Smart Grid Applicability Prioritisation Of Neighbourhoods by Developing a Geospatial Decision Support Model

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DEDICATION

My angelic mother Gulser Ozturk and my dear father Fahrettin Ozturk taught me how to stand as steady as rock against the facts of life, in the most honourable way. Though it is no match to their unconditional love, I would like to dedicate my dissertation to my beloved parents as a present.

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ABSTRACT

Environmental concerns comprising pollution and global warming are among the key parameters that steer policy making actions regarding sustainability. Energy industry that comprises energy generation, distribution, and transmission phases of energy loop is at the core of these concerns and faces challenges. Due to handling capabilities, present electricity grid is not robust enough to utilize desired level of renewable energy sources due to their intermittent nature. On the other hand, emerging policies are targeting the increased utilization of renewable energy sources. In the light of environmental policies and increased stability requirements of the electricity grids, a new concept called “smart grid” emerges. Smart grids are intended to eliminate the limitations of present electricity grids such as offering increased handling capacity for renewable energy, increased interaction of the consumers with the utilities, and increased supply and demand management. It is not easy to express a solid smart grid definition as each party (energy generation, distribution, and demand side management) has its own approach in line with the desires. Due to the potential environmental benefits of smart grids, some governments engage smart grid projects to their agenda. As solid smart grid definition does not exist, there is no available solid strategy for smart grid implementations. On the other hand, it is well understood that failure in deployment of smart grids (regardless of the technology) will have undesirable impacts on growth of renewable energy generation, and failure in meeting EU carbon targets consequently. This research seeks to develop a model that seeks optimization of smart grid implementations, and it assists decision makers with deciding on the priory areas for smart grid applicability. Stated areas in this case are neighbourhoods comprising of residential buildings where considerable amount of energy is consumed. A set of criteria regarding to residential energy use and renewable energy technologies, are defined in the study. Proposed model is embedded in a GIS platform, and the main process carried out is a prioritization mechanism that comprises Analytical Hierarchy Process (AHP) and geospatial computations like clustering and regression analysis in order to evaluate the alternative neighbourhoods. Proposed model optimizes smart grid projects by ranking of alternatives in terms of smart grid applicability. Such an aid in optimizing smart grid projects has the potential to maintain progress of smart grids in a timely manner.

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CHAPTER: 1 INTRODUCTION

1.1 Research Background and Justification

Climate change and other environmental concerns drive the policy initiatives to be renewable energy oriented. Such environmental concerns are reflected in the EU Climate and Energy package where this package targets energy efficiency, on the basis of reducing greenhouse gas emissions and make more widespread use of renewable energy sources (European Commission, 2010). Increasing the share of renewable sources in the energy mix may damage the infrastructure due to the nature of current energy grid (Momoh, 2009). Future developments, such as the large scale introduction of intermittent low carbon energy sources (wind, solar) and new loads (electric vehicles, heat pumps) are expected to form great challenges for the ageing electricity grids in EU. Significant increase in the energy demand and the case of renewable energy penetration to the grid makes it inevitable to improve the transmission grid.

Smart grid technology emerged as a result of these constraints and limitations of the present grid. Smart grids provide higher quality of power that will enable saving money wasted from outages, they are more efficient and they have higher capacity for penetration of intermittent power generation sources (Li et al., 2010). Modeling and experimental work on smart grids suggest that they may not only contribute to achieving environmental goals, but also reduce the strain on electricity systems currently subject to considerable stress (Clastres, 2011). Smart grids offer many advantages: they improve both the physical and economic operation of the electricity system by making it more sustainable and robust, more efficient by reducing losses while at the same time offering economic advantages for all stakeholders (Verbong et al., 2012).

Marcotullio and Schulz (2008) state that urbanization itself accounts for a vast amount of energy and explain that cities are centres of resource consumption and buildings can account for 40-60% of the urban energy usage. As a result of the energy consumption in the buildings due to current energy use behaviour pattern which mostly relies on high Green House Gas (GHG) emitting fossil fuels which are known to be the primary cause of climate change, 50% of the greenhouse gas emissions (30% from residential buildings and 20% from commercial buildings) are sourced from building stock for heating, cooling and lighting purposes (Murray, 2008).

The impact of carbon emissions and other greenhouse gases on climate change was acknowledged in 1992, when 154 governments and the European Community signed the United Nations' Framework Convention on Climate Change at the Rio Earth Summit (Earth Summit, 2010).

To cope with buildings related climate change, through its "*Building a Greener Future policy statement"* in 2007, the UK Government has committed to reduce carbon emissions from domestic buildings to ensure that all new homes will be zero-carbon by 2016 (Communities and Local Government, 2007). As simplified by BRE Environmental Assessment Model (BREEAM), zero carbon describes the case when the amount of energy taken from the grid is less than or equal to the amount put back through renewable technologies (BREEAM, 2010). The implementation of the policy stated above is the package of regulations called the Code for Sustainable Homes which is an assessment and rating system covering key areas including water, energy and CO2 and the aim of the code is to improve the impact of new homes build after May 2008 (Communities and Local Government, 2010).

The Code for Sustainable Homes, on the overall seems to be a good approach against climate change, but when it comes to the implementation, three critical questions emerge. Firstly, as the 'zero carbon' scheme offers feeding the grid with renewable sources, how suitable is the electricity grid for two way energy distributions? Secondly, since the renewable sources are intermittent or periodically fluctuating, is the electricity grid reliable enough to accommodate uncertain oscillations of power? And finally, what is the efficiency of the grid hence the efficiency will affect the quality and quantity of the renewable energy generated by "zero carbon" homes circulating within electricity distribution and transmission infrastructure?

The given questions above point out that a sustainable carbon reduction implementation strategy should focus not only on the building regulations but also the electricity grid.
UK policy points that a transition to smart grids is in the agenda and will be implemented initially until 2020 and developed further until 2050 (The UK Low Carbon Transition Plan, 2009).

As the smart grid transition aforementioned in EU and UK policies is on the way and is inevitable, the management of this transition process is becoming a critical issue. This study focuses on the prioritization and decision of smart grid implementation areas in terms of relative deprivation of energy related criteria. The scale is limited to neighbourhood level due to time constraints of PhD study. A geospatial decision support model comprising decision making methods and geospatial data management techniques is proposed with the intention of building up and implementing an optimized neighbourhood selection approach for smart grid applicability. Stated model is called "Geospatial Decision Support Model for Smart Grid Applicability (GDSM4SGA)".

1.2 Smart Grid Context Specific Motivation Behind This Research

Author of this thesis has been prepossessed by tangible benefits of smart grids that are advocated by research societies, organisations and communities like Greenpeace, Gridwise Alliance, European Renewable Energy Council, Electric Power Research Institute to name a few. Stated benefits are further elaborated in Chapter 2, but they mainly comprise reduced carbon emissions, increased use of renewable resources for energy, and increased efficiency of transmission and distribution infrastructure.

Highlighted benefits drew heavy attention of many countries worldwide, and enabled Smart Grids taking place in environmental and economic policy agenda. In this regard, as UK government develops plans for Smart grid transition, Smart Grid GB (an independent, cross-industry stakeholder group acting as the national champion for smart grid development in Britain) forecasts the costs for the stated transition in grid technology. Figure given below depicts an estimate of the costs required to upgrade the power infrastructure between now and 2050.

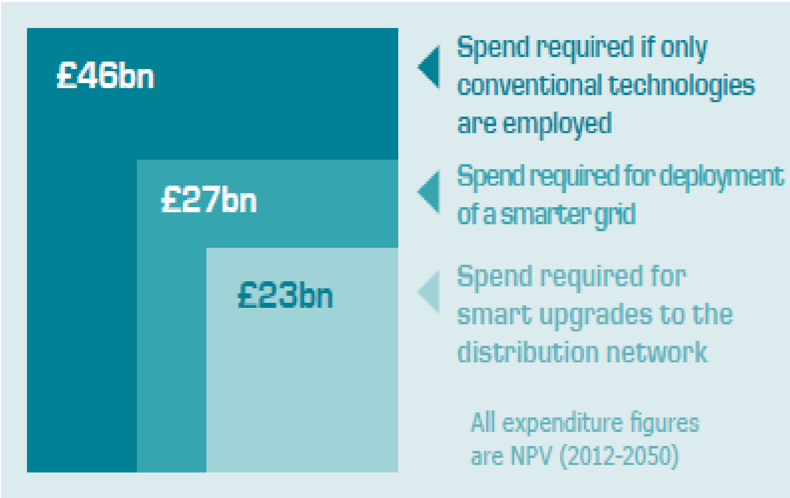


Figure 1.1 Costs of Smart Grid Transition (Smart Grid GB, 2012)

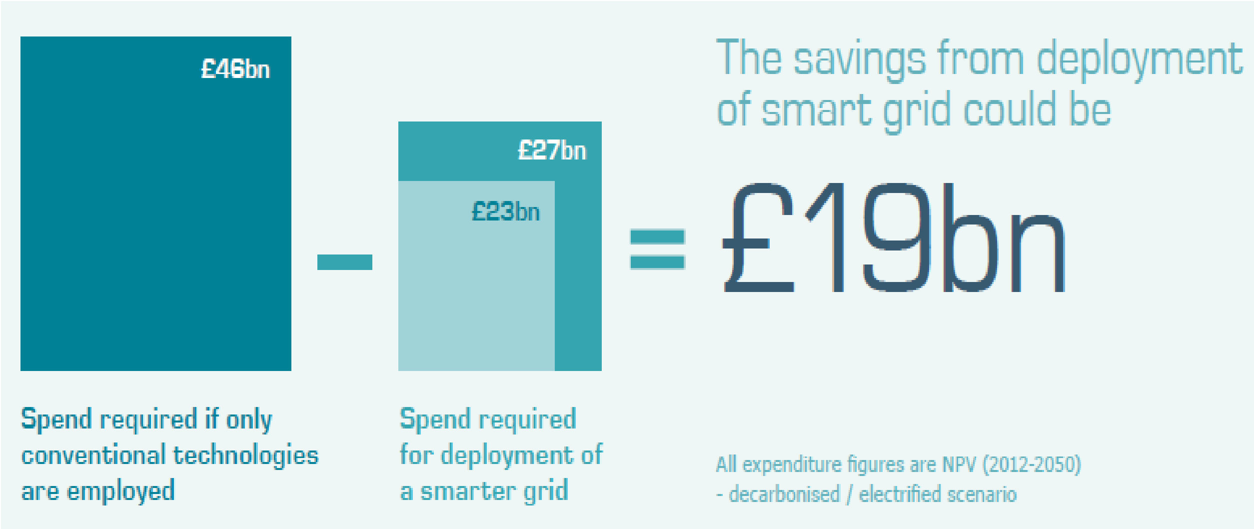


Figure 1.2 Potential Savings Offered by Smart Grids (Ibid)

As it is clearly seen from the given figures that, conventional upgrades regarding "business as usual" case, costs are expected to be almost the double when compared to smart upgrades to the power infrastructure. It should also be well acknowledged that, besides offering lower costs, smart upgrades also offer abovementioned environmental benefits.

From a broader perspective, this case can be interpreted as the cost of not deploying smart grids being much bigger than the transition investment itself. Logically, this statement can be generalised to worldwide grid infrastructure requirements. In a nutshell, it can be said that timely roll out of smart grid infrastructure would have a vital positive impact on economic and environmental pillars of sustainable development.

The author of this study is aware that the transition in electricity grid technology requires key resources such as "money" and "skilled labour", but also agrees that stated resources are scarce. In this respect, management of the transition process comes into prominence. The idea of making a contribution to the stated smart grid transition process is the main motivation behind the conducted research. Therefore, after conducting a comprehensive literature review, researcher proposed a simple, yet holistic, approach to assist smart grid deployment projects, and endeavoured to develop a geospatial decision support model to assist decision makers and stakeholders regarding smart grid projects on the priory areas of resource allocation.

1.3 Research Question, Aim and Objectives

Research question identified for this study is:

“Which alternative among neighbourhoods has the optimum applicability for smart grid implementations?”

Based on the research question, the aim of this research is to develop a geospatial decision support model to decide on the priory areas for smart grid implementation.

To achieve this aim, the following objectives are identified:

I. To carry out detailed literature review about environmental sustainability, climate change, renewable energy sources, present electricity grids and related challenges, smart grid systems and related challenges, and decision making

II. To identify a set of indicators via extraction from the related literature covering smart grids and residential energy use

III. To identify ontology as a set of assessment rules which will provide conditions and constraints during the diagnosis and evaluation of neighbourhoods’ potential of smart grid applicability

IV. To propose a model which will enable geospatial decision support for the selection of optimum neighbourhood in terms of smart grid applicability

V. To test the proposed model via case study neighbourhoods

VI. To validate and propose the geospatial decision support model for its use in the smart grid realization via focus group comprising academics and industry professionals

1.4 Research Methodology in Brief

The research strategy of this study is the exploratory case study research that focuses on understanding the dynamics present within single settings. Criteria identification, data collection, and validation stages of the research have been carried out in a qualitative manner whereas the data analysis and some parts of conceptualisation stages have been carried out using quantitative techniques. As the research aims to generalize a concept of smart grid applicability assessment, inductive approach has been adopted throughout the study. Questionnaire surveys and interviews are the methods employed for data collection.

1.5 Scope and Limitations

The focus of this study, as previously highlighted, is to develop a geospatial decision support model in order to identify the priory areas among alternatives in terms of smart grid applicability. The overall intention is to develop a holistic model that assists smart grid realization projects. The proposed model itself is an Analytic Hierarchy Process (AHP) algorithm integrated within a GIS medium, and it enables profiling of each alternative area in accordance with the identified criteria. The scale is limited to the neighbourhood level (1000 dwellings approximately) due to the timescale of this study, but a system development approach for the model has also been supplied so that the overall concept can be extended to larger scales.

In addition, the research has been conducted in the axis of five justified criteria of smart grid applicability. ICT related issues, social sustainability issues, and energy storage technologies is beyond the scope of this study.

The prominent limitation throughout the research was the difficulty to access real life data regarding smart grid applicability criteria which in turn forced the researcher to make assumptions whilst developing scenarios for alternative neighbourhoods. It is well worth mentioning that, any cost related issues are set apart from the conducted research as these would require financial analysis which is beyond the scope of this study.

1.6 Guide to Thesis

The rest of the thesis is structured as follows:

In Chapter 2, energy and built environment interaction is handled, and "smart grid" concept is elaborated. Initially, building energy consumption and related environmental concerns are introduced. Then, grid technology is elaborated for present electricity grids, related challenges are addressed, and smart grid technology is raised as a remedy to those challenges. Subsequently, different smart grid project examples are examined, and a critical review on the matter has been made. Finally, the need for a transition in grid technology is addressed.

In Chapter 3, decision making concept and its geospatial application domain are covered in detail. Presence of a variety of decision methods is introduced, and AHP method has been raised among the alternative techniques as the appropriate method to be adopted throughout the study. Lastly, data visualisation concept is highlighted as an approach of disseminating knowledge to decision makers. Chapter 2 and Chapter 3 are both reviews of the related literature, and they fulfil the first objective set for the research.

In Chapter 4, essentials of conducting a research have been digested. Widely accepted research steps ranging from philosophical stance to data processing are introduced. Subsequently, adoption of an appropriate research methodology for this study is presented, and adopted methodology is mapped out in a systematic form (Research Design). Stated research design points out that the adopted research methodology is epistemologically based on objectivism, and positivism appears to be the dominant philosophical stance for conducting case studies in inductive approach. Additionally, interviews and questionnaires are proposed as data collection tools, and finally mix methods for data analysis and evaluation.

In Chapter 5, key enablers of smart grid applicability are addressed. Initially, five criteria regarding smart grid applicability are identified. Secondly, questionnaire study that is carried out in academia and industry is analyzed with the intention of obtaining the criteria weights. Subsequently, interviews carried out in academia and industry are analyzed in an attempt to enhance and strengthen the questionnaire results. Additionally, reliability and validity of the abovementioned data is discussed. AHP based methods acted as the backbone for the stated analysis. Chapter 5 fulfils the research objective 2.

In Chapter 6, formulation and structuring of smart grid applicability mechanism is elaborated. A geospatial decision support model for smart grid applicability (GDSM4SGA) is proposed, data requirements and functionality of the model is discussed, and embedded ontology is explained. The model is depicted in two different approaches where the first one indicates the components of the model and the second approach illustrates the conceptual form of the model. Lastly, modeling via UML is carried out with the purpose of obtaining a systematic layout of a standardized and generic smart grid applicability assessment mechanism. Chapter 6 fulfills the research objectives 3 and 4.

In Chapter 7, proposed model is run and tested. Three alternative neighbourhoods, each reflecting different characteristics against the identified criteria, are assessed. The outputs are obtained for each individual criterion. Additionally, an overall assessment is also obtained through the model. Requirements of research objective 5 are fulfilled within chapter 7.

