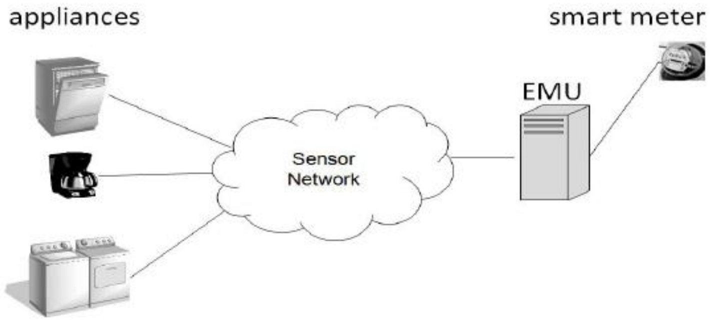
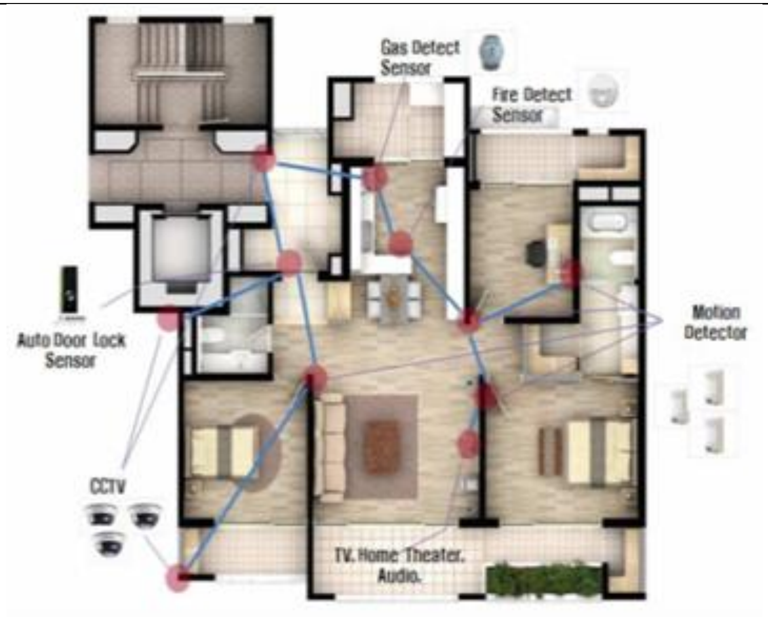
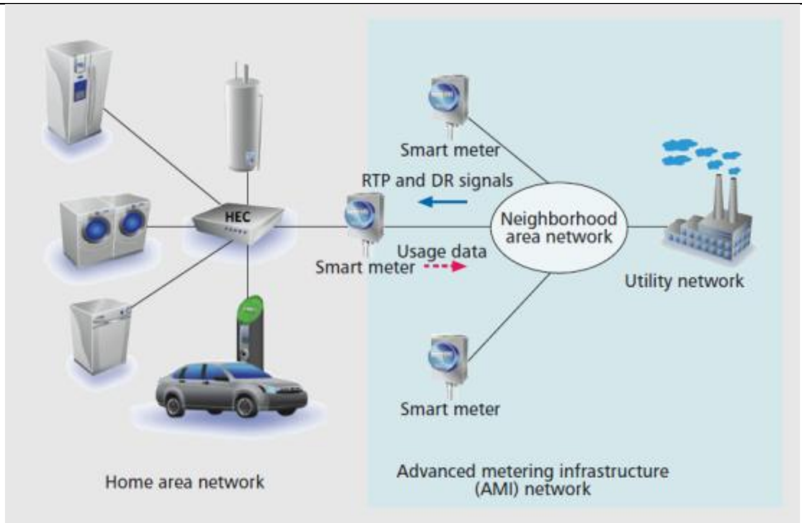
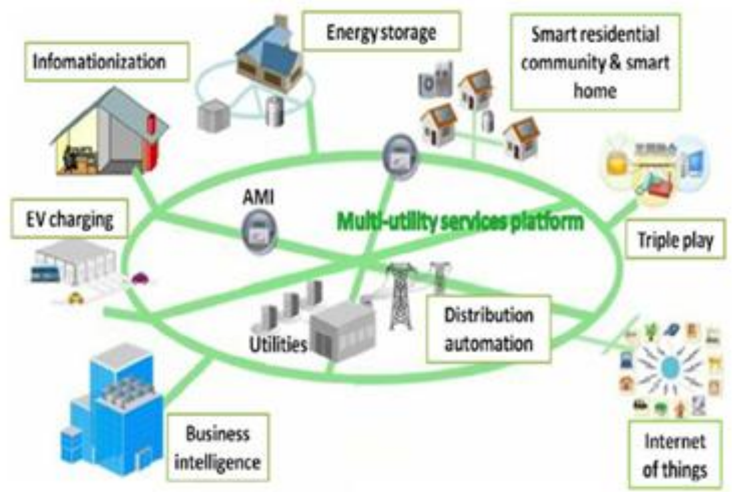
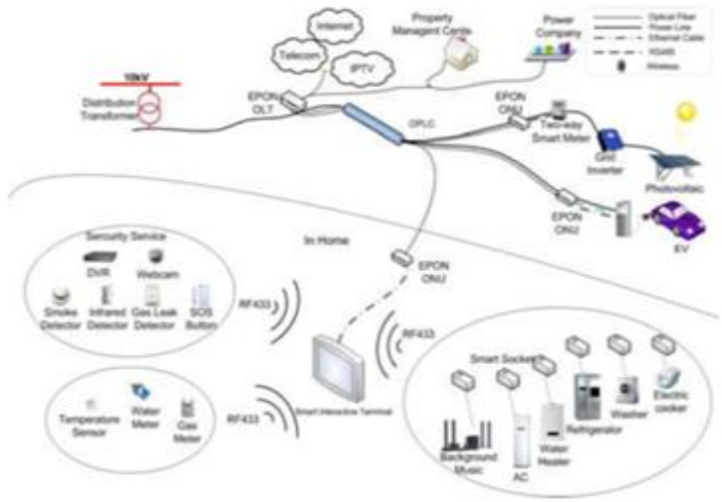
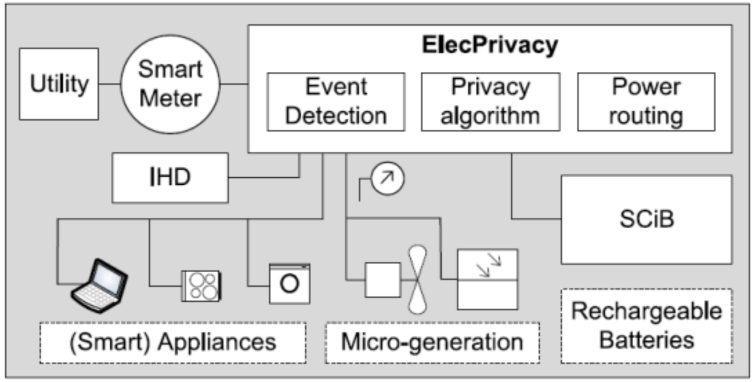
5	 Source: Byun et al., 2011	connected appliances and state of their surroundings to ensure efficient distribution and management of electricity.	This diagram illustrates the overview of the SEDMS. It consists of two components: smart energy distribution system (SEDS) and smart monitoring and control system (SMCS).	X	X		X
6	 Source: Choi et al., 2009	Choi et al. (2009) reviewed international residential smart metering system to guide the development of a smart metering system for Korean homes. A pilot test was conducted to between 12/2008 - 02/2009. The focus was on in home display (IHD) to demonstrate energy saving without	This diagram shows the schematic of the developed smart metering system. Each household has an information display, IHD and smart meter for periodical logging of information regarding power consumption.	X	X	X	

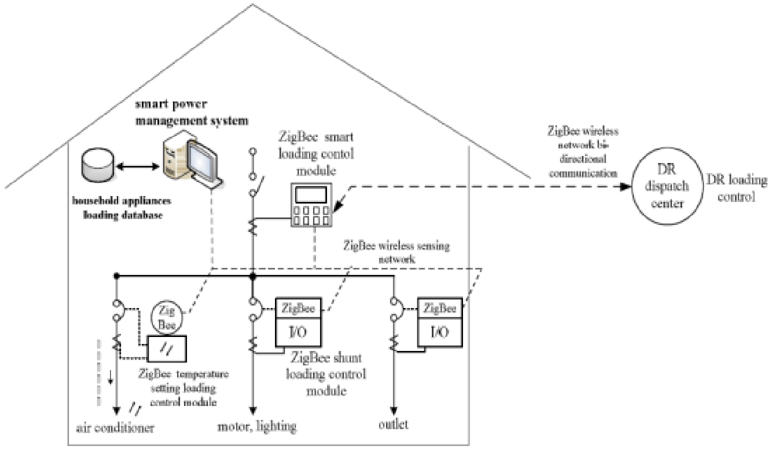
		changing electricity tariff or using management systems.					
7	 Source: Darby, 2011	Darby (2011) discussed the development of smart metering and how it may affect fuel poor households in the UK. This diagram was produced by DECC.	It visualises the function of the smart metering system in UK homes.	X	X		
8	 Source: Erol-Kantarci & Mouftah, 2010	Erol-Kantarci&Mouftah (2010) proposed the Appliance Coordination (ACORD) scheme. This scheme made use of Wireless Sensor Networks (WSN), which delivers consumers' requests from appliance controls to the Energy Management Unit (EMU). The EMU can control appliance start time to reduce consumption costs.	This diagram illustrates the architecture for the ACORD scheme.	X	X		

9	 Source: Frenzel, 2010	In the article, Frenzel (2010) discusses the importance of consumer buy-in for the success of Smart Grid.	This diagram was produced by Park Associates (a market research and consulting firm) to depict Smart Grid technologies that may be installed in future homes.	X			
10	 Source: Han & Lim, 2010	Han & Lim (2010) developed a lighting control system based on sensor networks. This system was tested in a testbed using ZigBee devices mimicking a smart home environment.	This diagram was used to illustrate a type of home area network that ZigBee technology can facilitate.	X	X	X	

11	 Source: Iwayemi et al., 2011	Iwayemi et al. (2011) discussed that in future, electricity may have real-time pricing. Scheduling a large number of appliances is complex. Without the necessary tool, consumers are unable to take advantage of this new tariff, but automation systems on trial still require human intervention. In order to lower the cost of electricity consumption and minimise inconvenience in scheduling appliances, Iwayemi et al. devised an automation system that utilise the optimal stopping-based solution.	This diagram illustrates their proposed system, which centered on the home energy controller (HEC).	X	X		X

12	 Source: Jianming et al., 2011	Jianming et al. (2011) discussed how optical fibre could be used to transmit both energy and information. They proposed the Multi-Utility Services Platform (MUSP), which made use of Power Fibre to the Home (PFTTH). Pilot projects were carried out to show that MUSP is capable of carrying energy and information.	This diagram shows an overview of the piloted system.	X	X		
13	 Source: Jianming et al., 2011		This diagram shows a more detailed version of the piloted system.	X	X	X	

14	 Source: Kalogridis et al., 2011	Smart meters can measure energy consumption and communicate this information with both the consumer and the utility. Depending on the frequency of data collection, the smart meter can potentially reveal household consumption habits as well as the state of occupancy. To protect consumers' privacy, Kalogridis et al. (2011) presented a smart metering privacy protection system that made use of batteries to hide household appliances.	This overview of this system is shown in the diagram.	X	X		