In Chapter 8, a focus group study comprising experts from academia and industry is presented. Experts are asked to evaluate the model (GDSM4SGA proposed in previous chapter 6) in SWOT (Strengths, Weaknesses, Opportunities, Threats) manner. An overall assessment of experts regarding the model has been supplied. Chapter 8 fulfills the validation requirements raised by research objective 6.

Chapter 9 is the conclusion chapter and it summarises the research and its contribution, lists the research outputs and results and the recommendations for the implementation of the proposed GDSM4SGA and also the recommendations for future research directions.

Chapters are provided with appropriate “Introduction” and “Concluding Remarks” sections.

CHAPTER 2: ENERGY MATTERS AND BUILT ENVIRONMENT

2.1 Introduction

This chapter of the thesis incorporates literature review on three following clusters:

- Buildings, Energy, and Environment
- Energy (electricity) networks
- Need for transition in grid technology

The first cluster is discussed briefly in order to highlight environmental concerns related to residential buildings. As the main focus of the research is optimizing the transition from present energy networks to smart grids at neighbourhood level, the primary attention dominating the literature review on energy and built environment are electricity networks and the need for transition in grid technology.

2.2 Buildings, Energy, and Environment

Built environment (covering buildings, construction, infrastructure etc) is a key sector for sustainable development (UNEP, 2007). The construction, use and demolition of buildings produce considerable social and economic benefits to society, but may also have serious negative impacts, in particular on the environment (Haapio and Viitaniemi, 2008).

Buildings are among the main energy consuming sectors in the European Union (EU) and numerous studies state that, building energy efficiency implementations could contribute to the reduction of the current energy consumption in the EU countries (Blok, 2004). In Europe, buildings account for 40-45% of energy consumption in society, contributing to significant amounts of carbon dioxide (CO2) emissions. In the UK, 47% of the energy consumed in the country is a result of building energy use (DTI, 2005). The building sector therefore offers the largest single potential for energy efficiency in Europe which is more than one-fifth of the present energy consumption and up to 45 million tonnes of CO_2 per year could be saved by applying improved standards to new and existing buildings (Maldonado, 2005).

International Energy Agency states that approximately one-third of end-use energy consumption in IEA member countries occurs in residential, commercial and public buildings. Uses include heating, cooling, lighting, appliances, and general services. Buildings are therefore a major demand on energy resources and the emissions associated with supplying and consuming this energy make up an important component of total emissions. Using an accounting system that attributes CO_2 emissions to electricity supply rather than building end uses, the direct energy-related carbon dioxide emissions of the building sector are about 3 Gt/yr (International Energy Agency, 2008).

Kavgic et al. (2010) express that efficient and realistic implementation of building stock related carbon dioxide emission reduction schemes should cover baseline energy demand of the existing building stock, and exploration of possible implementations that are benefiting from new energy technologies.

2.3 Electricity Grids

From a broader perspective, the terms ‘electricity grids’ and ‘electricity networks’ are the general names of the infrastructure system that delivers electricity to the end user (or loads) from energy generation plants via transmission and distribution lines.

This specific part of the PhD thesis discusses characteristics of the present electricity networks, smart grids and example applications around the world, and the need for a transition to smart grids.

2.3.1 Present Electricity Network

As extracted from the interdisciplinary study conducted by Massachusetts Institute of Technology (Carrerio, 2011) power is traditionally generated at remote, centralized plants and then transmitted to load centres over high-voltage transmission lines before being distributed to the consumer. As being designed and deployed almost half a century ago, present electricity grid infrastructures, and the systems that monitor and control them, are sternly becoming out of date and incapable of meeting tomorrow's energy needs (Battaglini et al, 2009).

In this part of the thesis, the primary focus is on the electricity grid that exists in the UK (specifically England and Scotland); more commonly known as the National Grid. The national grid is a high-voltage transmission system that transports electricity from large power stations, to the low-voltage, regional distribution networks in the UK. It operates at a frequency of 50 hertz (Hz), a combination of 275 and 400 kilovolts (kV) (and 132kV in Scotland), and is a three-phase AC (alternating current) system. Figure 2.1 depicts the current structure of the transmission network, and how it operates between power stations (A) and local distribution networks (D).

The alternating current is produced by generators located at the power stations. In each generator, mechanical energy is converted into electricity by use of a rotor, which creates a rotating magnetic field within a set of stationary coils. This action induces an alternating sinusoidal current within the coils, the frequency of which is determined by the angular velocity of the rotor. On a balanced AC power system, the frequency of this current must be synchronised exactly to the frequency of the grid, which in the UK is 50Hz. Three-phase current is achieved by securing three sets of windings around the generators; positioned equally apart so that the associated currents are shifted in phase by 120 degrees of angles. Three-phase systems are beneficial as they ensure a constant and adequate net transfer of power, known as *real* power, whilst incurring minimal material costs. The high operating voltage of the system is needed in order to optimise the transmission of large amounts of power over such long distances (Andrews and Jelley, 2007, Schavemaker and Van der Sluis, 2008).

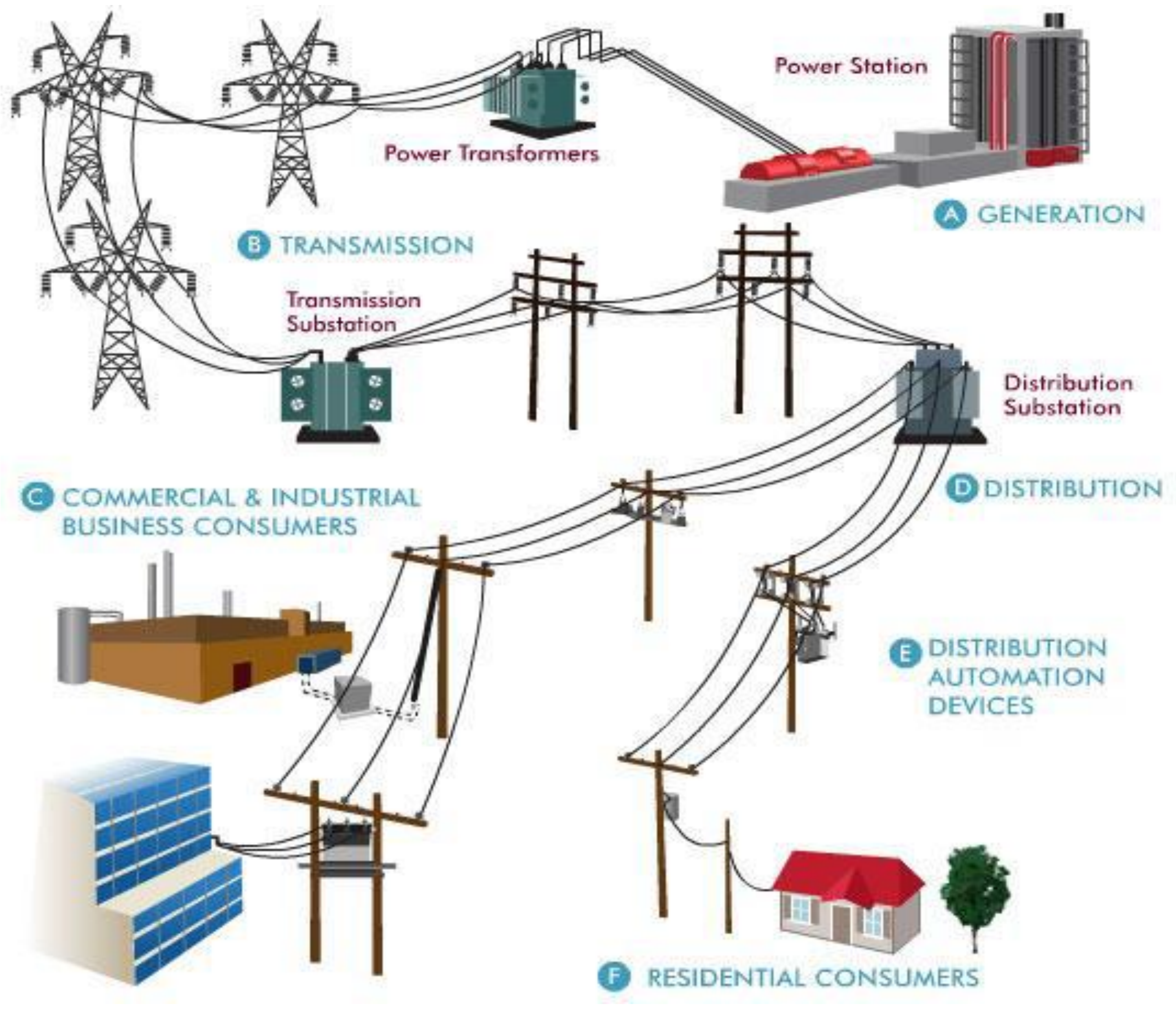


Figure 2.1 Structure of present transmission and distribution networks (Byrne, 2011)

2.3.2 Smart Grids

In the fable of the blind men and the elephant, a group of men come upon an elephant, each encountering a different part of the body. Much disagreement and confusion follows as consequence, as the group struggles to reach agreement about what an elephant is. This fable has emerged as a popular metaphor for the smart grid, as the electric energy, telecommunications and technology industries converge at the smart grid intersection (Figure 2.2).

Here is a bunch of selected definitions from the literature that support the aforementioned metaphor for the smart grid concept:

Climate Group (2008) defines 'Smart-grid' as a set of software and hardware tools that enable generators to route power more efficiently, reducing the need for excess capacity allowing two-way, real time information exchange with their customers for real time demand side management. Additional benefits are listed as improved efficiency, energy monitoring and data capture across the power generation and transmission and distribution network

Franz et al. (2006) describes smart grid as the convergence of the present electricity with Information and Communication Technology.

According to Adam and Wintersteller (2008), smart grid is a system that employs digital technology to optimise energy use, better incorporate intermittent sources of renewable energy, and engage customers through smart metering.

As observed from the smart grid perceptions derived from the literature, there is currently no one generally accepted definition of a smart grid, but it is widely held that smart grids will consist of distributed generation and demand points connected at all levels of the system, thus removing the current distinction between transmission and distribution networks (Carvalho, 2010, Wissner, 2011). The theory implies that operations of smart electricity grids will be based on introducing two-way communication and power flows between the distributed load and the supply; in order to maximise the efficiency and stability of a network that is largely sustained by renewable energy generation (Ipakchi and Albuyeh, 2009, Orecchini and Santiangeli, 2011).

Stated smart metering system, also known as Advanced Metering Infrastructure (AMI), comprises of a smart electricity meter installation. The new metering infrastructure is essential for energy efficiency measures, the monitoring and management of grids as well as load balancing and shifting. Smart meters are central gateways located on the customer's site that support two-way communication and allow consumers to make informed decisions via price signals received from the utilities (Kranz and Picot, 2011, Blumsack and Fernandez, 2012). To improve the integration of renewable sources into the low-voltage grid, local small storage systems can either be installed close to prosumers (combination of a consumer and a producer) or directly at prosumers (Römer et al., 2012).

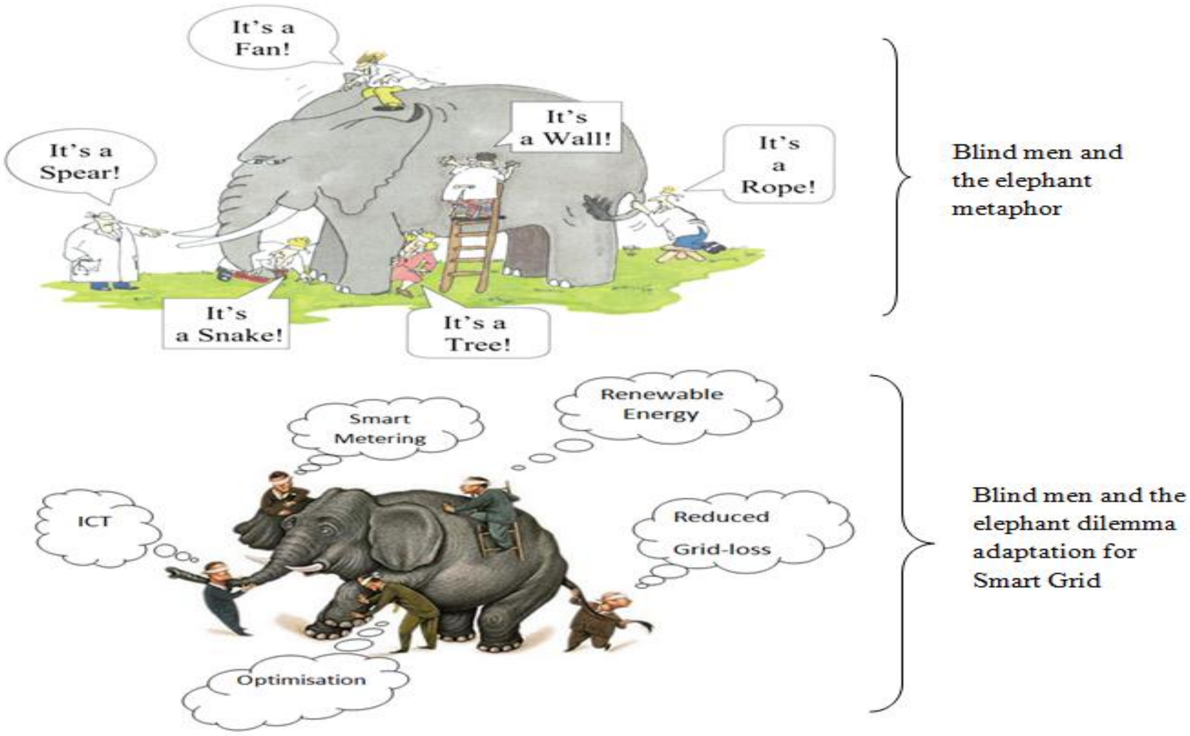


Figure 2.2 Blind Men and the Elephant Metaphor and Smart Grids

Pratt et al (2010) underlines that, rather than focusing on the smart grid visions, it might be a more solid approach to map out the smart grid in terms of assets that would be purchased and functions that would be used and/or functions that would derive benefits. Given matrix in the following Figure 2.3 depicts a number of key functions and assets associated to smart grids.

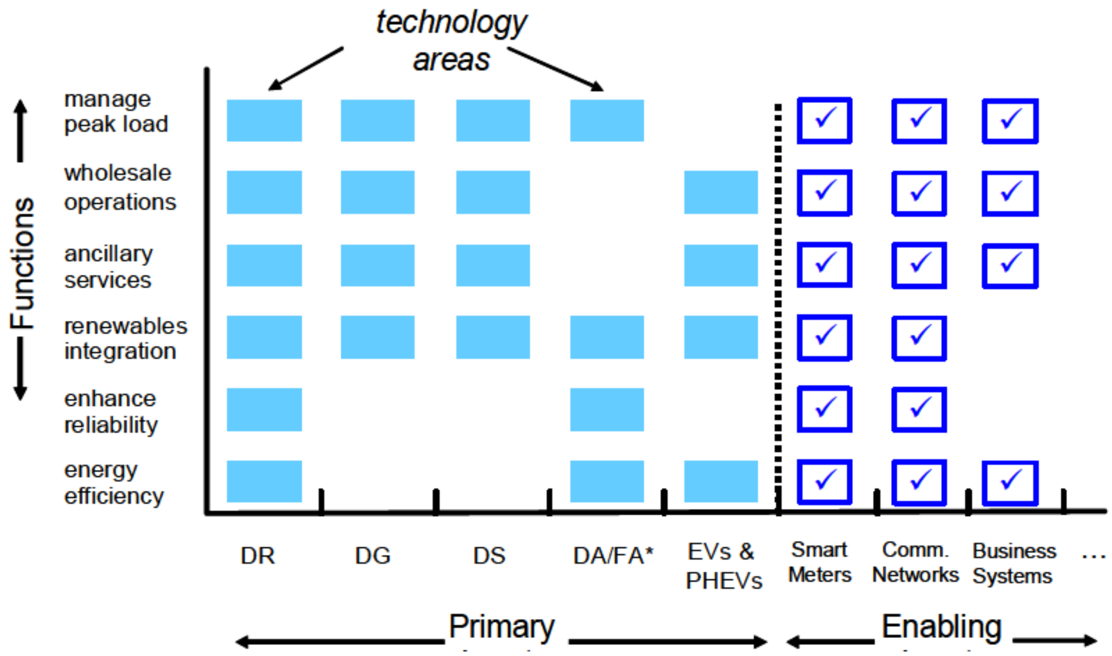


Figure 2.3 Smart Grid in terms of Assets and Functions (Pratt et al, 2010)

(Key to Figure 2.3 DR: demand response, DG: distributed generation, DS: distributed storage, DA/DF: distributed automation/feeder automation, EVs &PHEVs: electric vehicles/ plug-in hybrid electric vehicles)

In the given Figure 2.3 above, functions are represented on the vertical axis and the assets are shown on the horizontal axis and are divided into two main clusters as primary assets (that are actively controlled to manage the grid's operational conditions) and enabling assets (that are required for primary assets to respond to grid conditions). The intersection of an asset and a function, referred as a technology area, is the set of policies, engagement strategies, incentive mechanisms, control strategies, software applications, and capabilities of the primary and enabling assets required to accomplish a given function.

Electric Power Research Institute (EPRI) has conducted an in depth study for 2030 in United States projecting the smart grid benefits brought through the stated functions of "Renewables

Integration" and "Energy Efficiency" and the given table 2.1 summarizes the main outcomes of the projection study (derived from Ibid).

Table 2.1 Smart grid Benefits for US (Reproduced from Pratt et al, 2010)

Reduction	***Energy (%)***	***Carbon Emissions (%)***
Direct reduction	9	9
Indirect reduction	6	6
Total reduction	15	15
Total reduction including EVs/PHEVs	18	18

Reductions mentioned in the table given above are due to increased renewable energy use (solar and wind power), and increased efficiency in electricity grid operations (reduced distribution losses, conservation effect of consumer feedback, efficiency savings from equipment performance diagnostics). Direct reductions occur due to operational efficiency of the grid, and indirect reductions occur due to behavioural change in consumption that is enabled via smart grid infrastructures. Total reduction in energy is forecasted to be 15 % of the total energy consumed and as a function of energy demand reduction, and as an outcome the level of Carbon emissions is forecasted to decrease by 15 %. Moreover, if the use of electric vehicles and plug-in hybrid electric vehicles are concerned, an additional 3% will top-up the aforementioned reductions, and both carbon and energy demand reductions will reach to 18% in total. It should also be noted that one third of the stated reductions in the table are from residential buildings. In other words, smart grid implementations will bring residential buildings to have potential of up to 6% of reductions in both CO_2 emissions and energy demand by 2030 in US.

As stated earlier in the introduction chapter of this thesis, this research has been conducted within boundaries of residential energy use and neighbourhood scale smart grids. Thus, at this point, it is well worth mentioning that what researcher of this study understands from overlapping of 'smart grid' and 'residential buildings' is: i) increased consumer engagement to the grid (via smart meters), ii) increased utilization of local renewable energy sources, and iii) reduced demand for energy in households in order to reduce the stress over the grid to balance the supply.

2.3.3 Smart Grids vs. Microgrids

When maintaining urban electricity infrastructure, the initial step logically should be reducing the stress over the grid. Urban concepts like Eco-Towns emerged in line with the stated idea of reducing residential end-use stress on the grid. Although the main purpose lying beneath was to supply affordable housing, higher environmental standards are also at the core of Eco-Towns approach (Cooper, 2007). Along with approaches to embedding sustainable behaviours among the community, Eco-Towns are planned in a way which supports low carbon living (Directgov, 2012). The study conducted by Campaign to Protect Rural England (CPRE) show that there are already some Eco-Towns or similar eco developments in England and in other European countries (CPRE, 2010):

- Northstowe (UK): It is a new community in Cambridge and occupies 9500 new homes that are aimed to consume up to 50% less energy and water
- Vauban (Germany): It is a district of 5000 homes which offers 50% less traffic by car share scheme and also occupies 100 energy producing houses.

- The BO 01, Malmo (Sweden): It consists of 600 homes that are 100% reliant on renewable energy
- Nieuw Terbregge, Rotterdam (The Netherlands): It contains 860 homes, and CO2 emissions are up to 55% lower than new housing produced in 1996.

It is seen from the examples that, the most common property of these eco developments are generating whole or a proportion of their energy usage, which can more broadly be explained by "microgrid" concept. Microgrids are generally defined as low voltage networks with Distributed Generation (DG) sources, together with local storage devices and controllable loads (e.g. water heaters and air conditioning), and microgrids can operate in parallel with the electricity grid or in island mode (Lo Prete et al, 2012).

According to the conducted literature review (Myles (2011); Campbell (2012); Bossart (2012); Ye et.al (2005); Voima and Kauhaniemi (2012)), key features of a microgrid include:

- Ability to operate in both island (isolated) mode or grid-connected
- Connecting to the Macrogrid (main grid) as a single controlled entity
- Provision of varied levels of power quality and reliability for end-uses
- Being a combination of interconnected loads and co-located power generation sources (DG)
- Being designed to accommodate total system energy requirements

The following Figure 2.4 depicts the general structure of a microgrid and its connection to the main grid (macrogrid). It is seen from the stated figure that the microgrid offers a combination of power generation sources (main grid, renewable sources, and fossil fuels), and its architecture capable of isolating from the macrogrid (islanding mode) ensures a reliable power supply to the end users when there is congestion or disturbance over the main grid.

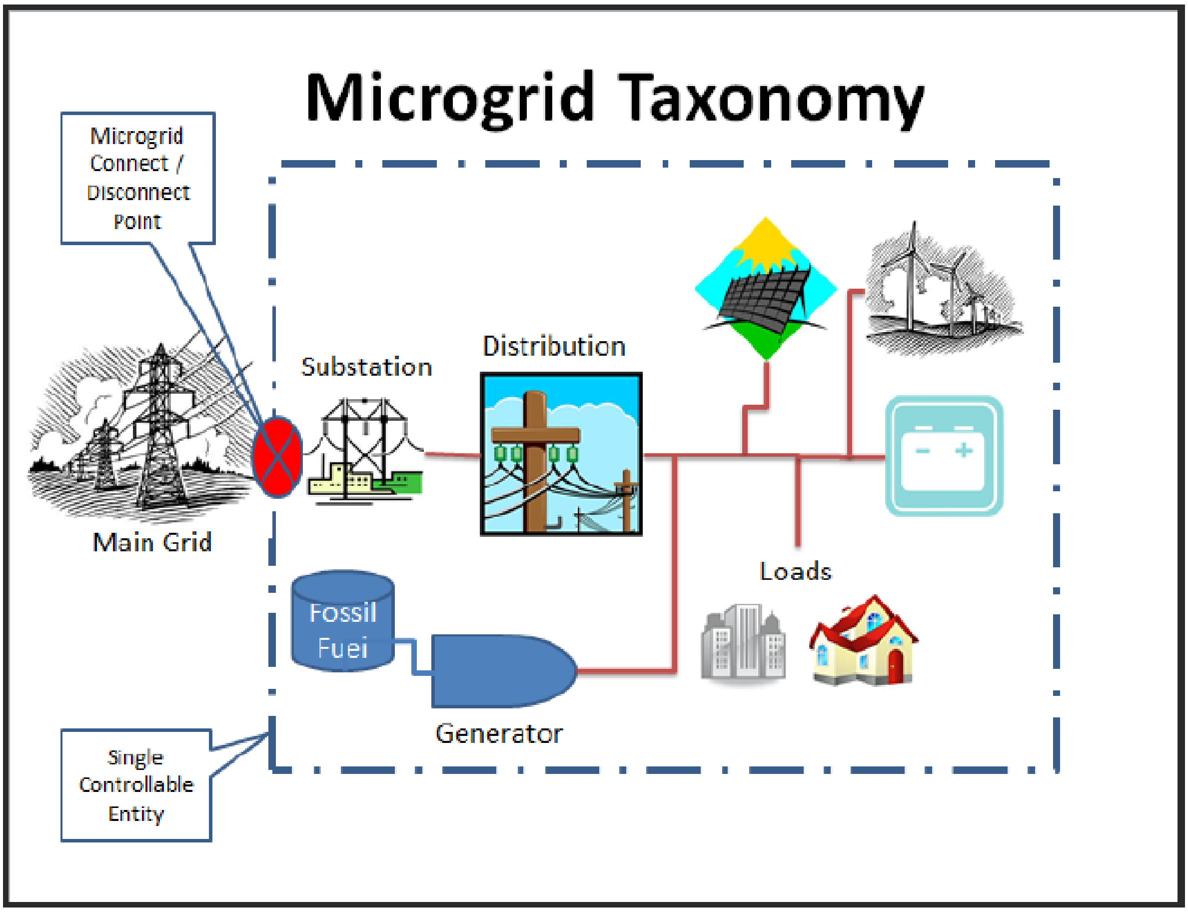


Figure 2.4 Structure of Microgrids (Hayden, 2013)

Besides its islanding capability and enhanced utilisation of distributed generation (DG), a microgrid (MG) is a miniature representation of the macrogrid, and the size of microgrids is described as having a total installed capacity in the range of between a few hundred kilowatts and a couple of megawatts (Homerenergy, 2010). Therefore, it is mostly preferred in rural electrification of small communities (Ibid). The Microgrid technology, as stated in the eco-development examples, reduces the stress on the grid and helps to achieve low carbon living at a neighbourhood level. However, when it comes to meet high load demands with renewable energies such as heating requirements in extreme climates, microgrids may not be self-sufficient. Bulk penetrations of renewable energy sources require more holistic solutions and that is the point where Smart Grid concept emerges.

Smart grid, as introduced earlier in previous section, is a modernized electricity infrastructure that brings ICT to forefront so that the balance between supply (energy generation companies and/or utilities) and demand (end users) can be achieved in an automated fashion to improve the sustainability of the production and distribution of electricity.

Given figure 2.5 below illustrates the distinctive feature of smart grids, which is the bi-directional flow of energy and information together between energy generation nodes (conventional facilities and renewable energy technologies) and the consumption nodes (end use points comprising industrial facilities and residential buildings). This key aspect not only makes it possible to create synergy among individual components/actors across the value chain of power grid, but also enables smart grid to be able to control consumption, depending on the availability of electrical power in the grid. In conventional power networks, generation of power depends on consumption levels.

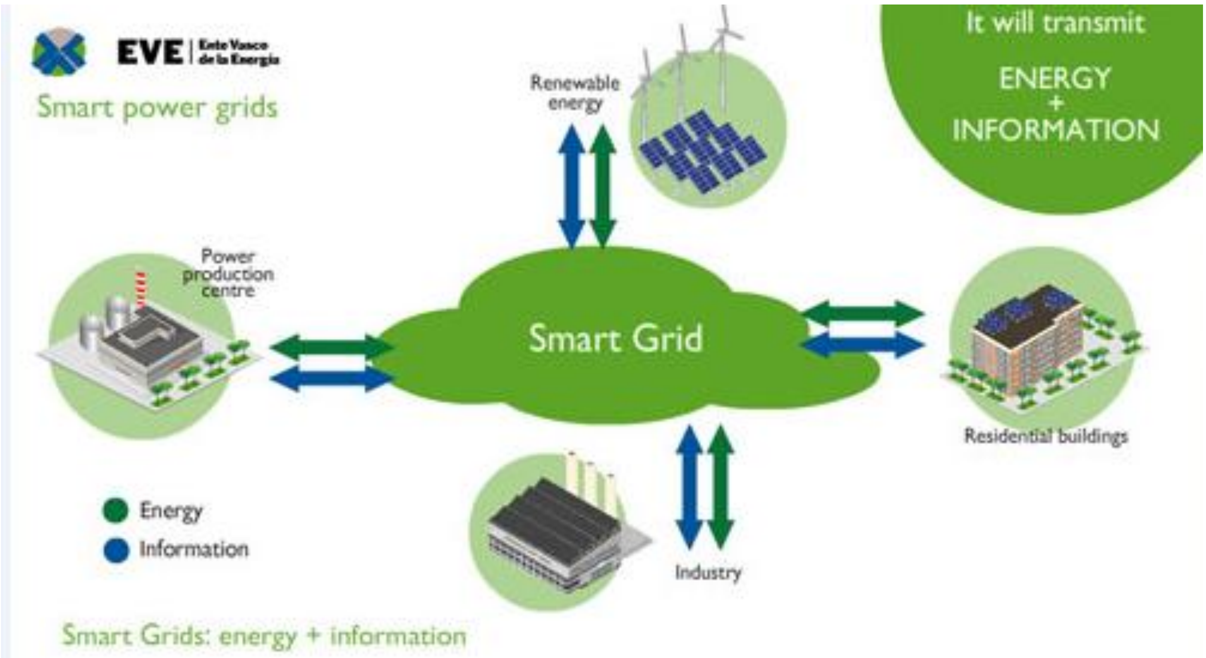


Figure 2.5 Basic Structure of a Smart Grid (EVE, 2013)

To sum up, microgrids can be installed locally and they have the potential to meet the electrification demands in rural communities (or small local communities). On the other hand, modern world energy markets (including policy makers, technology suppliers, financial actors, producers and consumers, and so on) require not only the benefits brought by microgrids (Such as utilization of distributed generation (DG), and islanding capability to increase reliability), but also improved efficiency at all points of power distribution and transmission, and improved interaction with end users for demand reduction and dynamic pricing purposes which cannot be met via microgrids. However, microgrids can still be used as basic blocks for future system expansions, and in the long run, propagation of individually controlled microgrids can form a basis for integrated and interconnected smart grids.

2.3.4 Smart Grid Examples

As mentioned in previous sections, a solid definition for a smart grid does not exist. For that reason, implemented smart grid projects vary in accordance with the perception and the needs of stake holders and communities. It is mentioned by Kempener et al (2013) that demonstration projects that try out smart grid technologies can provide insight into performance of specified smart grid smart grid technologies within specific systems.

In this section, four different (two from Europe and two from US) smart grid projects are examined, and their major characteristics are highlighted. The information given when presenting the smart grid examples are compiled from European smart grid initiative (EcoGrid), and Electric Power Research Institute (EPRI) press releases.

2.3.4.1 EcoGrid-EU European Smart Grid Prototype in Bornholm Island – Denmark

Bornholm is a Danish island in the Baltic Sea, to the east of Denmark, south of Sweden, and north of Poland. EcoGrid smart grid prototype project, which is hosted in Bornholm Island, acts as a test bed for smart grid ICT, smart appliances, and environmental policy making for European Union member countries and the project aims to contribute to EU 20-20-20 target.

EcoGrid is a EU FP-7 funded project (21 million Euros in total) that engages diverse variety of stakeholders from all around EU each dealing with a specialized aspect of smart grid deployment.

Bornholm EcoGrid project serves 28000 customers which demand 268 GWh of electricity and 500 Gwh of heat annually. The grid installed is primarily based on a meshed 60 kV network with 16 60/10 kV substations that handle a peak load of 55MW. More than 50% of the electricity consumed on the island is supplied from distributed renewable energy sources incorporating 30 MW of wind power, 16 MW of biomass (via 5 CHP plants), 3 MW of solar photovoltaic power, and 2 MW of biogas power. Energy storage issues are demonstrated using heat pumps and district heat systems for Wind to Heat appliances. Additionally, electric vehicle batteries are being considered as direct electricity storage. The ambition for the future is to achieve 100% renewable energy deployment for the overall energy market. Figure 2.6 depicts geographical distribution of present power plants in Bornholm.

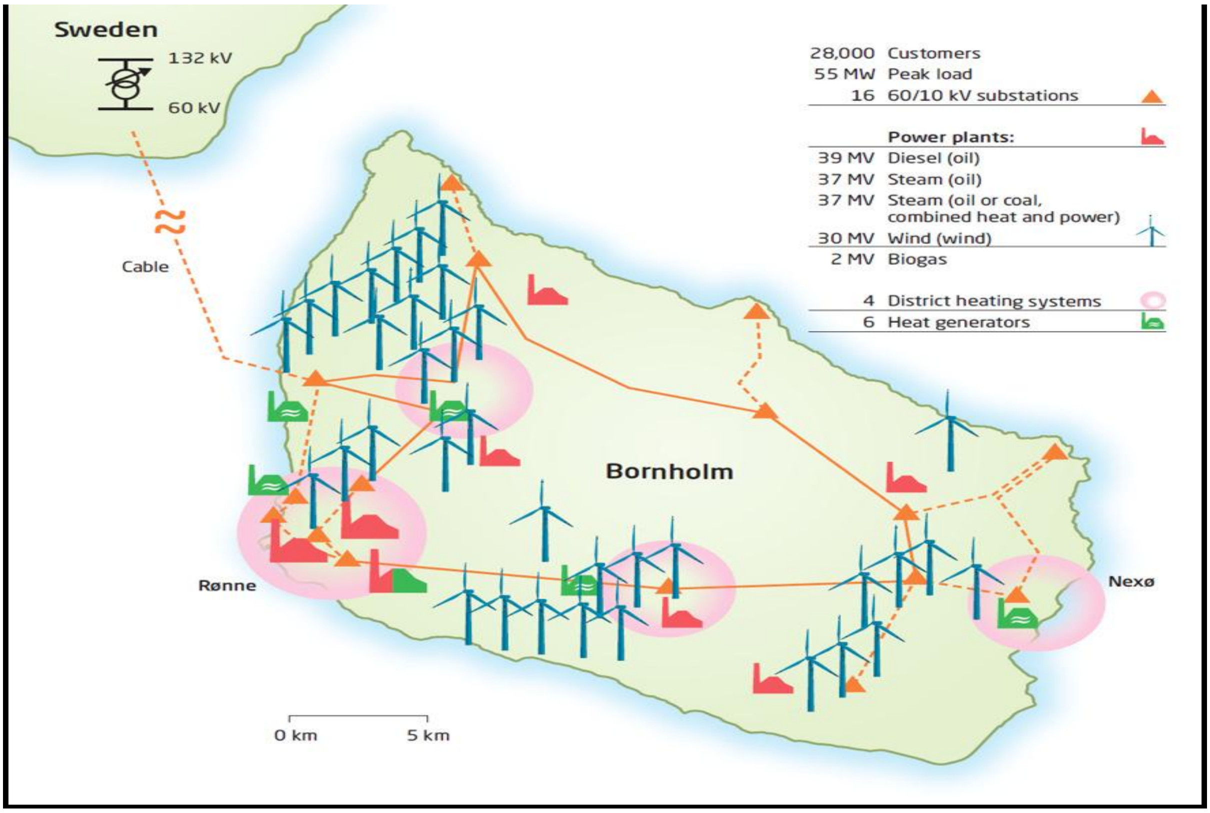


Figure 2.6 Geographical distributions of power plants in Bornholm (www.eu-ecogrid.net)

ICT infrastructure is structured in a way that it engages all actors (consumers, producers, and distributors) under the umbrella of smart grid. Smart metering, smart appliances, and electric vehicles are key enablers of the prototyped smart grid. Almost 2000 customers participate in the prototyping project, and those participants are clustered in order to conduct evaluation studies for different variations and combinations of technologies and deployment strategies. Given figure 2.7 depicts the structures of stated consumer clusters.