15	 Source: Kang et al., 2011	(Kang et al., 2011) developed an energy management system using ZigBee wireless detection network and distributed automation optical fibre. This system was for Taiwan household and low voltage commercial buildings. The system is capable of communicating with numerous consumers in order to determine the optimal control for each client.	This diagram illustrates the system developed by Kang (2011).	X	X	X	

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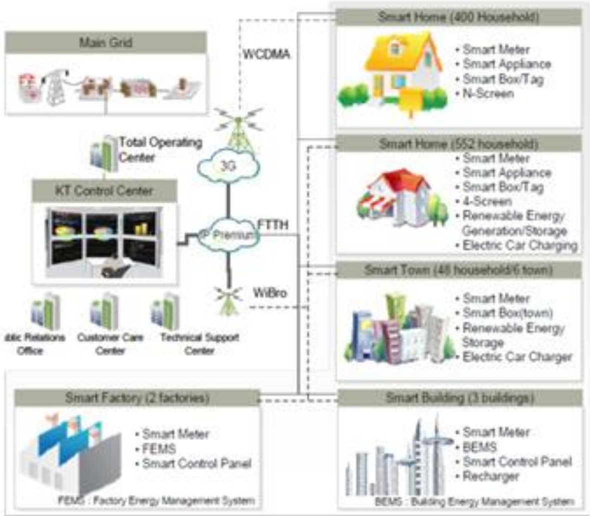
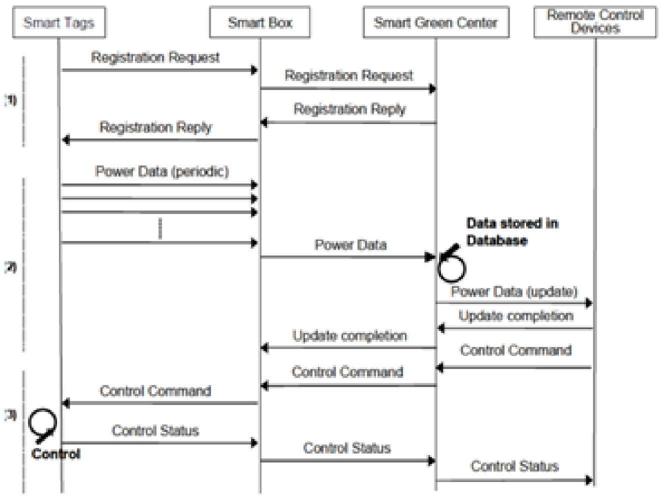
<tr><td>16</td><td>
Source: Lee et al., 2010</td><td rowspan="2">KT, a Korean telecom, aimed to provide Smart Grid service as one of its future energy businesses. Since December 2009, KT has been working in Jeju Island to build a Smart Grid infrastructure as a test bed. (Lee et al., 2010)introduced KT home energy management services, future Smart Grid business models, and presented on-going projects on Jeju island.</td><td>This diagram shows the overview of the Smart Place Energy Management project, which tested an energy management system with developing Smart Grid technologies.</td><td>X</td><td>X</td><td>X</td><td></td></tr>
<tr><td>17</td><td>
Source: Lee et al., 2010</td><td>This diagram illustrates the communication route and message send between the components of the smart green system (KT's home energy management service).</td><td>X</td><td>X</td><td></td><td>X</td></tr>
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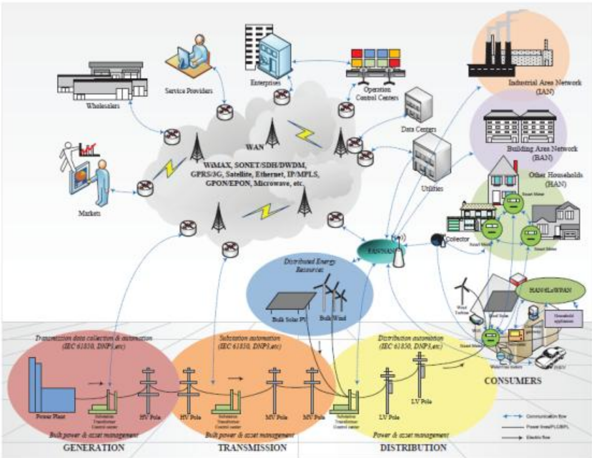
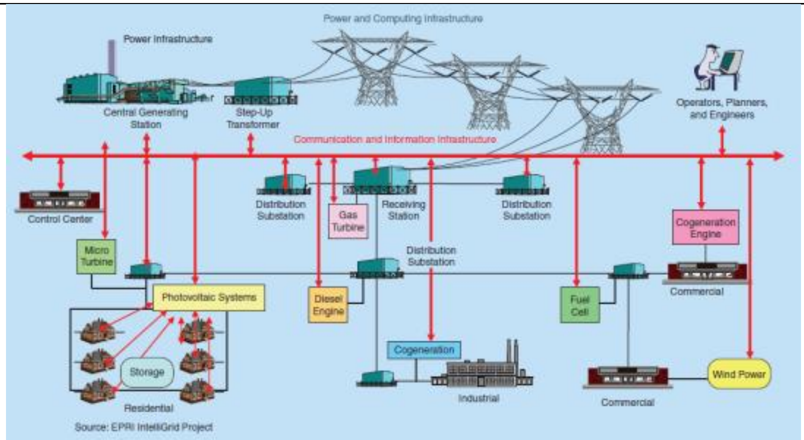
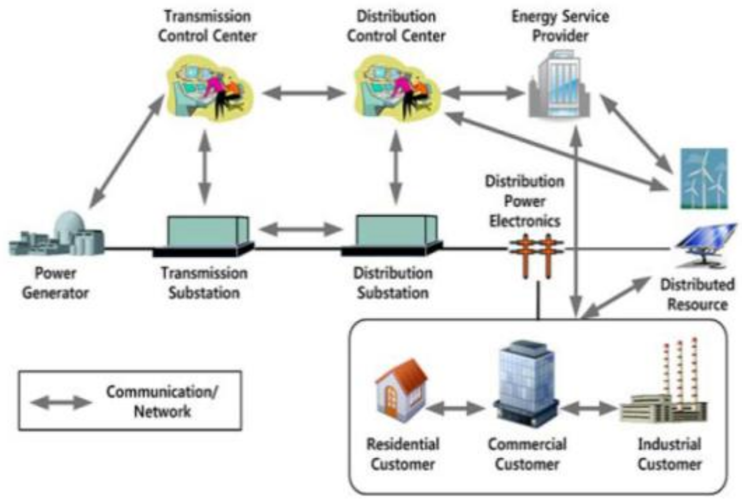
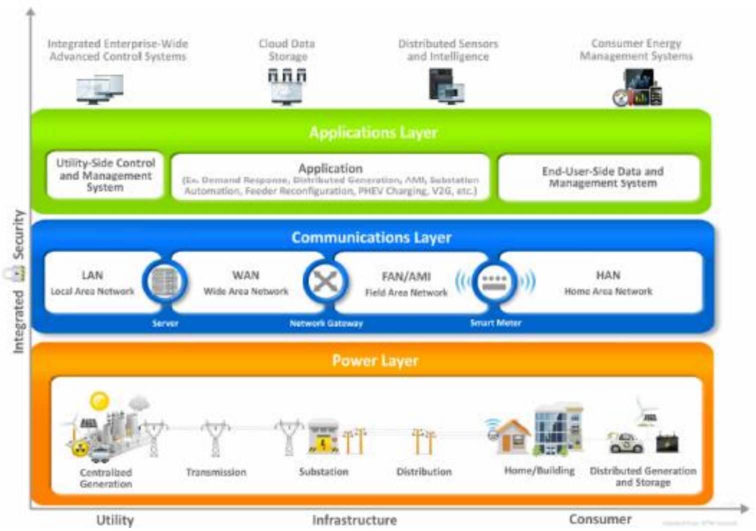
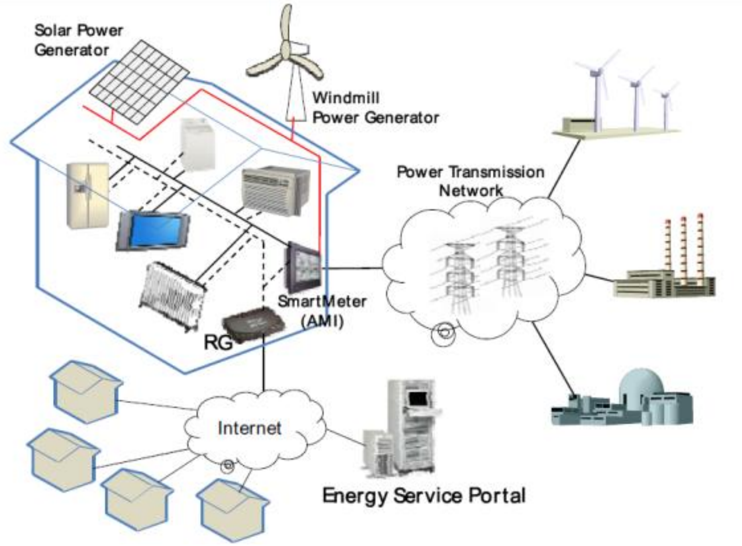
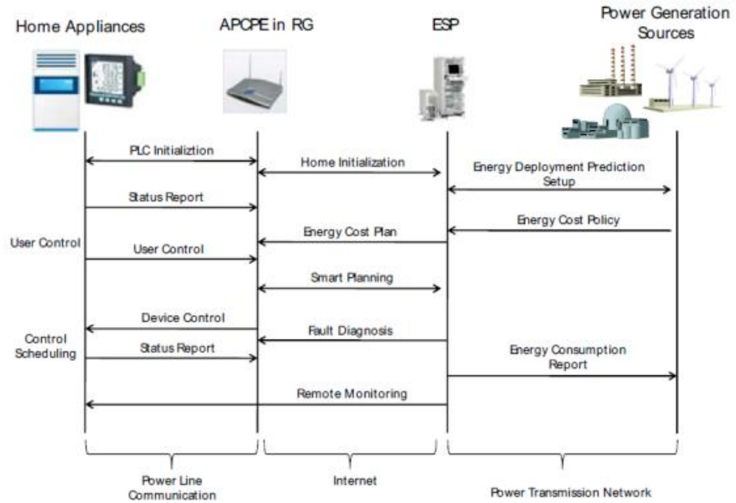
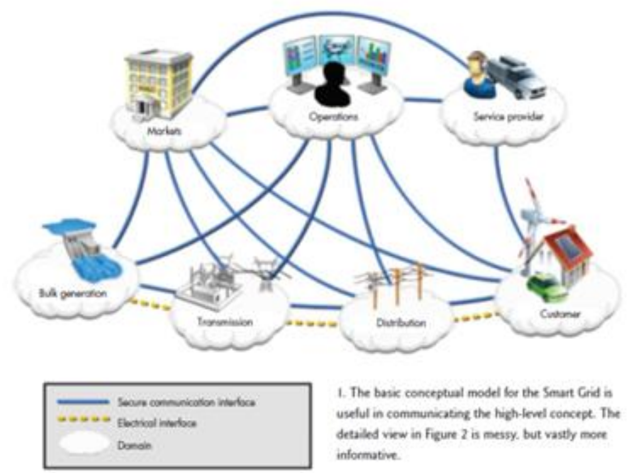
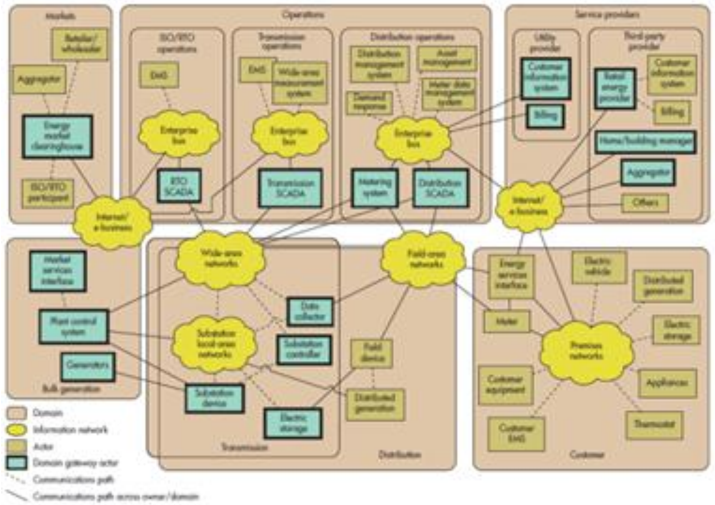
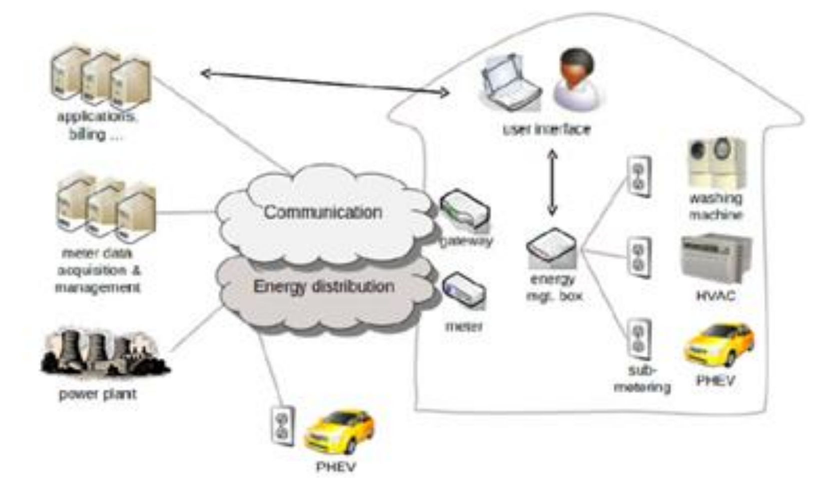
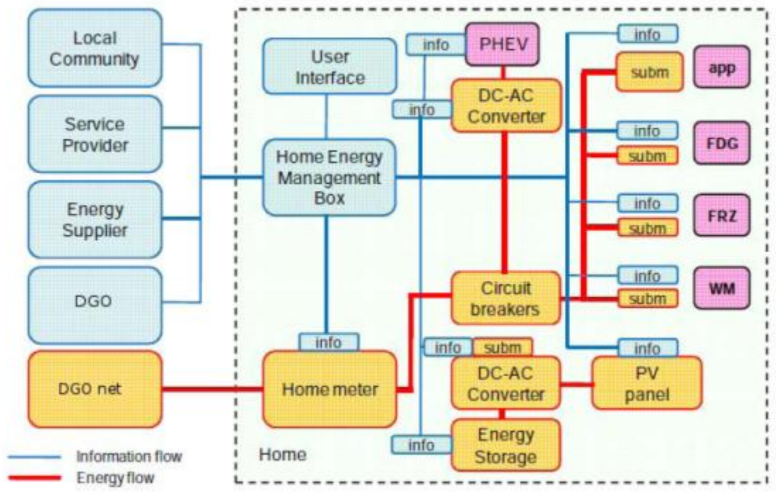
18	 Source: Lo & Ansari, 2011	Lo & Ansari (2011) discussed the different communication technologies available to build the Smart Grid and the challenges to implement them.	This diagram illustrates the overview of the components in the Smart Grid communication infrastructure.	X	X		
19	 Source: Morvaj et al., 2011	This diagram was adapted from Xcel Energy's vision of a smart house (Anon., 2009). Morvaj et al. (2011) investigated in demand response from a group of houses that is equipped with smart grid devices and energy generation capabilities. Simulations were used to experiment in a city context.	This diagram was usedto depict the type of Smart Grid technologies taken into consideration in Morvaj et al.'s simulation.	X			