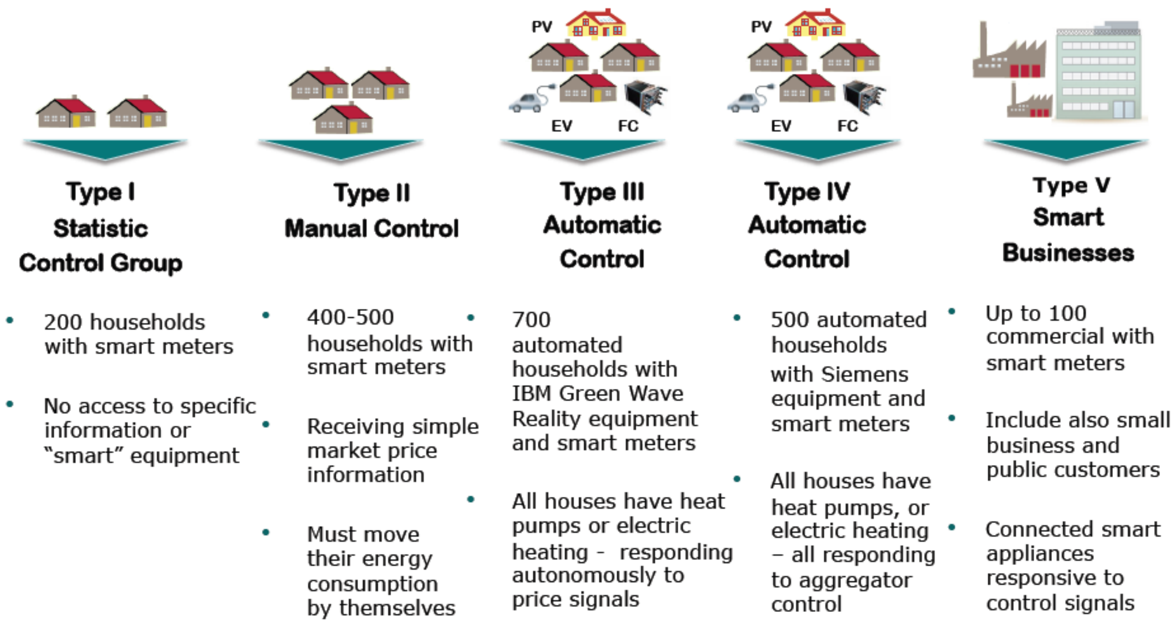


Figure 2.7 EcoGrid consumer clusters for testing different strategies of Smart Grid applications (www.eu-ecogrid.net)

Mentioned characteristics of the EcoGrid prototype strengthen the efforts towards sustainable and effective integration of Distributed Energy Sources in European energy marketplace.

2.3.4.2 EDF Smart Grid Demonstration Project in France

Eletricite de France (EDF), implemented a smart grid demonstration project in PACA region in south of France in which a robust 400 kV transmission line is hosted. The aim of the project is to develop and implement a smart grid infrastructure that optimizes integration of distributed renewable generation and storage for Carbon reductions and local load relief.

The demonstration covers eight major clusters energy implementations for exploration. These include:

i. Thermal storage for cooling applications
ii. Heat pumps coupled with hot water tanks to enable household load shifting
iii. Solar PV coupled with storage
iv. Solar heat pumps and hot water storage
v. Residential applications of load shedding modules
vi. Generating electricity with solar thermal storage
vii. Generating electricity with biogas
viii. LED based public lighting with dimming functionalities

See given figure 2.8 for representation of aforementioned clusters and how they are linked to control unit via communication technologies.

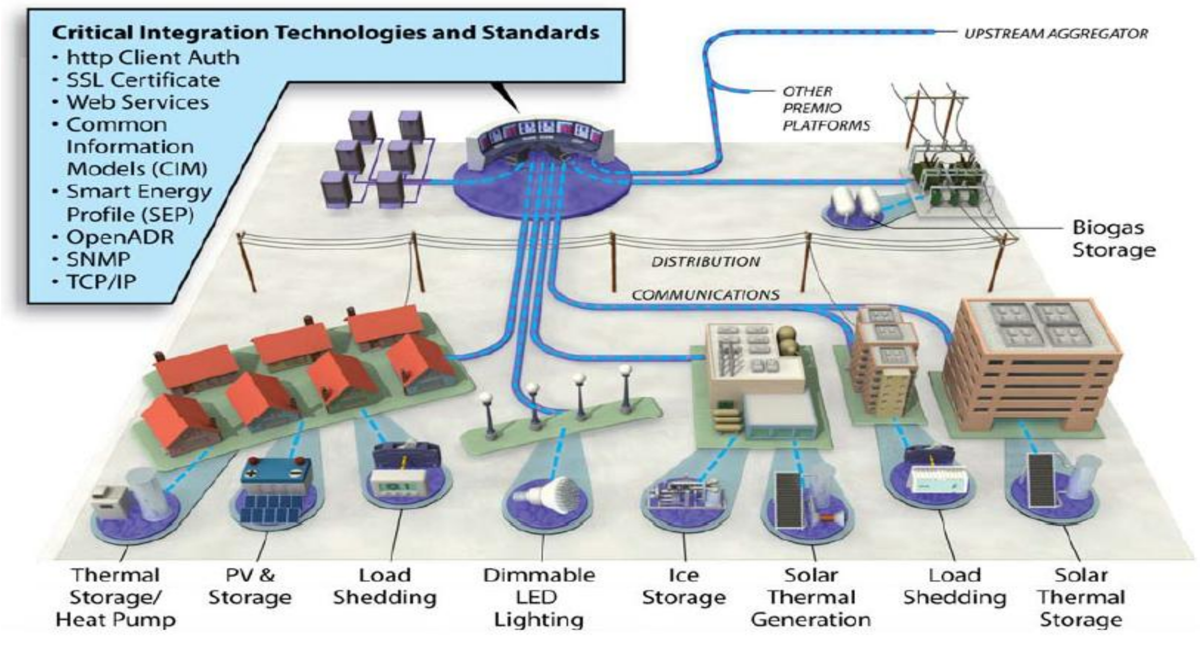


Figure 2.8 Energy applications explored in EDF Smart grid Demonstration

(EPRI/EDF, 2009)

The most significant property of this smart grid demonstration project is the primary focus being given to use a widespread renewable energy storage technologies assisted with biogas power plants. Variety of the technologies can also be interpreted as the site being feasible in terms of renewable energy sources. Engaging DER to electricity supply mechanism definitely plays a very positive and critical role on reducing stress over the grid and balancing the demand and response.

2.3.4.3 HECO Smart Grid Demonstration Project in Hawaii – USA

Hawaii is one of the USA states, and it is made up entirely of islands, and its geographical position is located in central Pacific Ocean. Primary energy needs of Hawaii comprising of transportation, and electrification are almost 90% dependent on imported fossil fuels. Therefore the state targets to increase the use of its own renewable resources like geothermal, solar, wind, wave, and waste-to-energy in their energy mix in order to build up a sustainable, cleaner, and secure energy supply. 2010 statistics show that the proportion of renewable energy is 10% of the total energy consumed, but the ambition is to increase this proportion to 70 % in 2030.

With the intention of reaching the mentioned target, 23 energy market actors and EPRI started a five-year smart grid demonstration project in 2011. The main objective of the project is to develop a virtual power plant mechanism that engages increased penetrations of renewable energy technologies to the overall energy system operations, appropriate power storage technologies and demand response. Figure 2.9 illustrates the overall structure of the demonstration project.

As depicted in the given figure below, high penetration of distributed energy resources is maintained. Wind and solar power technologies are widely deployed along with energy storage systems. Electric vehicle scheme is introduced for emission reduced dependency on imported fossil fuels, and for reduced GHG emissions.

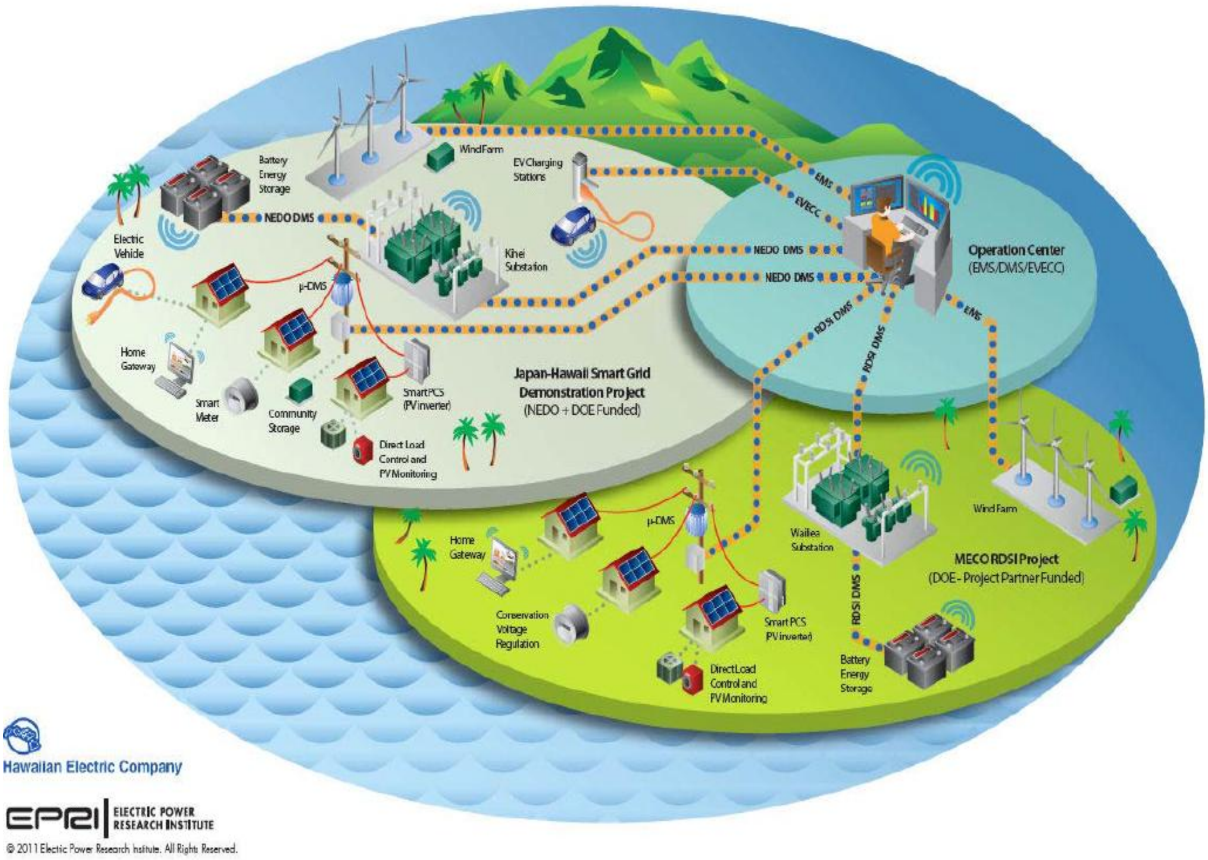


Figure 2.9 Structure of HECO Smart Grid (EPRI/HECO, 2011)

2.3.4.4 Exelon Smart Grid Demonstration Project in Philadelphia – USA

Exelon is a bridging project that links ComED and PECO projects (See Figure 2.10). ComED project is a customer energy use behaviour identification study that embeds smart metering, and in home displays as key technologies in order to explore the interaction between end user and the utility. The other partner component, PECO Energy Smart Campus project, is a microgrid application that involves on site wind and solar power generation technologies, thermal and battery storage applications, and an ICT solution for effective communication and management of local grid operations.

Figure 2.10 Exelon Smart Grid Demonstration Project (EPRI/EXELON, 2010)

Stated projects are brought together in a way that their strengths are united in order to construct a local scale smart grid prototype that targets improved interactions of residential end users with the local grid, and enhanced penetration of renewable energy sources coupled with storage technologies for sustainable grid operations.

2.3.4.5 Critical Review and Analysis of Smart Grid Example Projects

As stated earlier in this chapter, there is no solid definition for smart grids. When the given smart grid examples are taken into consideration, it is seen that they all differ from one another in terms of structure and functionality. The first identical difference is 100% renewable energy usage target in some projects, whereas some projects are hybrid applications that embed both renewable and conventional energy generation. Another difference is the presence of smart household appliances which are important devices in balancing the energy demand on the end user side. Additionally, it is seen that electric vehicle schemes are introduced in some projects for transportation related emission reductions, and for EV batteries to be used as energy storages for balancing the load on the grid. It is observed that logically all example projects adopt smart metering but only in one of them consumer feedback scheme via in home displays is implemented.

When those differences are interpreted, following two major influences appear as the cause:

1) Local policies, and local affordability
2) Site characteristics in terms of renewable energy potential and end use energy patterns

Despite the differences, there are a lot of common features that overlap in all given example projects. First of all, increasing the variations of the energy mix is at the leading strategy of the given example projects in order to establish a secure energy supply. Increasing the proportion of renewable and energy sources in the energy mix with the intention of clean energy production is another common feature of demonstration projects. Regardless of the type of technology, energy storage applications hold an important place in order to strengthen the energy supply. Finally and most dominantly, a sort of ICT infrastructure that brings smartness to the grid takes place at the heart of all demonstration projects. Utilization of such ICT infrastructure strengthens the grid stability against intermittent patterns of renewable energy sources, allows consumer engagement to the grid, and enhances operational and functional capabilities of electricity grids.

A structured taxonomy and analysis of smart grid demonstration projects can be found below. Given Table 2.2 depicts the technology (and/or application) decomposition of example smart grid projects, and highlights the presence frequency of such technology/application among selected projects.

Table 2.2 Classification of Demonstration Sites in terms of Smart Grid Technologies

Primary Integrated Technologies/Applications	***Demonstration Sites***				Frequency
	Ecogrid-EU	EDF	HECO	Exelon	
Demand Response Technologies	✓	✓	✓	✓	4/4
Thermal Energy Storage	–	✓	–	✓	2/4
Electric Storage	–	✓	✓	✓	¾
Solar PV	✓	✓	✓	✓	4/4
Wind	✓	–	✓	✓	¾
Distributed Generation	✓	✓	✓	✓	4/4
Grid (Network) Communication Technologies (Smart meters - AMI)	✓	✓	✓	✓	4/4
System Operations Integration	✓	–	✓	✓	¾
System Planning Integration	✓	✓	✓	–	¾
Facilitating Eco-friendly Behaviour (In home energy displays / smart appliances)	✓	–	✓	✓	¾
Electric Vehicle	✓	–	✓	–	2/4

When the data supplied with the table 2.2 are analysed, concerning presence frequencies of smart grid technologies/applications regarding selected smart grid demonstration sites, it can be extracted that demand response technologies are crucial elements for smart grid development. Additionally, distributed generation (dominated by renewable energy sources) is another key element of a smart grid. Moreover, smart metering infrastructure for effective grid communication between suppliers and end user appears to be the vital enabler infrastructure component that delivers bi-directional electricity and information. Furthermore, end user behaviour shifting technologies like smart appliances and in-home energy displays are seen as common applications that steer demand reduction functionality of smart grids. Lastly, Electric Vehicle technologies and enhanced ICT for effective control of the power network emerged as integral pieces of jigsaw puzzle that build up smart grid altogether.

When the stated smart grid examples are evaluated from the built environment perspective, smart meter installations, building scale renewable energy technologies, and smart appliances arise as key elements that bridge residential energy use and the smart grid concept.

Staying within boundaries of scope and limitations of the conducted research, in the light of taxonomy and analysis regarding smart grid demonstration projects supplied above, the term "*Smart Grid Implementation*" for residential sector can be described as a package for transformation of present electricity infrastructure that comprises:

- integrating local renewable energy sources as distributed generation for improved reliability and environmental sustainability of electricity supply
- installing smart meters to engage customers with the grid operations
- utilizing smart appliances/in home energy displays with the intention of reducing demand for energy

2.3.5 Need for transition in grid technology

In line with strategic energy policy objectives (European Commision, 2007b), the European Commission (EC) has put forward its vision for a Smart Grid (European Commision, 2006, European Commision, 2007a, European Commision, 2011a) which entails a paradigm shift from the present electricity network, based on centralized generation and top-down distribution, to a new digitalized grid, increasingly based on a distributed and networked architecture. A new grid architecture is a key enabler for the penetration of new technological applications for optimal management and control of the electricity grid (energy savings, reduction of maintenance/operational/disruption costs) and for the establishment of an internal energy market (new business models, new market players, consumer inclusion) (Wolfe, 2008; Battaglini et al., 2009; European Commision, 2011b).

Energy markets are changing rapidly and will lead to a substantial transformation of electricity systems. Conventional energies such as coal and nuclear power will increasingly be substituted by fluctuating renewable energy sources (RES) such as wind and solar power. A lot of this energy will be fed in to the low-voltage electricity grid. As periodically volatile consumption meets weather-dependent production, the exact balancing of demand and supply already is and will become a complex challenge (Mattern et al., 2010). Maintaining the stability of a power network is of key importance so as to prevent the occurrence of power outages, and to avoid damage to components of the system (Kundur et al., 2004). This is one of the most critical issues in the transition to less carbon-emitting energy supply systems within the next decades (Bedir et al., 2010).

Greenpeace and the European Renewable Energy Council (EREC) support the smart grid concept because it is an innovative approach to accommodate high percentage of renewable energy in a reliable and cost effective way and which is highly protected via intelligent management systems against blackouts and brownouts (Greenpeace, 2010). The Strategic Research Agenda released by the European Technology Platform (2007) indicates that EU adopts a Smart Grid vision to renew its aged transmission systems with a highly reliable, accessible and cost effective power supply across Europe.

With respect to the grid handling capacity for renewable energy sources, Butler argues that UK National Grid currently has the ability to cope with 10% intermittent energy (mainly renewable energy types like wind and solar) but with an increased interest in clean energy sources, current grid needs an upgrade to enable increased security and reliability to embed larger proportions of renewable energy sources into the energy scheme (Butler, 2001). This upgrade requirement of the present grid emerges the need for smart grid concept.

2.4 Concluding Remarks

In this chapter, characteristics of energy and built environment relation, and energy transmission and distribution systems (electricity grids), and the need for an upgrade and transformation in grid technology is covered in detail.

It is seen from the literature that, residential buildings are one of the major points that energy is consumed. It is widely known and well accepted truth that current conventional practices of energy generation emit Greenhouse Gases (GHGs) which cause climate change and environmental pollution. Additionally, fossil fuel sources used in conventional energy generation are in an increasing trend of depletion. Therefore, reducing the demand for energy in all sectors/areas including residential dwellings is vital for climate change mitigation.

Electricity networks or grids are the lines that electricity is transmitted and distributed to the end users. Literature highlights that present electricity grids are not robust as desired to prevent losses during transmission. Moreover, renewable energy integration capacity of the present grid is very limited due to the intermittent nature of renewable sources in a way that fluctuations in the supply may harm the installed grid. In addition, ICT infrastructure for dynamic controls, consumer communication, and operational management is very dramatically insufficient in present grids.

Smart grid concept emerged as a remedy to the problems addressed above. Although a solid definition does not exist, “smart grid” stands for electricity transmission mechanism with enhanced ICT for operations aiming loss reduction, increased renewable energy penetration, and increased participation of end users in the utility operations. Additionally, distinctions of two concepts, microgrids and Smart grids that bear resemblance to one another in some aspects are discussed.

In order to get a solid understanding of how smart grid trials are being implemented, four different projects are examined. After analyzing characteristics of stated projects in terms smart grid technology/application, “must-have” properties for implementing a smart grid in residential area (in this case neighbourhood) are identified as i) integration of local renewable energy technologies, ii) rolling out smart meters within project area, and iii) utilizing devices that aim to shift behaviour in energy consumption.

Due to the benefits offered by the idea of smart grid, mainstream environmental and political institutions strongly advocate the transition to smart grids.

The next chapter handles decision making and related methods. Furthermore, an appropriate decision making tool is identified, and dissemination of information and knowledge is discussed.

CHAPTER 3: DECISION MAKING

3.1 Introduction

In this chapter of the thesis, decision making concept, decision making techniques and selected AHP method, and geospatial decision making is elaborated. Relations of concepts with the conducted study are highlighted where appropriate. Moreover, effect of data visualisation on decision making is discussed.

3.2 Decision making concept

Decision making process, from a broader perspective, is described as the study of identifying and choosing alternatives based on the values and preferences of the decision maker (Harris, 1998). Making a decision implies that there are alternative choices to be considered, and in such a case the intention is not only to identify as many of these alternatives as possible but to choose the one that best fits to decision maker's goals, objectives, desires, values, and so on. An ideal decision environment can be described as medium where all possible accurate information and every possible alternative are included (Harris, 2009).

Baker et al (2002) suggest that a systematic decision making process should include the following eight steps explained below:

Step 1- Define the problem: It is the expression of the issue in a clear, generally one-sentence problem statement that describes both the initial conditions and the desired conditions.

Problem defined in this research: Management of prioritization and deciding on neighbourhood areas for neighbourhood areas in terms of smart grid applicability.

Step 2-Determine requirements: Requirements are conditions that any acceptable solution to the problem *must* meet. Requirements spell out what the solution to the problem must do.

Requirements determined for the case: Solution to the problem must identify the best-fit option (neighbourhood) in terms of energy vulnerability.

Step 3-Establish goals: Goals are broad statements of intent and desirable programmatic values. The process of establishing goals may suggest new or revised requirements or requirements that should be converted to goals. In any case, understanding the requirements and goals is important to defining alternatives.

Goals establish for the study:

- Prioritize the neighbourhood (in terms of schedule of a broader implementation project) within an area where smart grid transition will be applied.
- Maximising the sustainability benefits that smart grids offer, by scheduling the transition among neighbourhoods. (Starting the project from the most needed neighbourhood)

Step 4-Identify alternatives: Alternatives offer different approaches for changing the initial condition into the desired condition. The description of each alternative must clearly show how it solves the defined problem and how it differs from the other alternatives.

Alternatives for the case: In the conducted study, alternatives are neighbourhoods of an area where a smart grid project will be implemented.

Step 5-Define criteria: Decision criteria which will discriminate among alternatives must be based on the goals. It is necessary to define discriminating criteria as objective measures of the goals to measure how well each alternative achieves the project goals. Each criterion should measure something important, and not depend on another criterion. Criteria must discriminate among alternatives in a meaningful way.

All criteria regarding to the conducted research are extracted from the relevant literature (covered in Chapter 5) and are defined individually as follows:

- Energy performance of individual buildings
- Energy consumption of buildings
- Climate data of the area
- Smart meter availability at individual building
- Smart appliance availability

Step 6-Select a Decision-making tool: The method selection needs to be based on the complexity of the problem and the experience of the team. In common, simpler methods are preferred due to their ease of application. More complex analyses can be added later if needed.

Decision making tool selected for the study: AHP is adopted as decision making tool for identifying the importance of criteria which will then take part in the ontology prepared within a GIS environment.

Step 7-Evaluate alternatives against criteria: Alternatives can be evaluated with quantitative methods, qualitative methods, or any combination. Criteria can be weighted and used to rank the alternatives.

Evaluation of alternatives of the study: Neighbourhoods are evaluated via the ontology that is formed through weighted criteria.

Step 8-Validate solution against problem statement: After the evaluation process has selected a preferred alternative, the solution should be checked to ensure that it truly solves the problem identified.

Validation of the solution: the proposed model will be validated via focus group comprising academicians and industry professionals.

The following Figure 3.1 illustrates the aforementioned steps of general decision making:

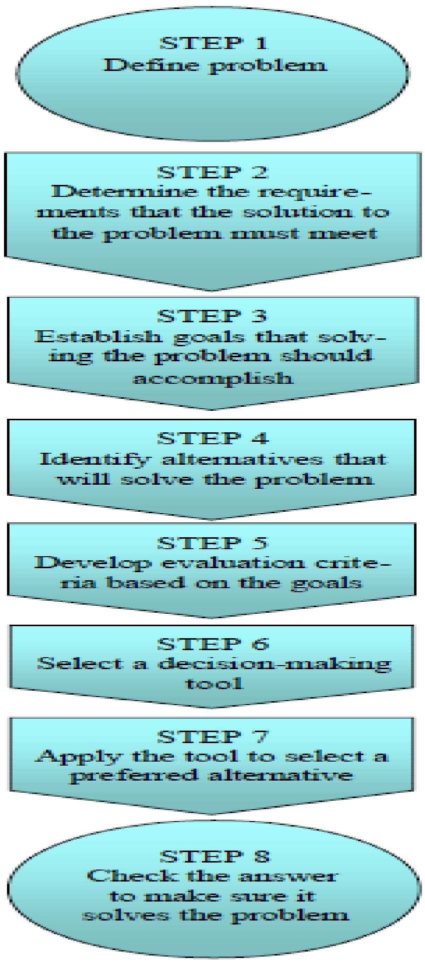


Figure 3.1 Decision Making Process (Baker et al, 2002)

Another systematically approached representation for decision making process incorporates main steps of decision making as Framing, Designing, Evaluation and Selection, and Verification and Implementation (Booty and Wong, 2010). See Figure 3.2 for a detailed breakdown of stated decision making process structure:

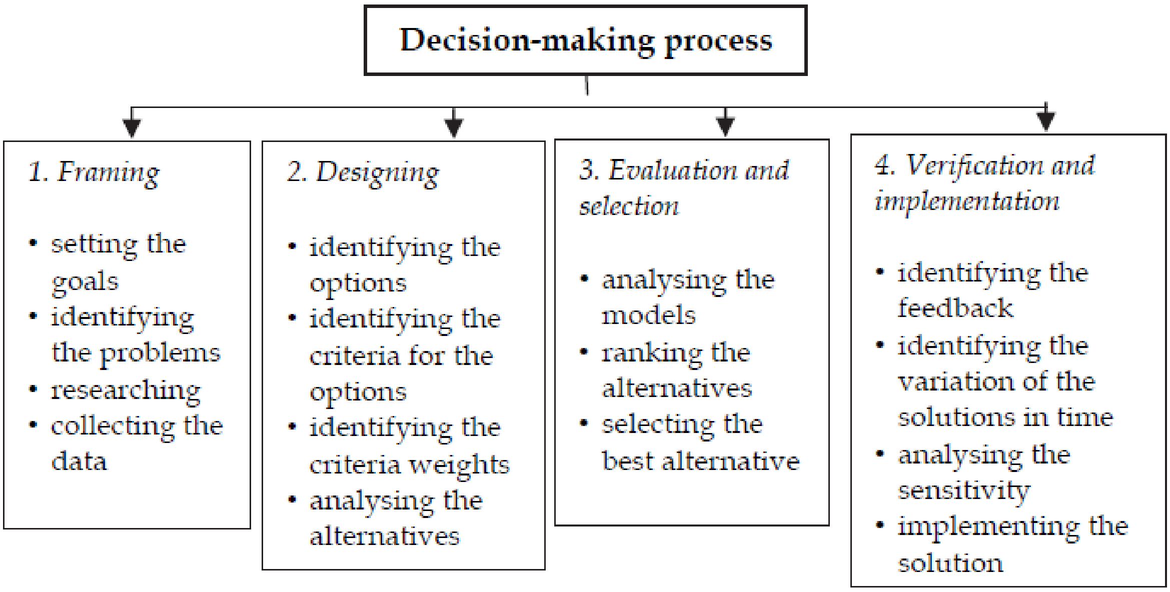


Figure 3.2 - Decision making process structure (Ibid)

All decisions differ from one another because of being specific to a problem's context. As extracted from the abovementioned literature on decision making process, the following should be considered when making a decision:

- Clear goals
- The problem(s)
- Criteria that shapes the efficiency of choice
- Solution and its variables
- Restrictions and risks within the problem's environment

Fulop (2005) points out the importance of identifying the nature of a decision problem in terms of presence of a single or multiple criteria. A decision problem may have a single criterion or a single aggregate measure like time. Then the decision can be made entirely by determining the alternative with the best value of the single criterion or aggregate measure. On the other hand, if the decision problem contains finite multi criteria and finite alternatives for solution, then the solution can be accomplished via applying an appropriate multi criteria decision method (MCDM). International Society on Multiple Criteria Decision Making (MCDM) defines MCDM as the study of techniques and procedures that aid integrating concerns about multiple conflicting criteria into the decision making process (Kou et al, 2011).

When the conducted study is considered, parameters like renewable energy utilization, energy efficiency and urban energy use patterns arise as the key criteria of sustainable implementation of smart electricity grid implementations at neighbourhood scale.

Due to the multiple criteria inclusion of the project as stated above, in order to achieve the decision goal, the study requires embedding a multi criteria decision method for conducting a multi criteria decision analysis (MCDA).

MCDA aids decision makers in analysing possible actions or alternatives based on multiple incommensurable factors/criteria. In other words, utilizing a decision system that deals with multiple criteria assists decision makers with to rating or ranking the alternatives

(Malczewski, 1999a;Figueira et al., 2005; Eastman, 2009). For mainstream practitioners of MCDA, it differs from quantitative optimisation in a way that concerns of subjectivity is also taken into consideration in quantitative approaches that structure and formulate a decision making problem (Belton and Stewart, 2002; Roy, 2005). The field is often referred to as multiple-criteria decision making (MCDM), but decision ―analysis or ―aiding (MCDA) better reflects the more subtle and broader-ranging intentions.

Following Figure 3.3 depicts the general structure of multi criteria decision making and it can be said that the given process flow is a specified iteration of general decision making process.

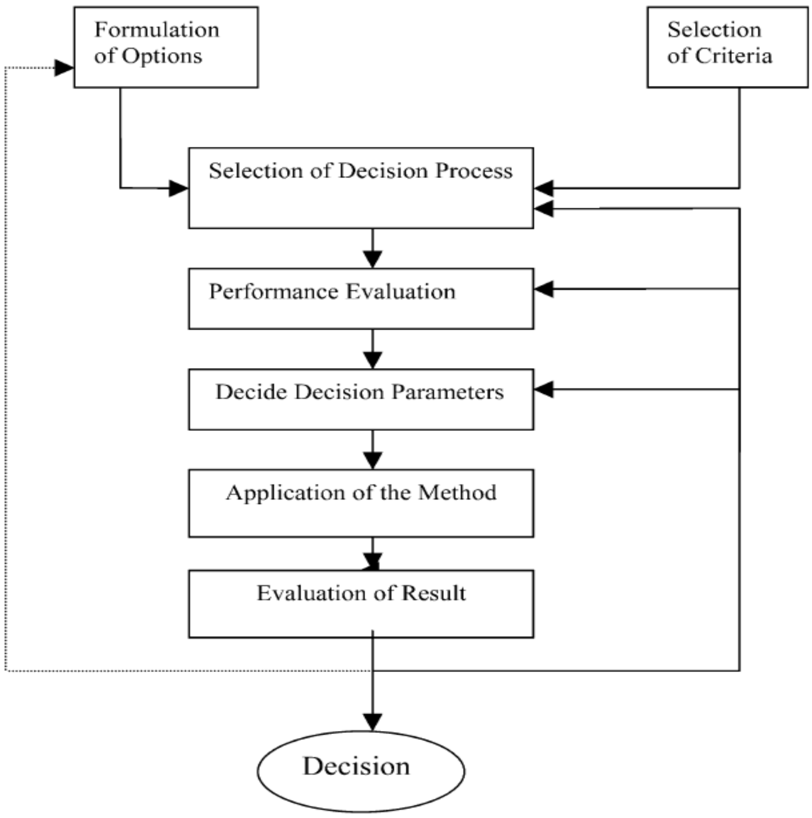


Figure 3.3 General structure of MCDM (Pohekar and Ramachandran, 2004)

MCDA methods are clustered as follows (Hobbs and Meier, 2000):

Outranking Methods:

- ELECTRE family (ELECTRE 1-2-3)
- PROMETHEE family (1&2)
- Regime Method Analysis

Value or Utility Function-Based Methods:

- Multi Attribute Utility Theory (MAUT)

- Simple Multi Attribute Rated Technique (SMART)
- Analytical Hierarchy Process (AHP)
- Simple Additive Weighting (SAW)

Other Methods:

- Novel Approach to Imprecise Assessment and Decision Environment (NAIADE)
- Stochastic Multi-objective Acceptability Analysis (SMAA)

As stated above, there are numerous MCDA methods developed to meet the needs of specific decision goals. Polatidis et al. (2006) highlighted that different multi criteria methods have been applied to energy and environment related issues.