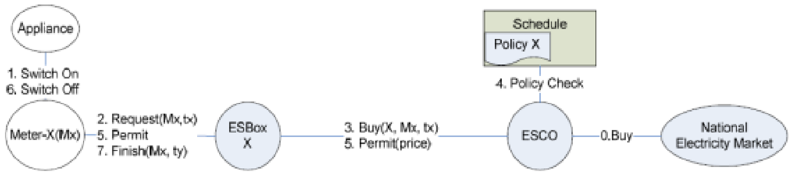
20	 Source: Paetz et al., 2011	As few people had seen or operated in an environment with a full range of Smart Grid technologies, Paetz et al. (2011) equipped a home with such technologies to demonstrate their features. Consumers' perceptions of this fully functional smart home were gathered.	This diagram shows in plan-view the layout of the Smart Grid equipment used in this experiment.	X			
21	 Source: Roy et al., 2011	In their article, Roy et al. (2011) discussed the network architecture and communication technology options described in current strategic plans to achieve a smarter power system.	This diagram shows an illustration of a communication infrastructure necessary for enabling the function of a Smart Grid.	X	X		

22	 Source: Sinha et al., 2011	Sinha et al. (2011) discussed the Smart Grid initiative in India, including issues such as the implementation methodology and identified the challenges and benefits.	This diagram illustrates an overview of the Smart Grid concept. This discusses how the Smart Grid can benefit an emerging economic country with growing GDP and energy demand.	X	X		
23	 Source: Slootweg et al., 2011	Slootweg et al. (2011) found that although there are different version of the Smart Grid concept, all current concepts describes the Smart Grid as the convergence of energy, telecom and IT sector.	In this diagram, Slootweg et al. illustrated the relevance of these sectors as three layers; power layer (energy), communication later (telecom), application layer (IT).	X			

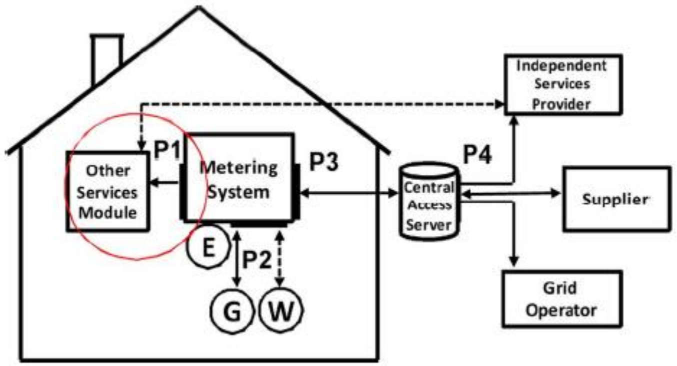
24	 Source: Son & Moon, 2010	Son & Moon (2010) developed and tested a home energy management system (HEMS) based on power line communication. This system makes use of the home network and the internet to manage home devices in order to optimise electricity usage.	This diagram illustrates the components included in Son & Moon's system.	X	X		
25	 Source: Son & Moon, 2010		This diagram show the type of data transferred between the components of the piloted system.	X	X	X	X

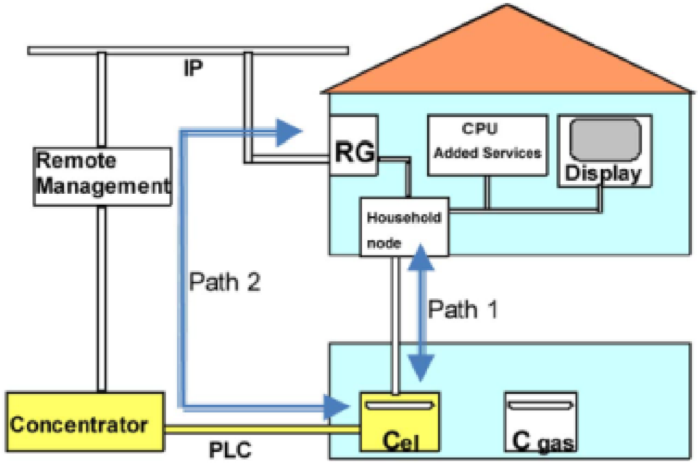
26	 Source: Tuite, 2010	Tuite (2010) discussed what a Smart Grid is. In using Smart Grid diagrams as tools to explain the overview of the concept,	Tuite (2010) found that basic conceptual models, such as the model shown in the diagram, are useful for communicating the high-level concept but they do not show the how the domains interacts.	X	X		
27	 Source: Tuite, 2010		Tuite (2010) found that conceptual Smart Grid models usually represent the Smart Grid in domains. Although this diagram illustrates the complexity of interactions between the domains, it could be hard to understand.	X	X		

28	 Source: Verschueren et al., 2010	Existing energy management systems only controls individual homes. To enable consumers to communicate with neighbouring consumers also with renewable generation and smart grid devices, Verschueren et al. (2010) designed a distributed energy management system that integrates with the electricity grid at both distribution and end-user levels.	This diagram illustrates the components within a Smart Grid concept.	X	X		
29	 Source: Verschueren et al., 2010		This diagram depicts the Smart Grid Service architecture designed by Verschueren et al. (2010).	X	X		

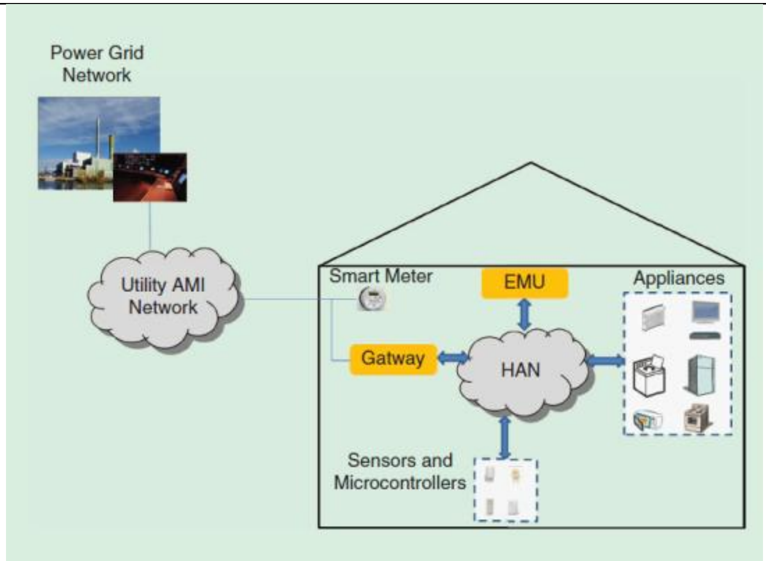
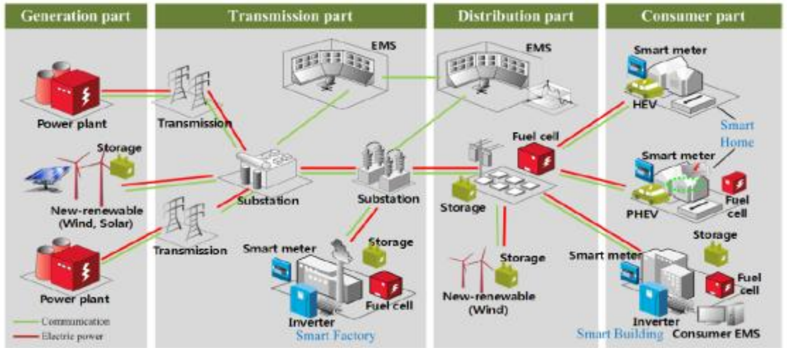
30	 Source: Wang et al., 2009	Wang et al. (2009) presented a three layered energy service model to optimise residential energy use. They designed an algorithm to balance overall electricity demands in time slots.	This diagram illustrates the control protocol in the system.	X	X		X