Sufficient and appropriate methods are crucial instruments to maintain actions towards new and more efficient energy systems (Manfren et al., 2011). Stated instruments should represent the major concepts of the emerging visions, starting from the presently available technologies and practices (Deb and Srinivasan, 2006). Toloie-Eshlaghy and Homanyonfar (2011) have conducted a comprehensive literature review, based on 20 scholarly journals published between 1999 and 2009 and classified MCDA methods in accordance with the application areas (See

Table 3.1). MCDA methods and their implementation frequencies related to energy management studies are highlighted in the stated table.

Identification of weighting factors for the criteria is to be carried out via an appropriate method. There are three steps in utilizing any decision-making technique involving numerical analysis of alternatives (Triantaphyllou et al., 1998) :

- Determining the relevant criteria and alternatives.
- Attaching numerical measures to the relative importance of the criteria and to the impacts of the alternatives on these criteria.
- Processing the numerical values to determine a ranking of each alternative.

When selecting a suitable MCDA method, researcher considers the following:

- ✓ Ease of use
- ✓ Ability to support large number of decision makers
- ✓ Ability to handle data comprising different units (such as climate data and smart meters)

Overlapping these considerations with the classification supplied in the

Table 3.1, Analytical Hierarchy Method (AHP) appears to be a frequently used method in energy management field and arises as the suitable method for adoption. Briefly, AHP method is a ranking mechanism via applying pairwise comparisons of the alternatives of a specific decision problem (Kazibutzki, 2012).

Analytical (-or Analytic) Hierarchy Process (AHP) is further elaborated in the following section of this chapter.

Table 3.1– Classification of MCDA Methods According to the Application Areas (Toloie-Eshlaghy and Homanyonfar, 2011)

Application \ Method	AHP	ANP	SAW	TOPSIS	ELECTRE	LA	GP	MOP	VIKOR	DEMATEL	PROMETHEE	SMART	FMCDM	Group MCDM	Group Decision Making	multiple criteria analysis	MAUT/MAVT	Compromise Programming	SMAA	OWA	DSS	DEA	choquet integral	rough sets Theory	Fuzzy set theory	Heuristic Algorithms	Other Methods	Total (Fuzzy/Crisp)	Total
Environment Management	3				1			1			3			1	1	2	1	2	1		9						2	27	32
	1												3								1							5	
Water Management	5		1	1	2		1				3					3	2	3		1	2				1		3	28	29
																				1								1	
Business and Financial Management	9	4	1	5	1		2	1	1	1	1				1	1	1				1	1		1			7	39	65
	5	2		2									8	1							1				5		2	26	
Transportation and Logistics	14	11		8			6	7	2	1	2	1			2	1			1		2	2	2			5	12	79	118
	9			5	1		2	4	1			1	4	2											8		2	39	
Manufacturing and Assembly	4	1		1			1	5	1						1		1	1			3	2				8	5	34	48
	4			1			1				1		4	1											2			14	
Energy Management	5				2			3			3				1	1					1						5	21	24
													2												1			3	
Agricultural and Forestry Management	1						2									1	3				2						3	12	12
																												0	
Managerial and Strategic Planning	9	6		3	1	1	2	4		1	4				2	1	1				1	2				1	8	47	58
	3			1			1						5								1							11	
Project Management and Evaluation	11	4		4			3	1		1					2	1					2	1			1		9	40	51
	6												1	1							3							11	
Social Service	1	2		1			1	3																			3	11	12
				1																								1	
Military Service	2			1				1			1	1									1						3	10	13
															1						1				1			3	
Other topics	7	3	1	4				4			1	1	2				1		1		1	1	2		2		8	39	50
	3	1		1									4														2	11	
Non application Papers	38	3	2	10	7		15	16	3	1	3	1		1	4		7	1	8	6	12	8	6	2		4	72	230	274
	2			5				3					11					2							12		9	44	
Total	**142**	**37**	**5**	**54**	**15**	**1**	**37**	**53**	**8**	**5**	**22**	**5**	**44**	**7**	**15**	**11**	**17**	**9**	**11**	**8**	**44**	**17**	**10**	**3**	**33**	**18**	**155**	**786**	**786**

3.3 Analytical Hierarchy Process (AHP)

As justified in previous section, Analytical Hierarchy Process (AHP) is chosen and adopted as the MCDM tool for the prioritization process that forms the basis of this study. Highlighted by Tam et al (2006), AHP is developed by Thomas Saaty in 1970s as a multi-hierarchy-layer comparison method for MCDM and characterised by decomposition of a complex decision problem into a system of hierarchies. AHP employs mathematic decision analysis to determine the priorities of various alternatives using pairwise comparison of different decision elements with reference to a common criterion (Nobrega et al, 2009).

Kusiak oledjo (2002) stated that a major part of decision making involves the analysis of a finite set of alternatives described in terms of some evaluative criteria. Criteria defined for decisions are commonly measured on different scales (such as colour and length), and therefore they cannot be directly combined (Saaty, 1994). At this point, priorities for the criteria should be derived from pairwise comparisons by using ratios or judgements in order to cope with the problem of having different types of scales (Saaty, 1999).

In order to obtain priorities, Saaty (2008) offers to decompose the decision making into the stages mentioned below:

- Describing the problem and deciding on the type of knowledge required.
- Constructing the decision hierarchy in a top down manner starting from the top with the goal of the decision, then the objectives from a broad perspective , through the intermediate levels (criteria on which subsequent elements depend) to the lowest level (which usually is a set of alternatives).
- Structuring pairwise comparison matrices including importance matrix to derive relative priorities.
- Applying obtained priorities in order to extract the weighting factors to define the overall priory among the final level of alternatives.

A structured representation of decision making decomposition via AHP technique is depicted in Figure 3.4. In the stated figure, Step 1 maps out the general decomposition of a decision problem. Step 2 covers the Importance Matrix (that involves the ranking of criteria among each other according to their impact on the goal), and Pairwise Comparison Matrices which are formed for each single criteria applied to individual alternatives. Finally, Step 3 is the stage where Synthesis Matrix (which is a bridging of Importance Matrix and the Pairwise Comparison Matrices) is obtained in order to formulate and apply a sorting solution among alternatives identified for a decision problem. In other words, best alternative solution is identified via applying a set of rules that work as a filtering mechanism which is formulated by relative relations of criteria.

In order to perform comparisons, a scale is required for determination of dominance of one element on the other regarding to the criteria that those elements are compared (Saaty, 2008). The following Table 3.2 depicts the aforementioned scale offered by Saaty for comparisons.

Table 3.2 – AHP scale of importance (Taken from Pun, 2002)

Intensity of importance[a]	Definition	Explanations
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over other	Experience and judgement slightly favour one activity over another
5	Essential or strong importantce	Experience and judgement favour one activity over another
7	Demonstrated importantce	An activity is strongly favoured and its dominance is demonstrated in practice
9	Absolute importantce	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values Between the two adjacent judgements	When compromise is needed

Note: [a]If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*

Thomas Saaty (2005), the founder of the AHP methodology, stresses that decision processes often include intangible factors that can be hard to digest by human understanding and highlights the importance of deriving relative priorities in decision making process. AHP is a quantitative procedure applied to multi criteria decision problems and it is observed from the literature that AHP enables a medium for quantifying the qualitative features to reduce subjectivity in decision making (Partovi, 2001; Scott, 2002; Mishra et al, 2007).

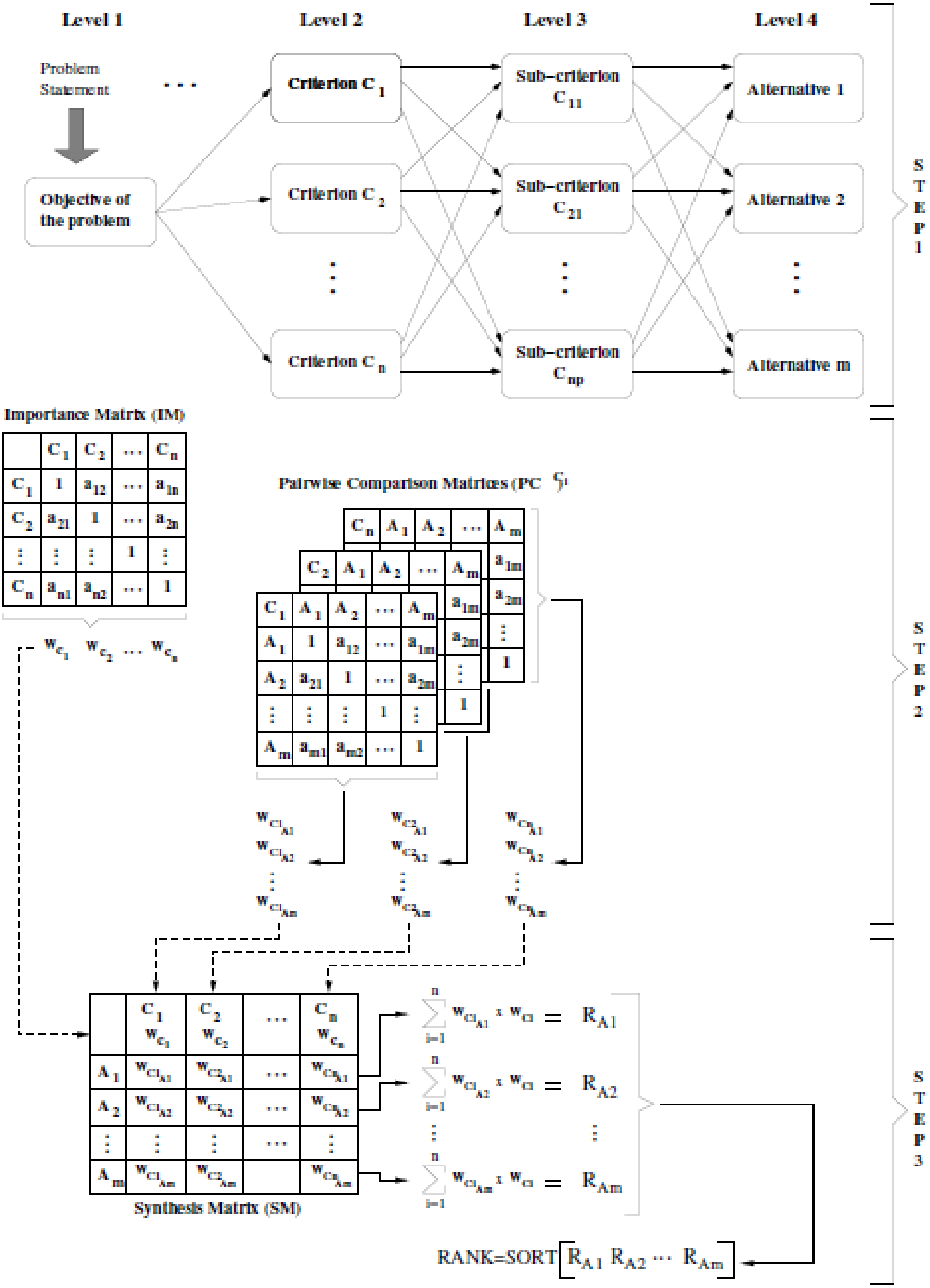


Figure 3.4 Decomposition of AHP (Cangussu et al, 2006)

3.4 Geo-spatial Decision Making

Campagna (2005) expresses that Geographical Information Systems (GIS) are approaches that offer wide range of reliable tools to support sustainable development led activities. Basic problems which have specific solution methods are easily solved by using GIS tools; however, when problems become complicated, the simple logic may not be enough for the solution. Decision Support Systems (DSSs) are developed to resolve more complex circumstances, and GIS is usually integrated as an enabler medium for the DSS development in order to meet such needs (Rodriguez-Bachiller and Glasson, 2004). Decision Support Systems are further explored and discussed in Chapter 6 which focuses on the specifications of the proposed Geospatial Decision Support System (GDSM) for smart grid applicability prioritization at neighbourhood scale.

As stated by Ali et al (2012), choosing a destination (in this case a neighbourhood for smart grid implementations) is a key player in decision making problems and therefore identifying the best alternative requires extra attention. Spatial decision making problems are not always structured or unstructured in real life but they may lie somewhere in between. Such decisions approaches are called "semi-structured", and most of the real life spatial decision problems are semi-structured (Malczewski, 1999b). Semi-structured decisions require cooperation between computer-based systems and decision. Spatial Decision Support Systems (SDSSs) can cooperate and organize all of the activities and interests with respect to decision maker's intention. Such systems simplify the relations of ideas, and evaluation of results and decisions. In other words, a DSS assists sharing the information among decision makers and concerns multiple criteria in a more rational and structured way (MacDonald and Faber, 1999).

Seffino et al. (1999), discuss that GIS is well known for providing a variety of analyses and visual demonstration of cartographic data, but they underline that its capabilities are limited in assisting the user to select the suitable functions for a specific intention, or to interpret the results. Considering spatial decision processes, a series of tasks are required in order to obtain results. Decision makers need to create the database relations and models, determine the suitable modeling strategies, go for the related data sets, and choose the analyses flow so that results of analyses can be demonstrated and solutions of the problems can be interpreted (Zhu et al., 1998). As a remedy to limited capabilities of GIS, integrating developed modeling algorithms incorporating complex analytical methods has the potential to turn GIS into a tool/method that adds value to SDSS by generating diverse geospatial visualisations of cartographic data associated with structured decision making problem (De Silva and Eglese, 2000).

MCDA methods have been intended for spatial problems by fulfilling the problem requirements with capabilities of geographic information systems (GIS) (Carver, 1991, Malczewski, 2006). It is observed from the literature that GIS has been used in many research approaches as well as real-life industrial cases as a method/tool for developing Spatial DSS. For example, Girardin et al. (2010) propose a SDSS in Italy which comprises GIS based evaluation of urban energy conversion technologies in urban regions. Banai (2005) suggests a SDSS prototype based on land resource sustainability for urban development in which Analytical Hierarchy Process is used as an MCDA within GIS environment that combines public policies and sustainability criteria in order to identify the best locations for future sustainable urban development. Rylatt et al. (2001) conducted a study to develop a SDSS for solar energy planning in urban environments. Howard et al. (2012) developed a decision support tool in GIS to assess building energy end use at an urban scale.

Malczewski (2006) suggests a decision flowchart for spatial multi criteria analysis and benchmarks phases of geospatial decision making process against GIS and MCDM (Figure). The stated figure depicts that problem definition including evaluation criteria and constraints form the intelligence phase that is covered with GIS. Multi Criteria Decision Methods (MCDM) forms the design phase that is used for the formulation of decision process involving decision rules and alternatives and so on. Finally, GIS and MCDM overlap to form a basis for the choice phase that includes sensitivity analysis and the recommendations made by the decision system.

Considering the literature on 'decision making' and 'geo-spatial decision making' it can be said that a tailor made geospatial decision support model is a highly required tool for implementing urban projects that have multiple dimensions comprising environmental, technological, economical parameters and so on.

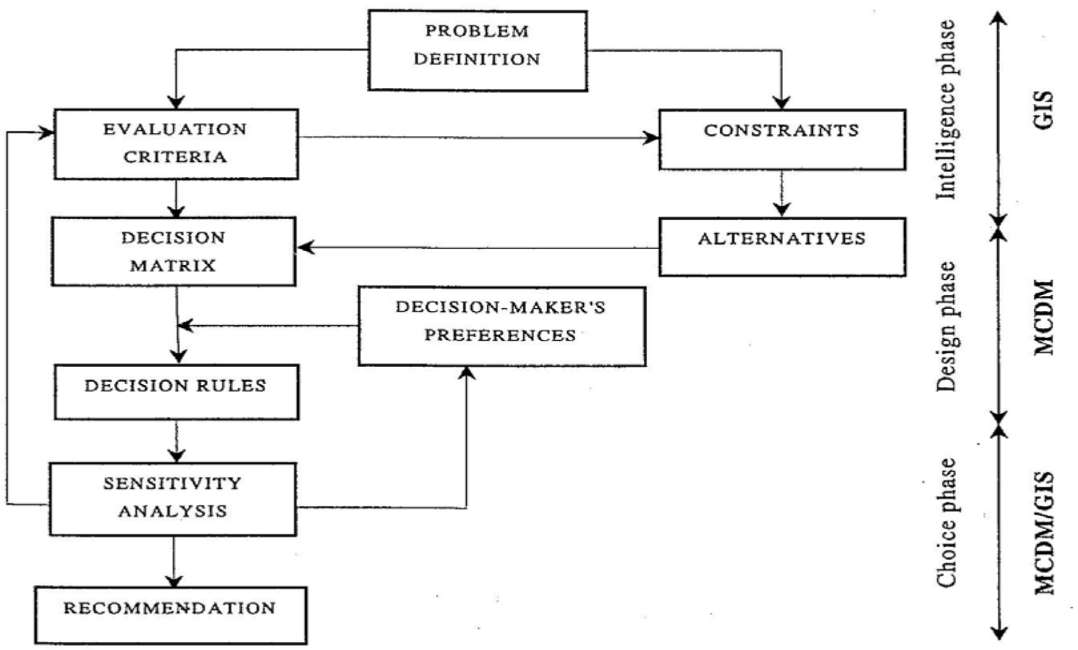


Figure 3.5 Decision flowchart for spatial multi criteria analysis (Malczewski, 2006)

3.5 Data Visualization and Decision Making

Visualisation of data is known to be an effective way of understanding/digesting the information presented. The reason for that , most of the other data presentation types require conscious thinking by the audience but visualisation shifts the balance between perception (seeing)and cognition (thinking) (Few , 2013).

People making decisions use visualization to explore and question the findings before they develop action plans (Myatt and Johnson, 2009). A well known solid example of data visualization directly influencing decision making dates back to 1855, when John Snow's study accurately traced the cholera epidemic to specific locations of contaminated water pump-wells. The visualization became a critical tool to inform, educate, and finally prompt decision makers to shut down those water pumps to save lives (Yudin, 2011).

Data visualisation is representation of the information that is made simpler for human understanding and it works as an enabler for extraction of knowledge through information. In that sense, knowledge discovery enabled via data visualization is schematized by Wijk (2005) in Figure 3.6.

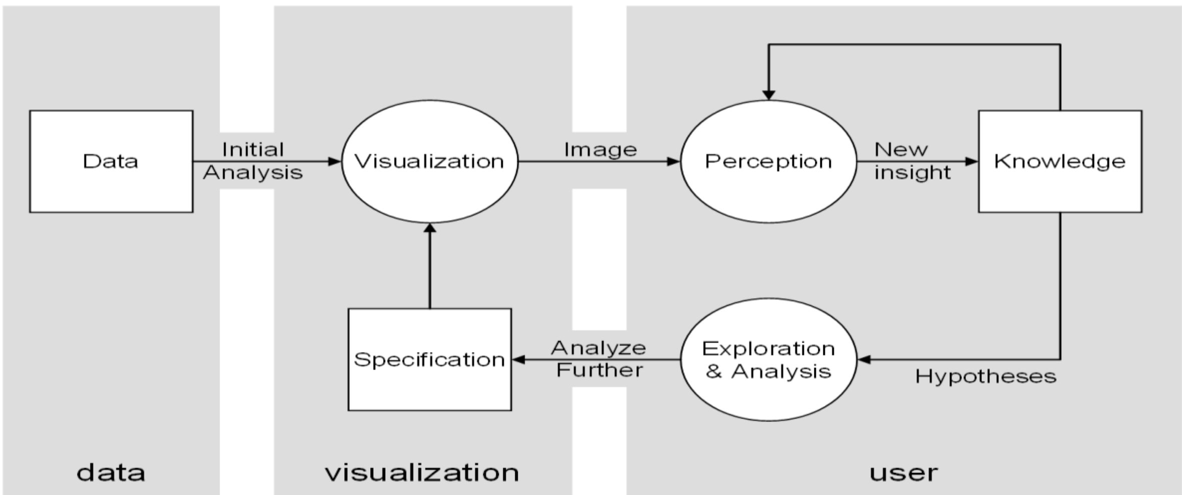


Figure 3.6 Combining Data, Visualisation, and User for Knowledge Discovery (Ibid)

From the perspective of the conducted research, analysis involved for data processing are geospatial statistics and clustering that are specified in Chapter 6 which deals with the structure and functionality of the geospatial decision support model.

Andrienko, N., and Andrienko, G., (2006) express that it may not always be likely to assess decision alternatives via numerically represented criteria, especially in cases involving spatial features which suffer from availability of sufficient numerical depiction. In such occasions, it is the time for decision makers to use their experience and knowledge to assess the solution alternatives (Ibid).

Visual perception plays a key role in “understanding”, and therefore it can be said that visualization and interactive structured visual interfaces are crucial platforms that support the inclusion of humans in problem solving by their intention of providing materials for decision makers for analysis and interpretation (Andrienko et al, 2009).

As digested from the related literature, decision process is highly influenced from human factors. In decision making problems, data is processed with computers, and therefore communication between computers and decision makers (humans) should be optimised. Visualisation arises as a bridging function for decision makers to digest the information supplied with computers, and data visualisation acts as an enabler platform that makes knowledge discovery through information possible for the decision makers. Given Figure 3.7 depicts the linkages between visualization, data analysis, and their interaction with decision makers.

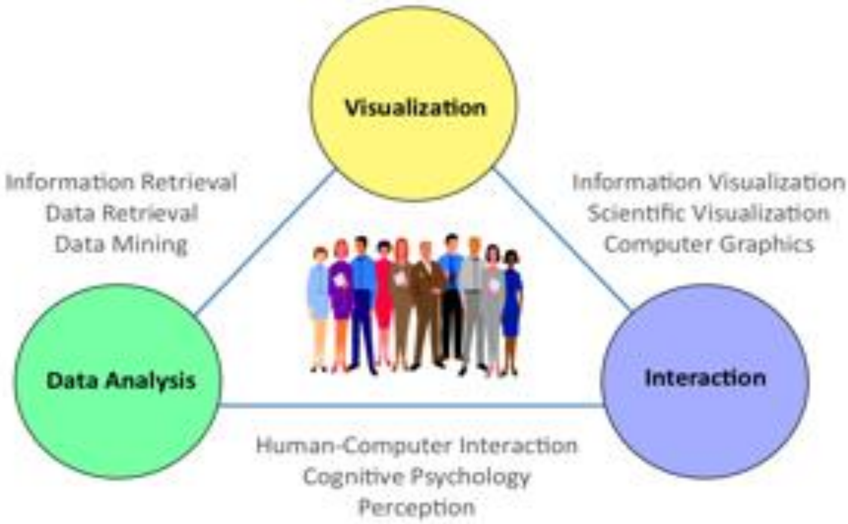


Figure 3.7 Linkage between interaction of decision makers, visualization and data analysis

(http://www.vismaster.eu/faq/related-research-areas/)

In other words, when human factors like cognition and intelligence are combined with data processing capabilities of computers, it is possible to make decisions with improved accuracy.

To sum up, it is obvious that data visualisation make it possible for users (humans) understanding the information in a simplified manner. From a decision making perspective, optimised interaction of decision makers with computerised analysis is crucial for robust interpretation for decision. Due to the benefits offered by data visualisation, proposed GDSM is structured concerning data visualisation approach for interpretation of included information and dissemination of knowledge.

3.6 Concluding Remarks

In this chapter, features of decision making process are covered in detail. Decision problems are categorized in accordance with the quantity of criteria involved in decision processes. As the conducted research requires inclusion of multiple criteria like building energy performance, presence of smart technologies, and availability of on-site renewable energy it is identified that the conducted research falls into the category of multi criteria decision making (MCDM).

It is seen from the literature that there are various available approaches developed for multi criteria decision making according to the specific needs of decision problems. At this point, concerning the requirements of the conducted research, Analytic Hierarchy Process (AHP) is adopted as the MCDM tool to be utilized in proposed GDSM. Although AHP has a major limitation of requiring all criteria to be fully depicted and accounted from the very beginning of decision making process (Palcic and Lalic, 2009), its ability for prioritization of alternatives and minimizing subjectivity whilst quantifying the intangibles makes it the most appropriate method for integrating with the conducted study. As the study is within a spatial domain due to the applicability issues of smart grids, spatial decision making techniques are also elaborated, and a GIS based decision support model raised as a crucial requirement for the decision problem dealt with.

After selecting the suitable tool for decision making, it is time to develop a strategy to disseminate the information effectively to decision makers so that a vigorous decision can be made. With its capabilities in aiding knowledge discovery, and strengthening the interpretation for decision makers, data visualisation is also taken into consideration.

The next chapter elaborates research methodology, and it formulates an appropriate methodology adopted for the conducted research.

CHAPTER 4: RESEARCH METHODOLOGY

4.1 Introduction

This chapter of the thesis covers the descriptive aspects of 'research', and 'research methodology'. Additionally, stages of the research including methods, procedures and models of research methodology are constructed in the form of a conceptual structure which is known as 'research design'.

4.2 Definition of 'Research' and 'Research Methodology'

The term "research" is a process of collecting, analysing and interpreting information to answer questions. A 'research' is conducted with the intention of determining, interpreting, improving, and developing standards to systematize measurements and help the progression of knowledge. In order to qualify a study as "research", the process should fulfil the following:

- It should be undertaken within a framework of a set of philosophies,
- It should utilise procedures, methods and techniques that have been tested for their validity and reliability.
- It is designed with respect to being unbiased and objective.

Philosophy can be described as belief which employs the cause and logic in an attempt with the intention of understanding reality and find answer to fundamental questions in relation to;

- Knowledge
- Life
- Morality
- Human nature

According to Collis and Hussey (2009), the term research methodology "refers to the overall approach to the research process, from the theoretical underpinning to the collection and analysis of the data". There is no best way in doing research but rather more suitable choices depending on the researched phenomenon, the research question, the conditions in which the phenomenon comes into being and the researcher's view of the world. The research philosophy of a research effort contains important assumptions about the way the world is being viewed and underpins the research strategy (Saunders et al., 2009). Therefore, it is important to clarify the researcher's position.

Saunders et al. (2009) describe research process within a concept of 'Research Onion' (illustrated in Figure 4.1) that comprises different layers where each layer of the onion refers to a research aspect beginning from the outer layer of *Philosophy* and narrowing the research down till *data collection and analysis* stage which is the centre layer. Layering is a formulation of the research process.

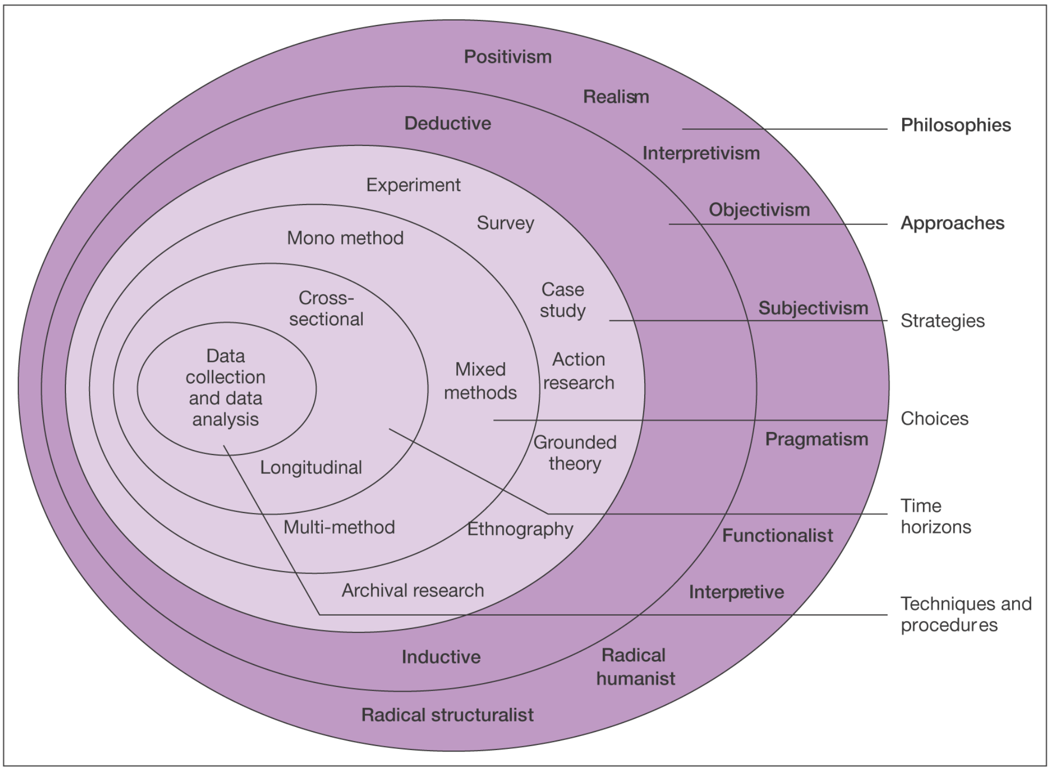


Figure 4.1 Research Onion (Saunders et al., 2009)

Overall research methodology will be discussed in the same manner of layering concept but not strictly in accordance with the mentioned research onion.

Additionally, where appropriate, layers are going to be individually described; the alternatives taking part in each layer are going to be listed, and it is going to be discussed why or why not the particular alternative is possible to adopt for the conducted research.

4.2.1 Research Philosophy

The three main aspects of research philosophy are ontology, epistemology and methodology. Scientific stance over the nature of being is labelled as ontological choices. According to (Crotty, 1998):

> "Ontology is the study of being. It is concerned with 'what is', with the nature of existence, with the structure of reality as such. ... it would sit alongside epistemology informing the theoretical perspective, for each theoretical perspective embodies a certain way of understanding 'what is' (ontology) as well as a certain way of understanding 'what it means to know' (epistemology)."

Consequently, epistemology is "the theory of knowledge embedded in the theoretical perspective and thereby in the methodology ... An epistemology ... is a way of understanding and explaining how we know what we know" (Crotty, 1998).

At least three positions of epistemology have emerged; objectivist epistemology, constructivist epistemology and subjectivist epistemology (Gray, 2009). The research methodology is shaped by the explanation of how we know what we know (See Figure).

According to Easterby-Smith et al. (2008), having an epistemological perspective is important for two reasons. Firstly, it can help to clarify issues of research design. Secondly, knowledge of research philosophy will help the researcher to determine which research design will yield meaningful answers to the research question.

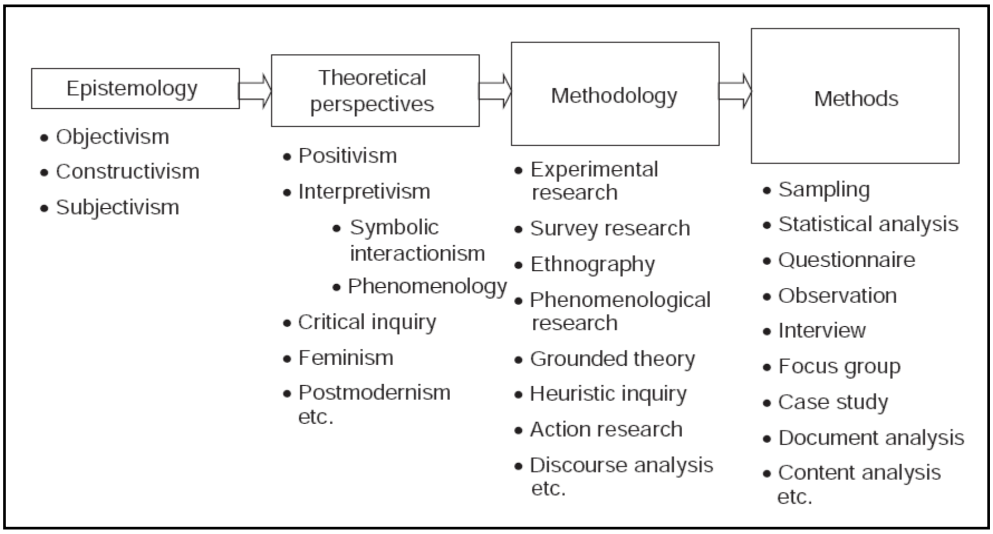


Figure 4.2 – The Relationship between Epistemology, Theoretical Perspective, Methodology and Methods (Adapted from (Gray, 2009))

Crotty (1998) defines objectivism as "the notion that truth and meaning reside in their objects independently of any consciousness". In objectivist view, "social entities exist in reality external to social actors concerned with their existence" (Saunders et al., 2009). Reality, which can be objectively observed and is 'out there', is independent of the actor's actions and experiences. Constructivism challenges objectivism by claiming "truth and meaning do not exist in some external world, but are created by the subject's interactions with the world" (Gray, 2009). Subjects construct their own meaning on the same phenomenon in different ways. Subjectivism, on the other hand, argues that "social phenomena are created from the perceptions and consequent actions of social actors" (Saunders et al., 2009). Subjectivism claims that "meaning does not emerge from the interplay between the subject and the outside world, but is imposed on the object by the subject" (Gray, 2009).