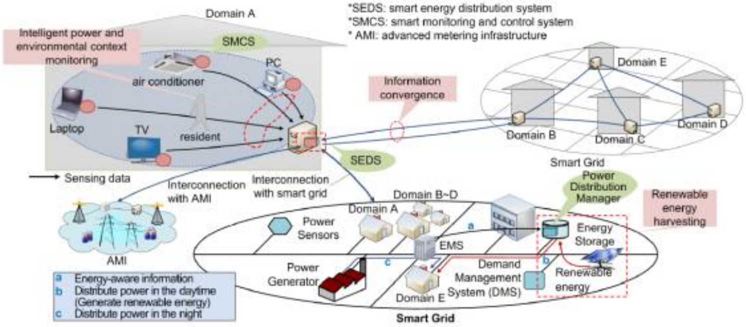
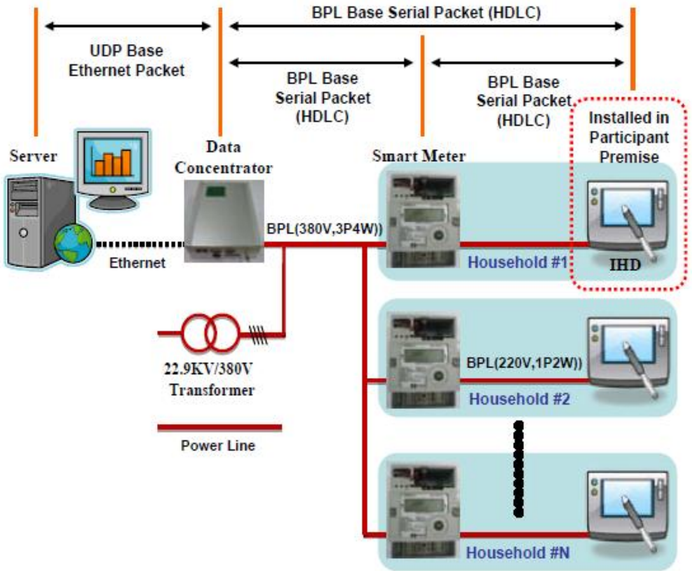
Appendix D - The Key Characteristics of Smart Grid Diagrams

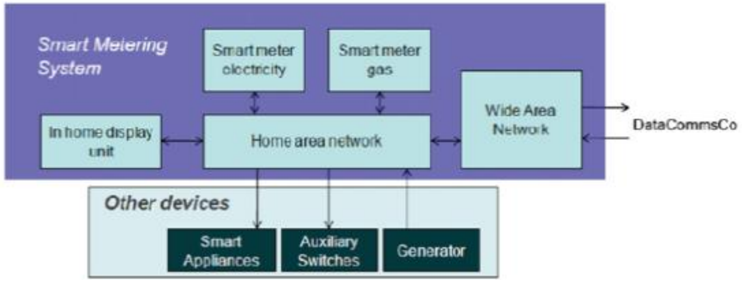
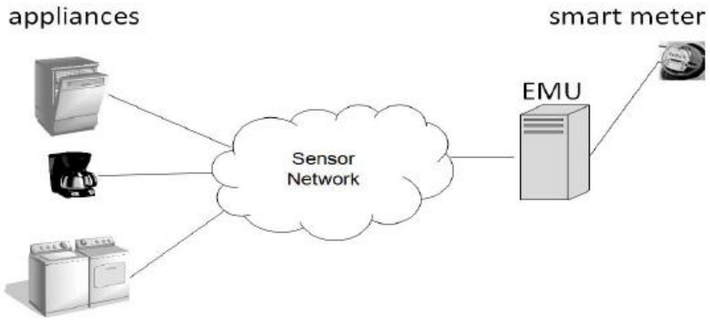
		1		2		3		4		5	
	Diagram	Physical	Conceptual	Open	Closed	Stochastic	Deterministic	Static	Dynamic	Continuous	Discrete
1	 Source: Benzi et al., 2011		X	X			X		X	X	

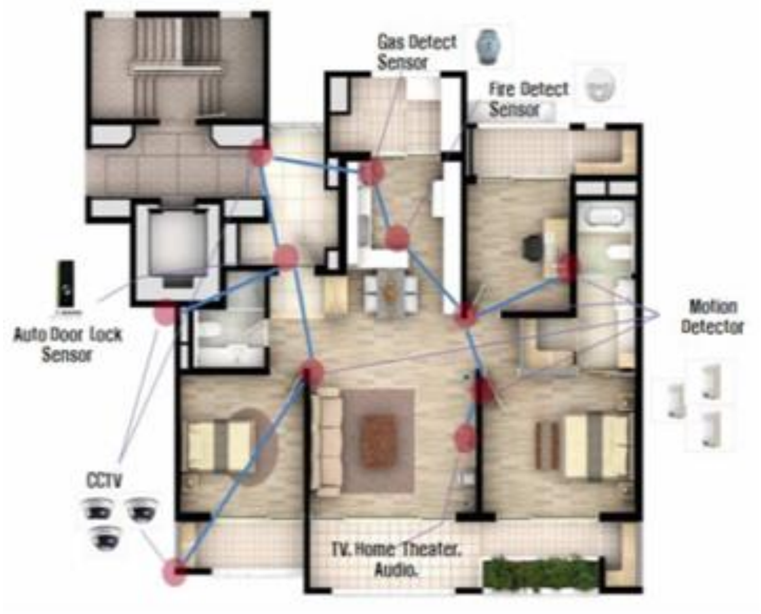
<table>
<tr>
<td>2</td>
<td>

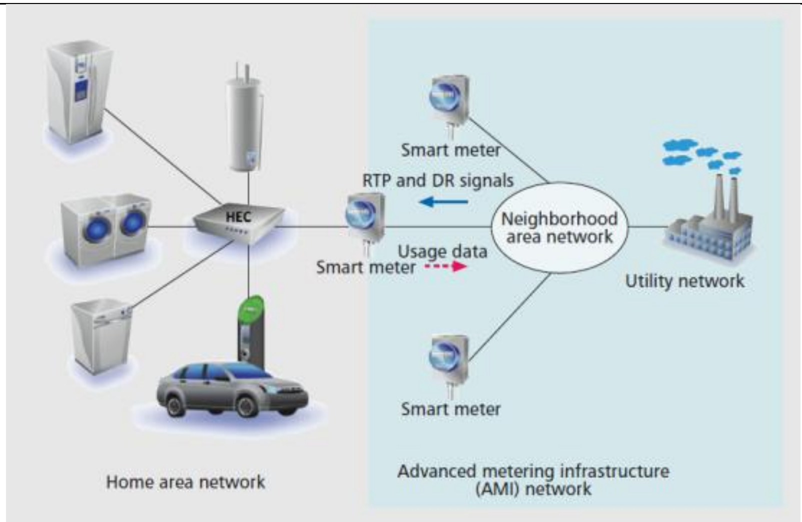
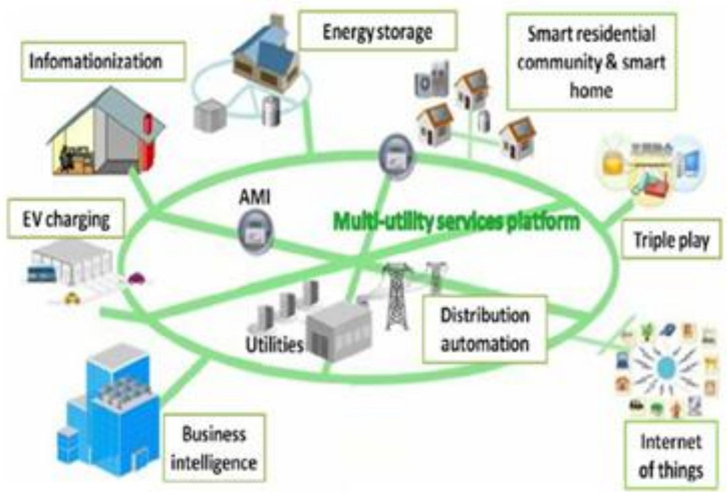
<table>
<tr><th colspan="2">Legenda</th></tr>
<tr><td>Cel</td><td>Electricity Counter</td></tr>
<tr><td>RG</td><td>Residential Gateway</td></tr>
<tr><td>CPU (Added services)</td><td>CPU based devices for added value services based on meter data</td></tr>
<tr><td>Cgas</td><td>Gas Counter or similar</td></tr>
<tr><td>PLC</td><td>Powerline</td></tr>
<tr><td>IP</td><td>Line TCP/IP – Web</td></tr>
</table>
Source: Benzi et al., 2011</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</table>

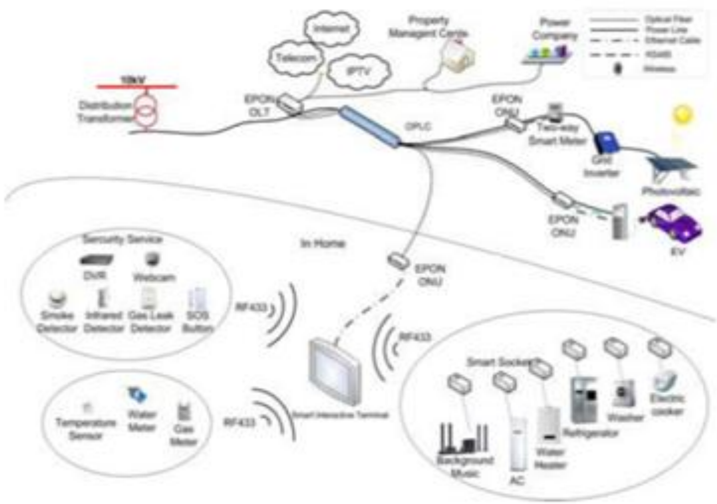
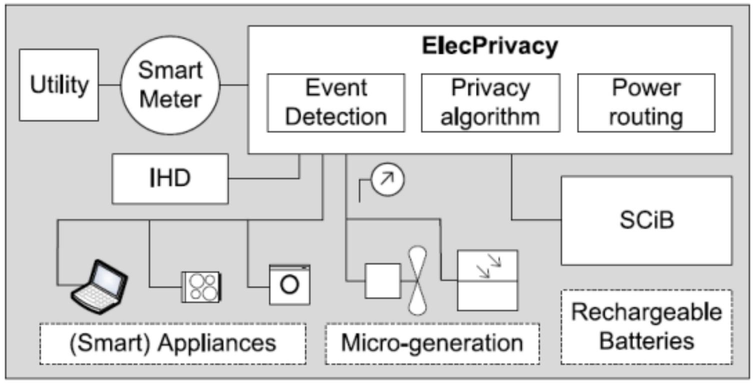
3	 Source: Bouhafs et al., 2012		X	X			X		X	X	
4	 Source: Byun et al., 2011		X	-	-	-	-	-	-	-	-

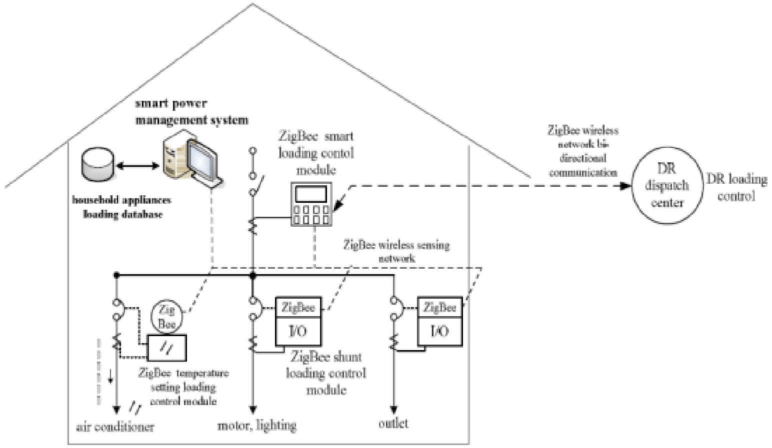
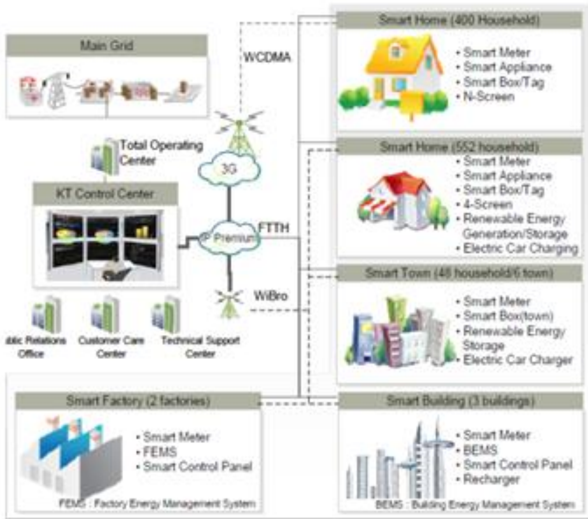
5	 Source: Byun et al., 2011	X		X			X		X	X	
6	 Source: Choi et al., 2009	X			X		X	X		-	-

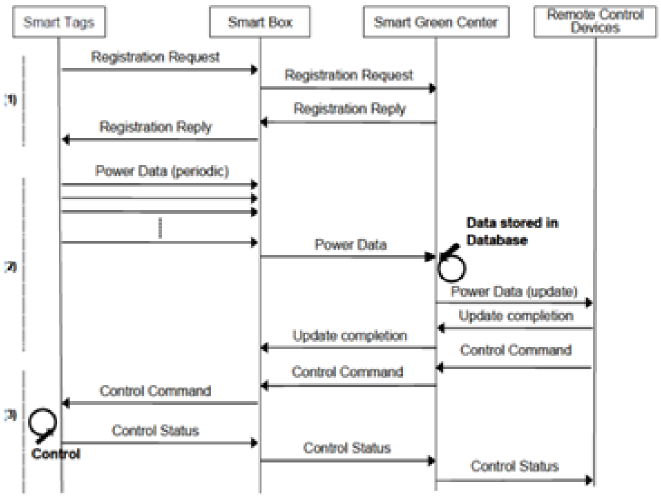
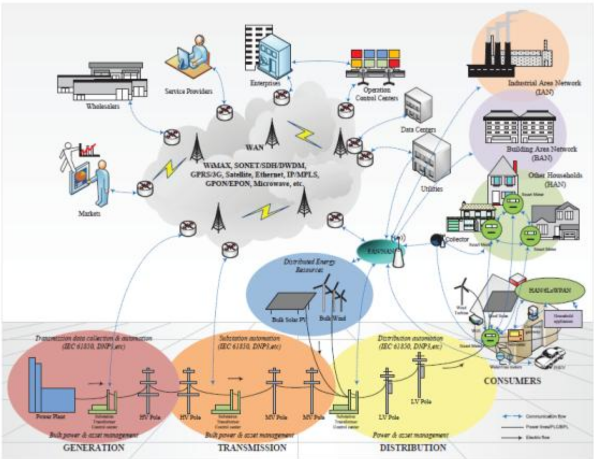
7	 Source: Darby, 2011		X	-	-	-	-	-	-	-	-
8	 Source: Erol-Kantarci & Mouftah, 2010	X		X			X		X	X	

9	 Source: Frenzel, 2010		X	-	-	-	-	-	-	-	-
10	 Source: Han & Lim, 2010		X		X		X	X		-	-

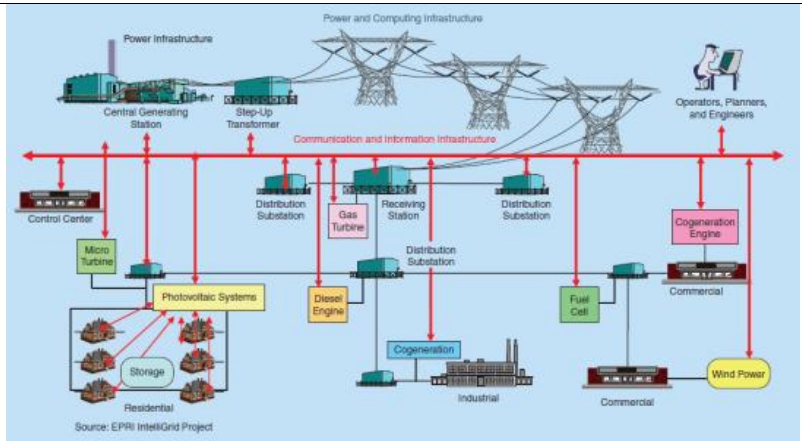
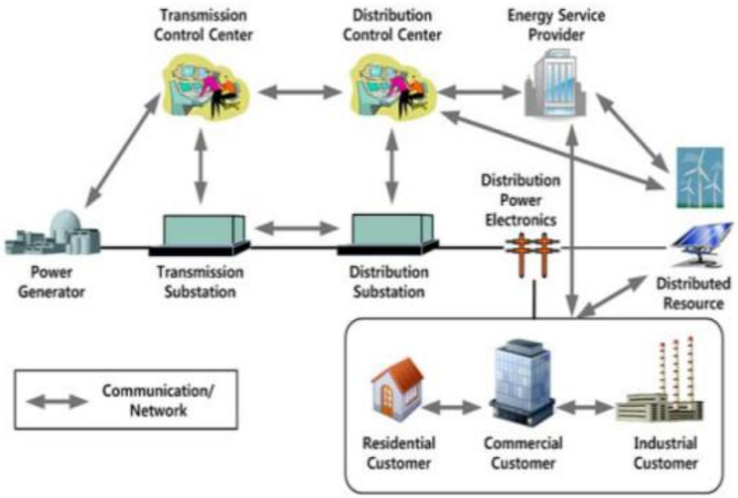
11	 Source: Iwayemi et al., 2011	X		X			X		X	X	
12	 Source: Jianming et al., 2011	X			X		X	X		-	-

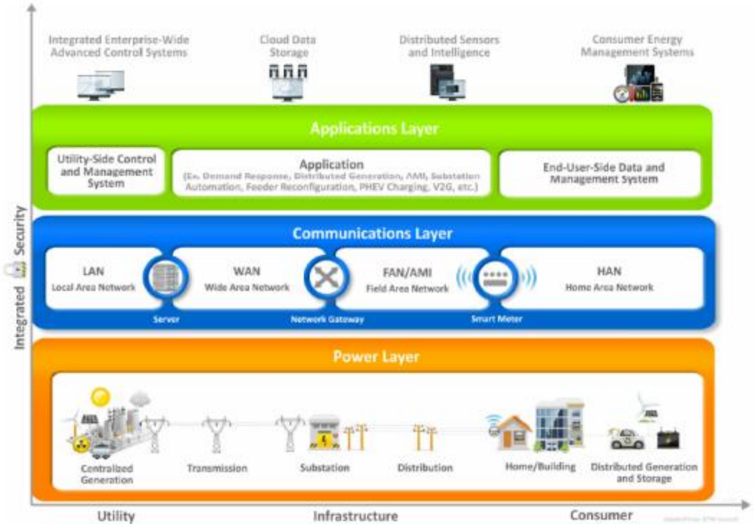
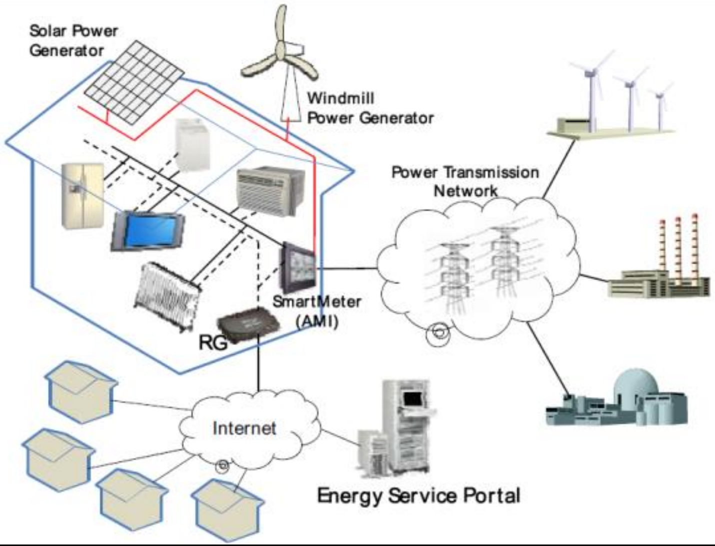
13	 Source: Jianming et al., 2011	X			X		X	X		-	-
14	 Source: Kalogridis et al., 2011	X			X		X		X	X	

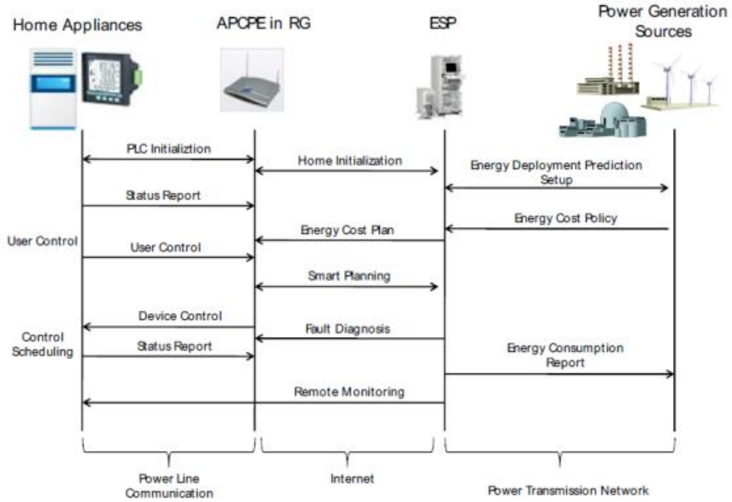
15	 Source: Kang et al., 2011	X		X			X		X	X	
16	 Source: Lee et al., 2010	X		-	-	-	-	-	-	-	-

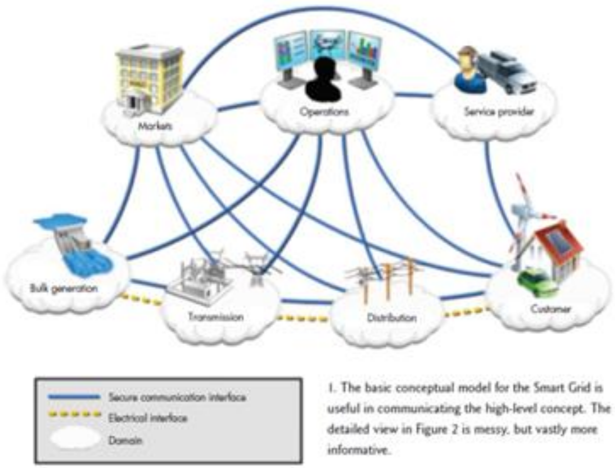
17	 Source: Lee et al., 2010	X		X			X		X	X	
18	 Source: Lo & Ansari, 2011		X	-	-	-	-	-	-	-	-

19	 Source: Morvaj et al., 2011		X	-	-	-	-	-	-	-	-
20	 Source: Paetz et al., 2011	X		X			X		X	X	

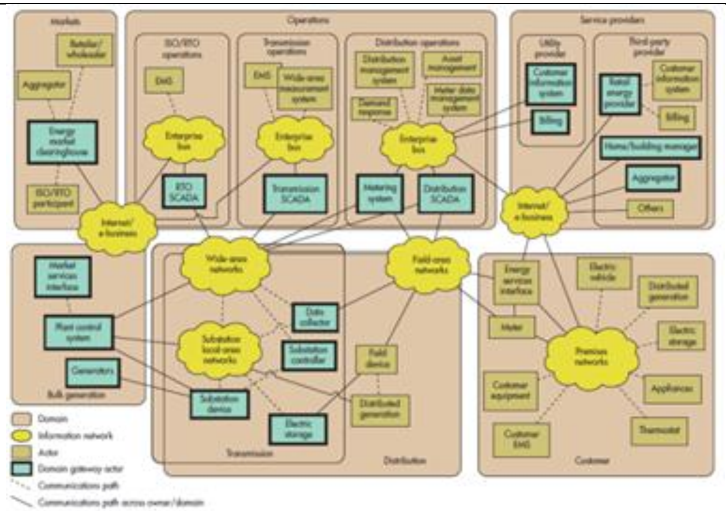
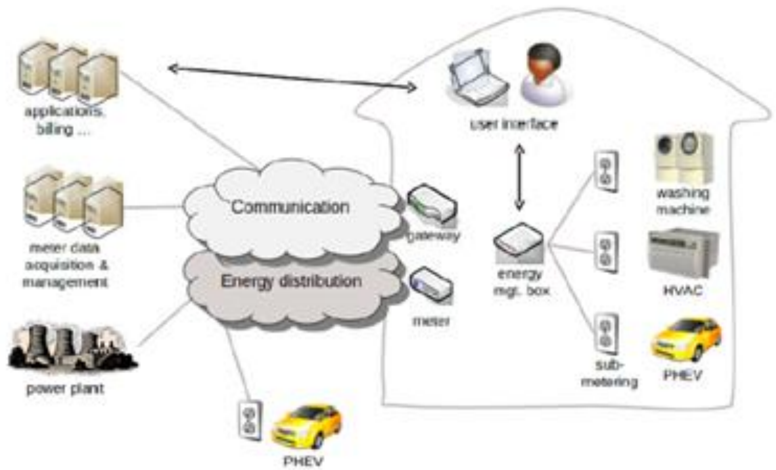
21	 Source: Roy et al., 2011		X	-	-	-	-	-	-	-	-
22	 Source: Sinha et al., 2011		X	-	-	-	-	-	-	-	-

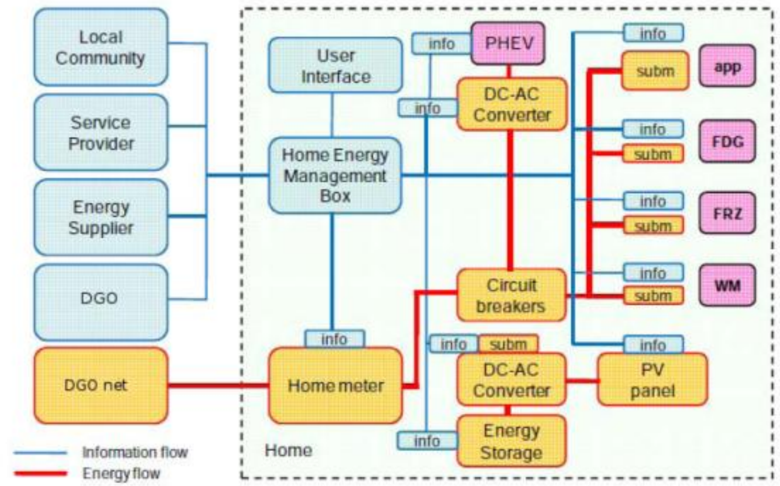
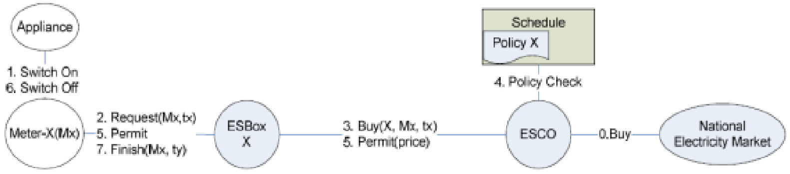
23	 Source: Slootweg et al., 2011		X	-	-	-	-	-	-	-	-
24		X		X			X		X	X	

<table>
<tr><td></td><td>Source: Son & Moon, 2010</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>25</td><td>

Source: Son & Moon, 2010</td><td>X</td><td></td><td>X</td><td></td><td></td><td>X</td><td></td><td>X</td><td>X</td><td></td></tr>
<tr><td>26</td><td>

Source: Tuite, 2010</td><td></td><td>X</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
</table>

27	 Source: Tuite, 2010		X	-	-	-	-	-	-	-	-
28	 Source: Verschueren et al., 2010		X	X			X		X	X	

29	 Source: Verschueren et al., 2010	X		X			X		X	X	
30	 Source: Wang et al., 2009	X		X			X		X	X	

Appendix E - Findings from Energy Companies' Website

E.1 - Smart Metering

Energy Company	Product	Cost	Description	Benefits
British Gas (British Gas, 2012b)	Smart Meter and In-Home Display	£0.00	• Smart Meter takes reading every half hour and sends data to the energy company every 24 hours. • In-Home Display provides information of household electricity consumption. • This system takes 90 minutes to install	• Meter readings are used to ensure the meter is working and to find faults quickly. • Presenting regular and accurate meter readings will allow consumers to make energy saving decisions. • Accurate bills. • No more meter readings
EDF (EDF, 2012)	Smart Meter and In-Home Display	n/a	• The Smart Meter Automatically sends consumption data to the energy company. • The In-Home Display presents information on past and present energy usage, the costs of usage and carbon dioxide emission.	• No more estimated bills. • Provide detailed information about energy usage to help consumer reduce their bills. • The On-Home Display can provide energy efficiency tips.
E.ON (E.ON, 2012)	Smart Meter and Smart Energy Display	n/a	• Automatic meter readings. • Installation takes 2 hours. • Smart meters use new technology and are not	• No more estimated bills. • Provide detailed information about energy usage to help consumer

			compatible with existing energy monitors.	reduce their bills. • New services and tariffs in the future. • Smart Energy Display has more functionality and more accurate than an energy monitor because it receives the latest information automatically from your Smart Meter.
Npower (Npower, 2012)	Smart Metering	n/a	• Smart Metering systems automatically send electricity usage electronically.	• Smart Metering will enable electricity readings to be taken at any time without the need for a visit from a meter reader. • Consumers will be able to compare their electricity consumption between different days.

E.2 - Energy Management Devices or Systems Available in the UK

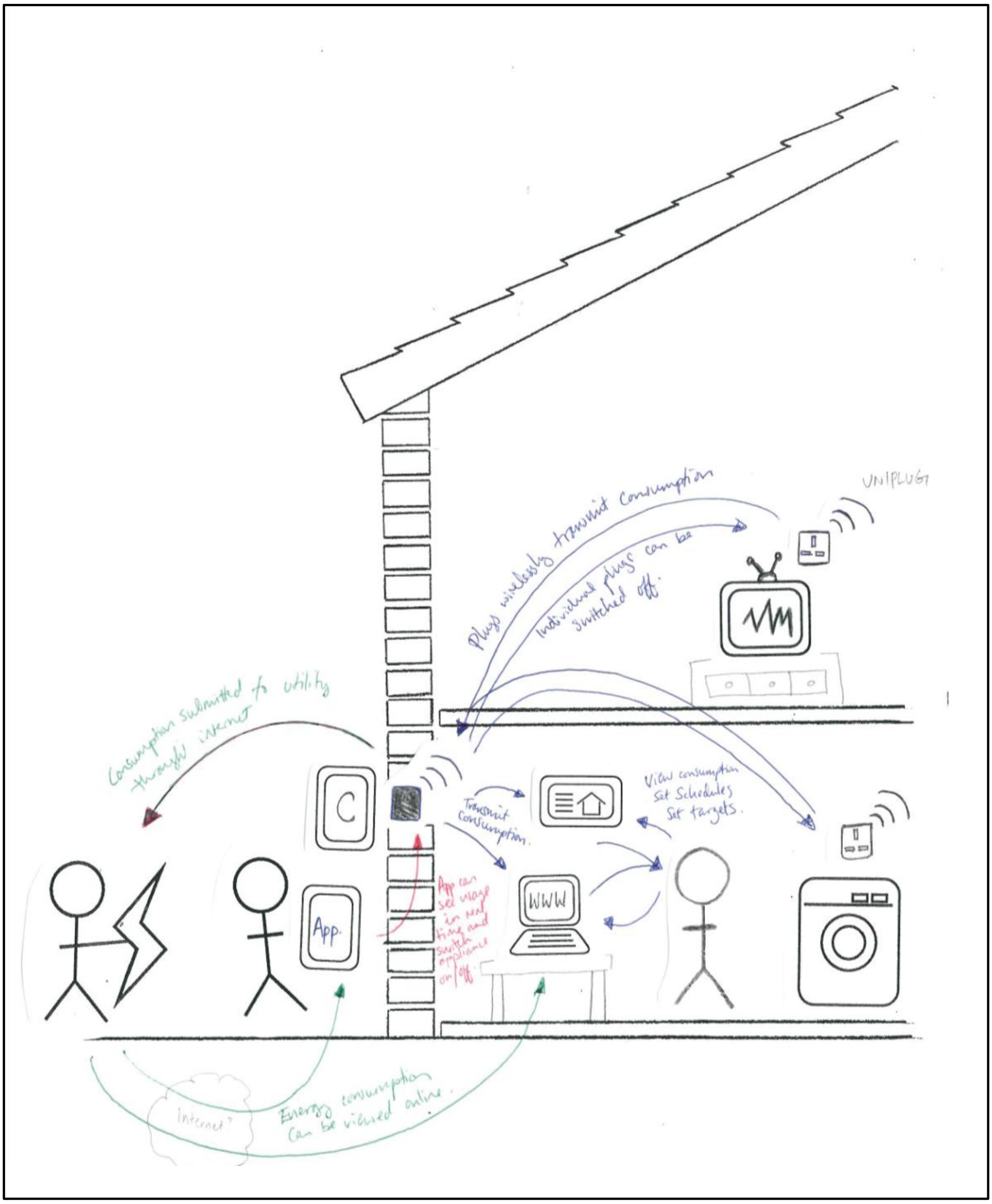
Energy Company	Product	Cost	Description
British Gas (British Gas, 2012a)	TREC Energy Monitor 	£29.99	• An electricity monitor that shows how much electricity is being used.
	Colour Energy Monitor 	£39.99	• An electricity monitor that shows how much electricity is being used and its costs in full colour.
EDF (EDF, 2012)	EcoManager 	£69.99	• This system consists of a display and 14 transmitter plugs. • The transmitter plugs with enable appliances connected to it to be monitored and switched on/off.
	EcoManger Whole House Transmitter	£14.99	• The transmitter provide the cost of running appliance that are “hard wired” rather than plugged in. • It connects directly to your meter and wirelessly links to EcoManager controller unit, transmitting the cost and total energy usage of all electrical devices from one

			central location.
SSE (SSE, n.d.)	Iplan 	n/a	• This system consists of a sensor (senses and transmits consumption data) and a display (provide electricity consumption information). • The display can sync consumption data onto a PC and submitted to the energy company online. • Energy reduction targets can be set on the display. • The display can provide energy saving tips.
E.ON (E.ON, n.d.)	Energy Saving Monitor 	£27.00	• The monitor shows electricity usage in real time (information is updated every 6 seconds). • The monitor can store up to 30 days of electricity consumption data.
Scottish Power (Scottish Power, 2012e)	UNIFI 	£124.99	• This system consists of a display (present electricity consumption data and control smart plugs), smart plugs (provide status of appliance connected to it), sensor and transmitter (measures and sends electricity consumption data), bridge (connecting all the devices) and a mobile app (view electricity usage and to control smart plugs).

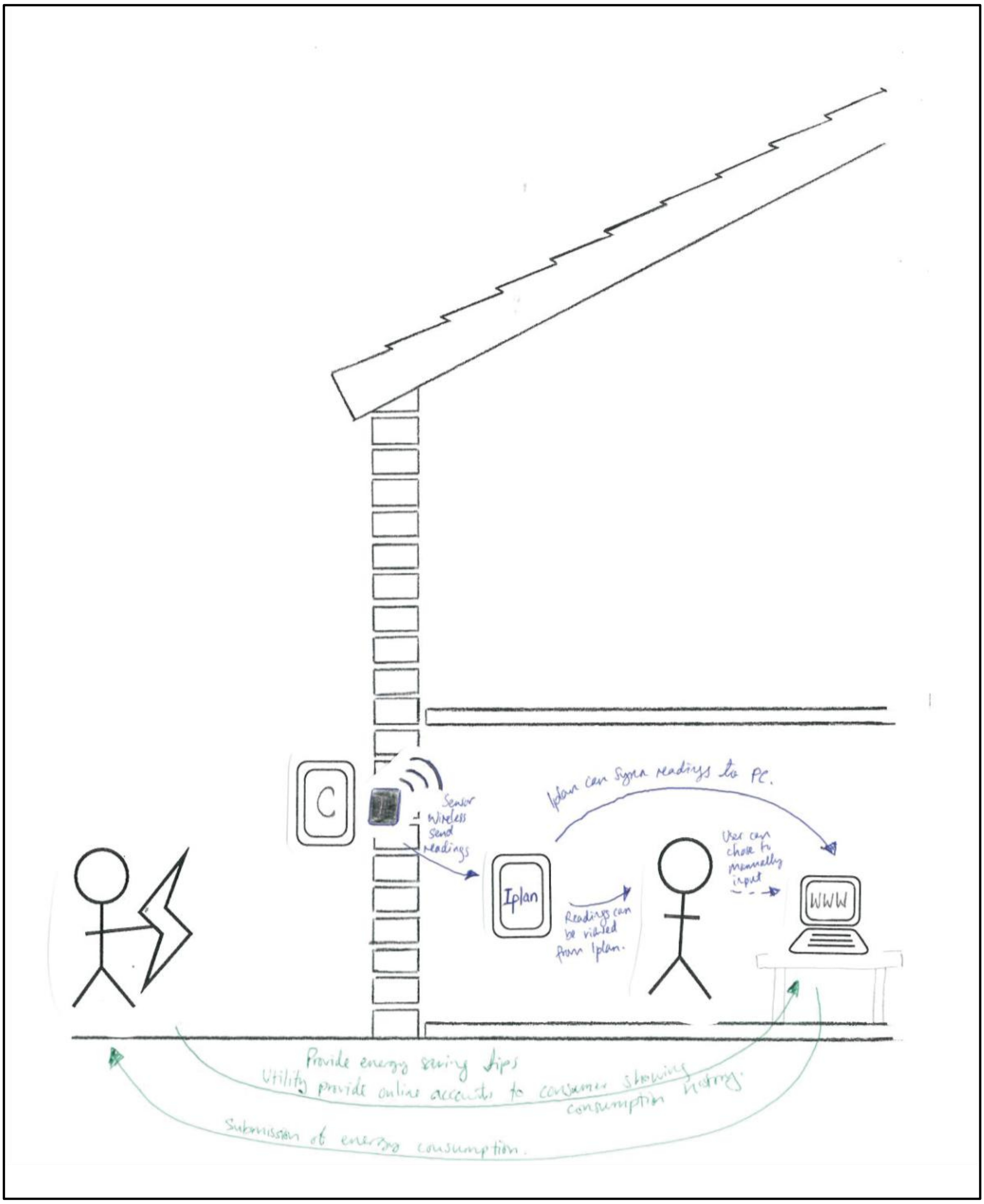
E.3 - Electricity Management System Option

E.3.1 - Scottish Power, UNIFI

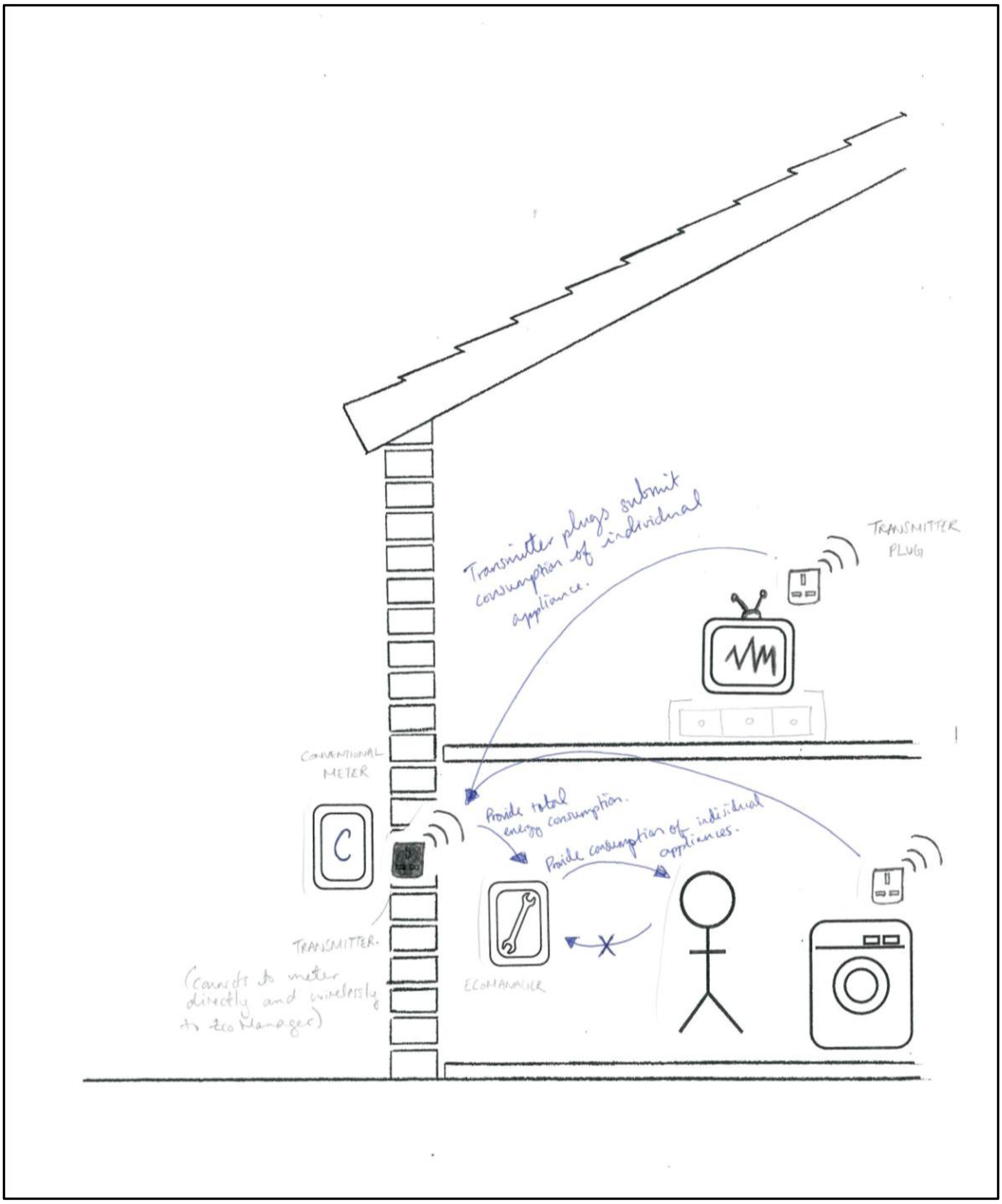
There were several videos submitted my Scottish Power on the internet which explained how their energy management system was used (Scottish Power, 2012a, 2012d, 2012b, 2012c).



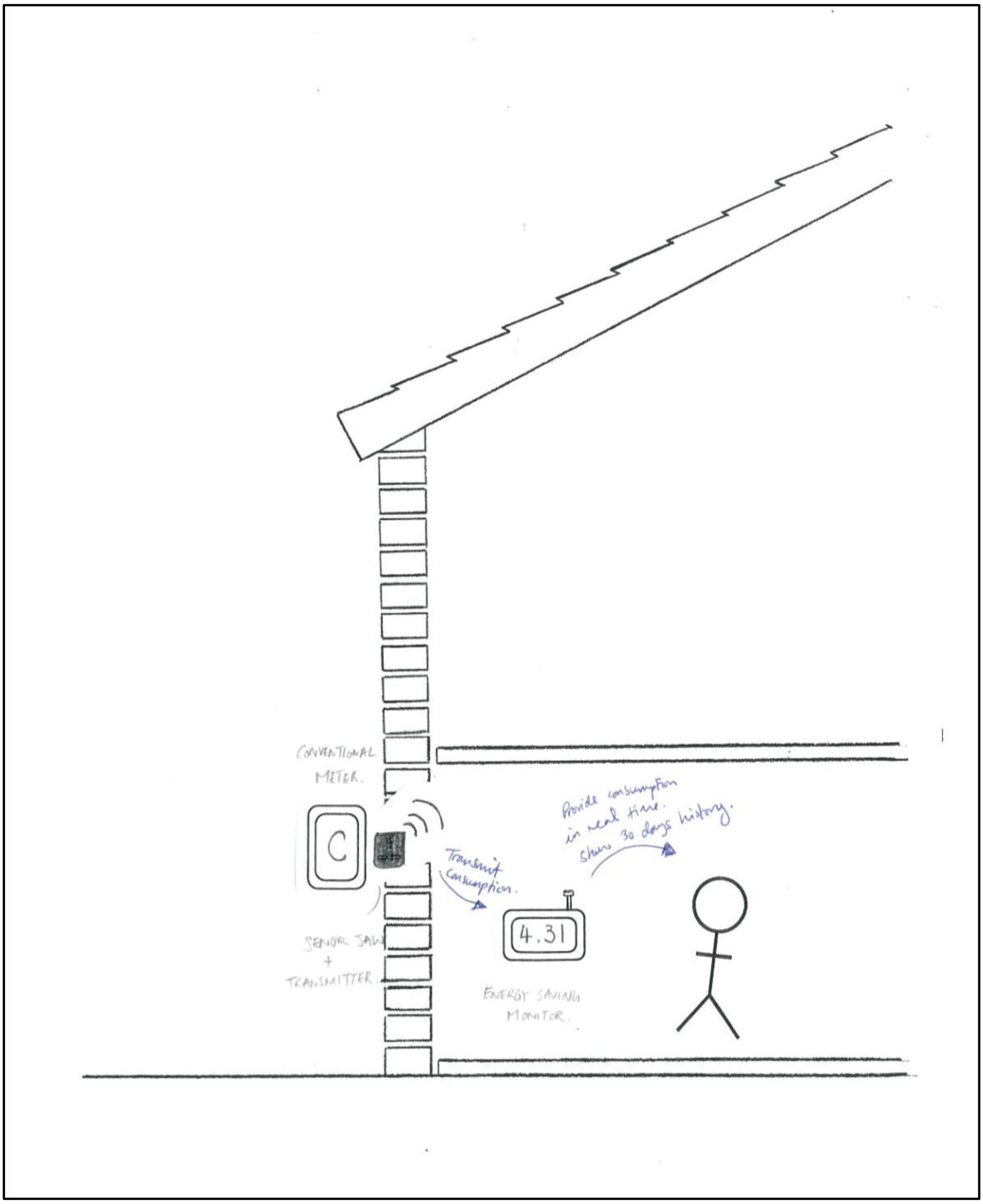
E.3.2 - E.ON, Iplan



E.3.3 - EDF, EcoManger



E.3.4 - E.ON, Energy Saving Monitor



Appendix F - Interview Questions

An Investigation in Consumer Opinions of the Electricity Grid Development

This interview is designed to find out residential electricity consumer opinions on new development of the electricity grid. It would take about 10-20 minutes of your time. The results would be kept anonymous and original records would be destroyed at the end of the project.

Name:

Age: 18-24 25-34 35-44 45-54 55-64 65+

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1. **Smart Grid Concept**
    a. Have you heard of the term ‘Smart Grid’ or ‘Intelligent Grid’ before?
    b. Do you find anything familiar to you in the description of Smart Grid?
    c. In percentage, how much information is new to you?
    d. Do you have any question regarding Smart Grid, or is there anything in the diagram that is unclear to you?
    e. Do you find the diagram helpful and have you any suggestions for improvement?
    f. How many marks out of 10 would you give for clarity?

2. **Home Electricity Management Systems**
    a. Have you heard of any of these technologies before?
    b. Do you have any of such technologies installed in your home?
    c. Can you see any benefits in installing either option? Which would you install?
    d. How clear are the diagrams to you and what can be improved?
    e. How many marks out of 10 would you give for clarity?

Appendix G - Interview Results

G.1 - Background

Interviewee	Male / Female	Age					
		18-24	25-34	35-44	45-54	55-64	65+
1	F			X			
2	F		X				
3	M		X				
4	M		X				
5	M		X				
6	M				X		
7	F					X	
8	M		X				
9	M			X			
10	F	X					

G.2 - Part 1: The Smart Grid Concept

	Question					
	a) Have you heard of the term 'Smart Grid' or 'Intelligent Grid' before?	b) Do you find anything familiar to you in the description of Smart Grid?	c) In percentage, how much information is new to you?	d) Do you have any question regarding Smart Grid, or is there anything in the diagram that is unclear to you?	e) Do you find the diagram helpful and have you any suggestions for improvement?	f) How many marks out of 10 would you give for clarity?
1	Yes.	I do not know about how much electricity is lost in transmission or the sharp increase in costs.	40%	Information on Home Management System is unclear. I would like to know more details of how it works.	I would like to have more detail on renewable generation so I could made decisions on future investments. I would also like to know when the problems will occur so that I am prepared.	8
2	Yes.	Everything about the Smart Grid is new to me. I only know about the conventional grid.	100%	I need clarity on how Electricity Trading works. Regarding decentralised generation, if electricity is generated close to residential homes, would it not also bring pollutions closer to our homes?	-	9

3	No	I do not know about two-way communication, energy trading or storage devices.	50%	-	-	8
4	Yes.	All the ideas of the Smart Grid are new to me.	100%	I have an electricity meter at home. If I wanted to, I can calculate my energy consumption using the figures shown on the meter. How is this different in the Smart Grid? If you build smaller generators closer to the home would not there be air pollution? How do you transmit electricity from large generators to storage? Would you need to build new infrastructure to support this?	-	9
5	Yes.	I have not heard of energy trading, decentralised generation and the smart meter. Storing electricity in	65%	Will there be any improvement for the transmission towers and cables? How would electricity be	What is ‘ageing infrastructure’ referring to, just the transmission tower?	8.5

		electric cars is also new.		generated in decentralised generation, because I am concern about the pollution it could generate closer to the home. Nuclear power cannot be used because it would be dangerous. Do they need some special equipment to enable energy trading? How do they send electricity back to the utility?		
6	Yes.	I knew it was possible to feed electricity back into the grid, but not so familiar with the possibility of storage.	50%	I think it is good that home owners can produce electricity using natural resources, closer to where it is needed. However, how much electricity can consumers produce at home? I think there will be enough electricity generated to power anything other than smaller appliances. If we are to trade electricity, can someone that uses a lot of electricity affect or disturb	I think how the two-way communication works could be made clear. Perhaps there should be an addition image showing who are we are communicating with. The transmission part is not very special, there should be more focus at the home management end. You should explain how the solar panel work, what other options are there to generate electricity.	9

				neighbouring houses?		
7	Yes.	I have heard a little of each idea before, just not in so much detail.	25%	With decentralised generation, if electricity is generated closer to the home, would there be more transmission towers built near the houses too? If so, cannot more people just install solar panels so that we do not need smaller generators?	-	8
8	Yes.	I have heard about all these concepts before.	0%	From what I know, electricity storage can only store electricity for a short time and holds a negligible amount. Unless there is a way of storing large volume of electricity, I believe the concept of storing is pointless.	The illustration of energy trading can be made clearer. You could show how electricity can be produced in homes (such as using solar panels or a wind turbine). Also, use different colours to show that electricity is transmitted to and from the home. Perhaps you can change the scale of the illustration. I do not know about transmission technology so the illustration on that part does not mean much to me. It is not relevant in the	8

					Smart Grid explanation.	
9	Yes.	I know that Spain have used decentralised generation technologies for a long time. The only novelty about the Smart Grid, for me, is enabling two-way communication between the consumer and the electricity supplier.	20%	-	The diagram is showing the Smart Grid at top-level with basic elements. To improve, you can go into more details. For example, show what kind of devices is used in transmission. Explain how electricity is shared and any safety issues involved.	8
10	Yes.	All the ideas are familiar to me. The least I knew about was decentralised generation.	10%	-	You should label the descriptions as ‘The Features of Smart Grid’, so it is clear for people looking at it.	9

G.3 - Part 2: Energy Management Systems

	Questions				
	a) Have you heard of any of these technologies before?	b) Do you have any of such technologies installed in your home?	c) Can you see any benefits in installing either option? Which would you install?	d) How clear are the diagrams to you and what can be improved?	e) How many marks out of 10 would you give for clarity?
1	Yes. The only device I have not seen before is the connection device.	I have a display, 2 smart plugs and, a sensor and transmitter that connects to the electricity meter.	I would install option 2 because it connects automatically to the internet, sending the necessary information. With the smart plugs I can make sure I switched off all the appliances at night to save money. It is useful for people who want to be more aware of their electricity consumption. I have moved house recently, if I had this system, I would have been able to compare the electricity costs of the two houses.	I think you should illustrate what types of information are provided on the display.	8
2	No.	No.	I would choose option 2 because it has remote control. At home, I	I think you should indicate where it begins. When I look at	8

			have a timer that turns my washing machine on, but for people without this device the remote control could be useful.	the diagram, I do not know where to start.	
3	I have heard of a device that when you plug it in, it tells you how much electricity you have consumed.	No.	I prefer option 2 because you can control all the appliances in the house. As the Smart Plug allows you to monitor individual appliances, you can choose which appliance you want to switch off when the bills are getting too high.	-	8
4	I saw on a television advertisement that there are technologies that allow you to turn on your central heating before you get home.	No.	Option 2 is more convenient and has remote control function. I can use it to check if all my appliances are turned off when I am away from home.	-	10
5	No.	No.	Option 2 has remote control function so I do not need to be present at the appliance to turn it off.	You can distinguish which devices require internet connection. I would also want to see what the benefits are, if I install a management system,	9

				what benefits will I get?	
6	Yes, I have seen a display before. It connects to the electricity meter, measures and converts the data into costs.	I use a timer to turn the washing machine at night time. I have a number of appliances, such as a TV that uses remote controls. I use the internet to submit my consumption rate online.	I would select option 2 because there are more functions.	I would want to know if I can connect renewable generators to this system. The background can be more colourful to make the new devices more prominent. The writing in the table should be bigger and the arrow lines can be thicker.	8
7	Yes, I have heard of all the devices apart from the connection device.	I have a computer and internet connection, which allows me to submit my consumption data online.	Option 2 is more convenient because it can automatically update my consumption data online. Option 1 does not have many functions. If I am going to install something, I want to have everything (all the available functions).	There is no other diagram to compare your diagram to.	10
8	I have heard about all the devices here before.	I have a display in my house. It displays how much electricity I have consumed. It has a sensor but you cannot use it to control appliances. I can also update my	If they are both easy to install I would install option 2 because it also has the control function. Option 1 only has a display, which seems pointless in comparison. If I am to install a new system, I would want the control as well or there is	The cloud shape representing internet seems to be taking over too much space. You can design a better graphic that makes it simpler. The information shown in the boxes are very similar, so why	7

		meter reading online.	no point for all the hassle.	not simplify it and use colour to represent the type of information sent (transmits, update and control)? In the diagram you have only represented one appliance. Can the system connect to the lighting? I think the outline could be made simpler and the emphasis should be placed on the appliances the system connects to.	
9	Yes, I have heard of these technologies before.	No.	I would pick option 1 because I want to install the basic one first. Perhaps when I know whether this system works or not I can change to the more complex system.	I do not understand how the internet functions in this diagram, it is a black box. Perhaps I don't need to know. For me to use this system, I just need the company to install this in my house and tell me how I can use it.	8
10	I have seen the smart plug and the display before.	The only communication I have with my electricity company is through the company website. I can enter my consumption data and it is translated	In the beginning, I would install option 1 because it requires minimal infrastructure. If I am first presented with my consumption data, I can try to understand and think about what to do with it. Once I have the basic features, I	Maybe you can just use colour to distinct the information and control flow, and use a key to indicate what type of information is shown in each instead of labelling each data flow.	6

		into monetary value so I know how much I have used.	would probably want to introduce new functions. But in the beginning, I am happy with just knowing how much electricity I am consuming.	You can also identify all the appliances in the house that can be connected to and be controlled by the system. What do I have in my house that can connect to this?	