Asserting that objective truths and meanings exist independently of human consciousness, objectivism encapsulates the spirit of the Enlightenment and the 'Age of Reason' in seventeenth-century England (Crotty, 1998). Objectivist epistemologies are associated with realist ontologies which view reality as an external objective phenomenon, existing independently of human consciousness (Guba and Lincoln, 1994).

The term paradigm refer to the progress of scientific practice based on people's philosophies and assumptions about the world and the nature of knowledge; in this context, about how research should be conducted (Collis and Hussey, 2009).

Selecting the research methodology appropriate to a research is very important for research problem and questions to be explored (Yin, 2008). Correct research methodology for any research provides the right research philosophy, approach and techniques adopted for each research topic. The concept of research philosophy refers to the progress of scientific practice based on people's views and assumptions regarding the nature of knowledge. There are two main views on the nature of knowledge: the positivism paradigm and the phenomenological one (Collis and Hussey, 2009). In between the two views, pragmatism philosophy; share characteristics of the two views. Some researchers call it mixed approach (Johnson and Onwuegbuzie, 2004). The goal of mixed philosophy is not to replace either of these paradigms but rather to draw from the strengths and minimise the weaknesses of both in single research philosophy and across studies. Logical positivism uses quantitative and experimental methods to test hypothetical-deductive generalisations. In contrast, Phenomenological inquiry uses qualitative and naturalistic approaches to inductively holistically understand human experience in context- specific setting (Amaratunga et al., 2002). The positivist approach seeks the facts or causes of social phenomena, with little regard to the subjective state of individual. Phenomenology is concerned with understanding human behaviour. Phenomenology is an example of an interpretive approach, which concentrates upon induction and the meaning of the findings in the view of the participants, rather than upon hypothesis testing, measurement and deduction.

Key to the positivist model was that science could produce objective knowledge. Thus the purpose of research was to uncover objective truths (Crotty, 1998). To capture and accurately represent an objective truth or reality, it was argued that the researcher must remain objective (Hammersley, 2000). Essentially the researcher was viewed as an `outsider', an independent observer, rigorously gathering data and reporting objectively on this data. The researcher's subjectivities were not allowed to impact on the research process as it was believed that this would lead to a distorted, invalid picture of reality. Neville (2005) states that positivistic approaches seek to identify measure and evaluate any phenomena and provide rational explanation to it.

As seen from the literature covered regarding philosophy layer of the research onion, there are two leading alternative philosophies: positivism and interpretivism. According to the positivist ontology there is a single, external and objective reality to any research question regardless of the researcher's beliefs. On the contrary, interpretivists believe that the reality is relative and multiple. The researcher of this study approaches the matter from the perspective of suitability and validity of the alternative in terms of achieving the research question, aim and the objectives. The research question seeks identifying best alternative among neighbourhoods in terms of smart grid applicability, and the objectives which pave the way for achieving research goal in systematic and quantitative scientific approaches that lead to uncover the objective reality that is independent of subjective thoughts of the researcher. Therefore it can be said that research philosophy to be adopted throughout the research is positivism. Additionoally, it is worth expressing that throughout the conducted study the researcher's epistemological stance is objectivism as the study requires real world conditions to be compared with physical indicators.

4.2.2 Research Approach

There are two general approaches to reasoning a research which may result in the acquisition of new knowledge. These approaches are known as 'Inductive Research' and 'Deductive Research'. Inductive Research is a theory building process, starting with observations of specific instances, and seeking to establish generalisations about the phenomenon under investigation. Deductive Research is a theory testing process which commences with an established theory or generalisation, and seeks to see if the theory applies to specific instances (Hyde, 2000). Neville (2005) states that deductive approach moves from general ideas to particular situation and on the contrary inductive research moves from particular situation. Given Figure 4 illustrates how deductive and inductive approaches are structured.

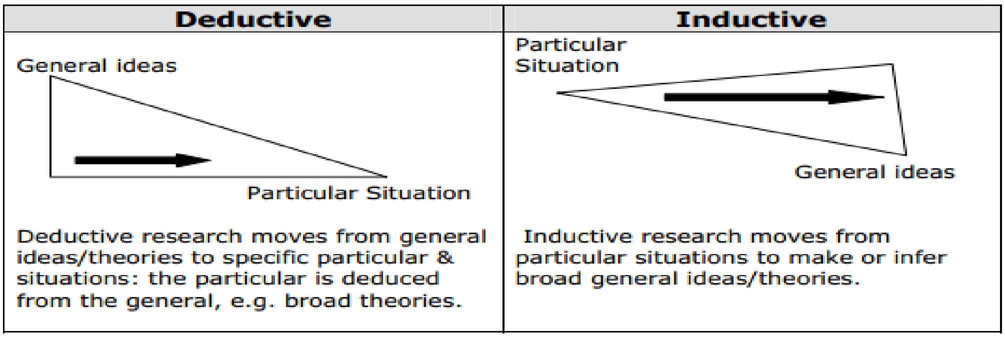


Figure 4.3 Comparison of Deductive and Inductive Research (Neville, 2005)

The conducted research starts with a particular situation of smart grid applicability and moves toward reasoning of smart grid transition with maximized benefits of sustainability. The researcher seeks to develop a model for prioritization of neighbourhoods in smart grid realization projects. Validation of the proposed model makes it applicable to all projects with similar constraints. As the research tends to generate general ideas from particular situation, adopted research approach in this study is inductive.

4.2.3 Research Strategy

Schell (1992) believes that research design requires a choice of research strategy. Saunders et al. (2009) describes the research strategy as a generic plan guiding the researcher to answer the specific research questions. Näslund (2002) argues that the selection of research method should be based on the research paradigm due to the fundamental nature of the research processes which are generally involved with a particular research strategy and method. There are various different research strategies. These are namely Experiment, Survey, Archival Analysis, History and Case Study. Given Table depicts the type(s) of strategy(ies) a research can utilise for research.

Table 4.1 Different Research Strategies (Yin, 2008)

Research Strategy	Form of Research Question	Control Over Behavioural Events?	Focuses Contemporary Events?
Experiment	How, Why	Yes	Yes
Survey	Who, What, Where, How Many, How Much	No	Yes
Archival Analysis	Who, What, Where, How Many, How Much	No	Yes / No
History	How, Why	No	No
Case Study	How, Why	No	Yes

Archival analysis and history research strategies are out of the scope of the research topic, therefore “experiment”, “survey”, and “case study” research strategies are considered as alternative research strategies for this study.

To start with experimental strategy, it is important to note down that empirical measure of the process is the only option. An experimental strategy is generally about establishing whether certain conditions produce better results. The approach is monitoring effects of the changes in conditions. For the conducted study, it can be said that there are at least two conditions (climate data, and building energy use) requiring empirical measurements that should be conducted at a neighbourhood scale (indeed it should be repeated in two different neighbourhoods so the better alternative can be identified). Due to lack of funding and other technical constraints, experimental research strategy is not a viable option for the particular research.

Secondly, Survey research strategy is the use of questioning as an enabler to elicit information from the participants. For the conducted research, interviews and questionnaires have been carried out with the intention of collecting data regarding identification of priority vectors of smart grid applicability criteria. As the research on the overall requires complex analyses and mathematical modelling for developing smart grid applicability assessment mechanism, survey research strategy is far from meeting the needs of the study, and therefore it cannot go beyond being a data collection tool throughout the study.

The third research strategy alternative is the “case study” research. Yin (2008) believes that the purpose of using a case study research is to do an in-depth exploration of the territory, to identify and describe the phenomena, or to identify the key concepts. This type of detailed inquiry is often part of a research design or, at a minimum, requires the use of data. Moreover, multiple cases serve to strengthen the results by replicating the pattern matching, thus increasing the level of confidence in the robustness of the theory. Each individual case study consists of a “whole” study, in which facts are gathered from various sources and conclusions are drawn on these facts (Yin, 1994).

From a case study perspective, Blaxter et al. (2010) defines exploratory research as the process undertaken when few or no previous studies exist. The aim is to look for patterns, hypotheses or ideas that can be tested and will form the basis for further research.

Suárez Bello (2003) suggests that there are several reasons to conduct a case study. These include:

1. The exploration of a question, program, population, issue or concern in order to determine appropriate research questions to facilitate future research.
2. The explanation of linkages between causes and effects.
3. The description of the real-life context in which an intervention has occurred.
4. The description of the intervention itself.
5. The exploration of those situations in which the intervention being evaluated has no clear set of outcomes.

Gray (2009) mentions that case study process comprises stages of: i) Defining and Designing ii) Preparing, Collecting and Analysing iii) Analysing and Concluding. Moreover, Yin (2008) illustrates the internal steps of a general case study (and/or multiple case studies) method as follows:

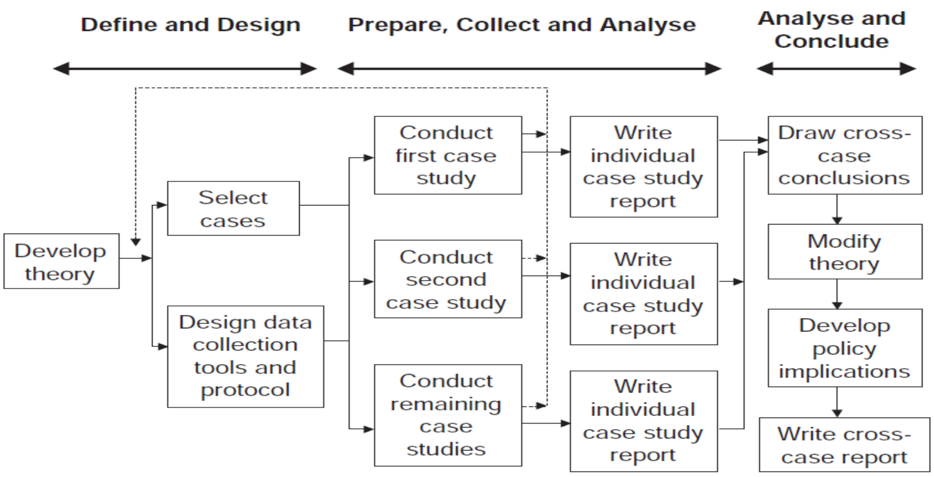


Figure 4.4 Multiple case study method (Adopted from Yin (2008))

The conducted research requires the following in accordance with the case study structure:

- selecting a specific case (smart grid implementation)
- designing data collection (questionnaire)
- analysis (AHP, geospatial benchmarking)

Additionally, the conducted study explores ‘residential energy use’ and ‘smart grid’ issues within a real-life context and intends to explain relations between cause and effect regarding to the transition process of electricity networks. In line with these stated points, the researcher adopts ‘exploratory case study’ as research strategy throughout the conducted study. Multiple case studies will be utilized whilst carrying out the research in order to involve comparisons of single phenomena which in this case are the comparison of alternative neighbourhoods in terms of smart grid applicability in order to identify the best option.

4.2.4 Research Choice

A research method can either be quantitative or qualitative. As described by Bryman (2012), research may incorporate the following alternative methods:

- mono-method (single-method) : a quantitative or a qualitative method on its own
- mix-methods : quantitative and qualitative methods used together
- multi-methods : multiple use of methods in a way that either ‘quantitative only’ or ‘qualitative only’

Noor (2008) believes that the choice of which method to employ is dependent upon the nature of the research problem and the actual suitability of a research method derives from the nature of the phenomena to be explored.

In order to achieve the aim of the study, mix-methods are adopted as research choice. The reason for that is at some stages of the study, data collection incorporates questionnaires that extract qualitative data in a form of subjective opinion of individuals (member of academia or industry) whereas on the other hand quantitative methods are utilized for identifying the renewable energy production yield of the specific area (neighbourhood).

4.2.5 Time Horizons

Time horizon focuses to keep time within the limits of a research. Kerlinger (1994) claims there are two types of time horizon; longitudinal and cross-sectional. Longitudinal is when the researcher set an order for the research tasks and work on a single task at a time, whereas cross-sectional is when the researcher works on multi-task at once.

Adopted time horizon of the conducted study is 'cross sectional time horizon' because the researcher requires working on multi-task such as collecting data, developing the model and strengthening the understanding via the literature at once.

4.2.6 Data Collection

This section elaborates the data that is needed in the study and method(s) of collecting the stated data. This research is being conducted in line with the University of Salford's code of ethics. Ethical approval procedure has been completed (a copy of ethical approval can be foun in appendices).

4.2.6.1 Description of the data types and data sources used

Data collection methods and associated topics covered in this part is extracted and compiled from Kumar (2011) and Dawson (2002). Bridging the data collection issues and the conducted study is supplied where appropriate.

To start with the data types, it can be said that there are two main sources of data:

- Primary data : data that has been collected for the first time
- Secondary data : data that has already been collected and analysed by someone else

Throughout conducting the research, the researcher adopts both primary and secondary data. Primary data collected comprised the questionnaire (which will later be elaborated; see a copy of the Questionnaire in Appendices) that was targeting experts (academics and industry professionals) for obtaining the rate of importance of the predefined criteria.

Semi structured interviews are also used for gathering in-depth data from experts and academicians (See chapter 5 for details).

Secondary data being used in the research can be exampled as the datasets that are available to public. The first source of secondary data is Master-Map topographical data (which is a GIS based layer that covers footprints and height data of buildings) from Ordnance Survey (OS) and it is an open access source for academia. OS MasterMap Topography Layer provides a highly detailed view of Great Britain's landscape including individual buildings, roads and areas of land. In total, it contains in excess of 400 million individual features. This will be utilized for creating base for geospatial data for buildings in neighbourhoods. A screenshot of the stated topography layer is given in Figure 4.5

Figure 4.5 Screenshot of MasterMap Topography Layer (Ordnance Survey, 2012)

With the help of stated topography layer, a platform can be build up for anchoring spreadsheet data pack (which will include the data of the aforementioned criteria) and benchmarking the data pack with individual buildings. Semantic relations between data types and evaluations will be carried out within the proposed platform, which in this case is called Geospatial Decision Support Model (GDSM).

For the stated spreadsheet data pack, ‘secondary’ data for each criterion is as follows:

Building Energy Performance: Building energy performance will be presented in the form of Energy Performance Certificate (EPC) for each building. National (UK) postcode based EPC database has been used for obtaining address based EPC data.

Home energy rating schemes are widely accepted and operate in many countries. HERS or HERS-type schemes exist in a variety of forms and the means of assigning a rating can vary from compliance with prescriptive guidelines, a standard (sometimes manual) calculation, a correlation technique, and simple or full simulation. HERS adopted in the UK is ‘Energy Performance Certificate’ (EPC).

The Energy Performance Certificate (EPC) is broadly similar to the labels now provided with domestic appliances such as refrigerators and washing machines. The European Directive on the Energy Performance of Buildings (EPBD) dictates that it is required by law that every building in EU must have an approved EPC by the end of 2008.

Its purpose is to record how energy efficient a property is as a building. The certificate will provide a rating of the energy efficiency and carbon emissions of a building from A to G, where A is very efficient and G is very inefficient. Given Figure illustrates an example energy efficiency graph for homes.

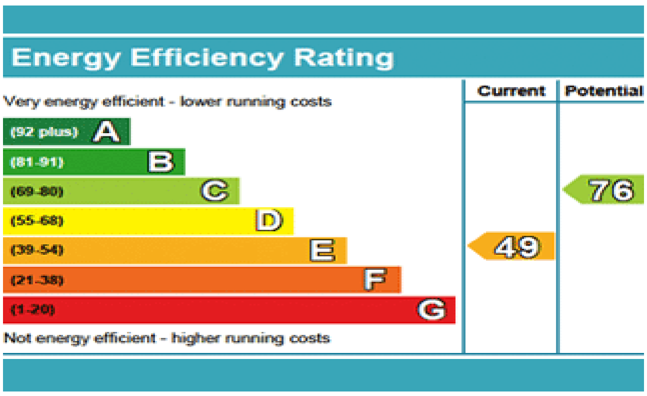


Figure 4.6 Example energy efficiency graph for homes in the UK (Directgov, 2012)

EPCs are produced using standard methods with standard assumptions about energy usage so that the energy efficiency of one building can easily be compared with another building of the same type. This allows prospective buyers, tenants, owners, occupiers and purchasers to see information on the energy efficiency and carbon emissions from their building so they can consider energy efficiency and fuel costs as part of their investment.

An EPC is always accompanied by a recommendation report that lists cost effective and other measures (such as low and zero carbon generating systems) to improve the energy rating of the building. The certificate is also accompanied by information about the rating that could be achieved if all the recommendations were implemented.

Energy Consumption of Buildings: Energy consumption of buildings will be presented in the form of electricity meter readings that are displayed in kWh (kilo watt hours). Local statistics on electricity consumption and sample point data (meter readings of real-life houses) are used for developing scenarios for consumption data of neighbourhoods.

Given Figure below is a screenshot from the monitoring system established in the Salford Energy House that enables real time monitoring (via the sensors and energy meters that are implemented) of energy performance and energy use of the semi detached residential house that is built in the controllable sealed chamber. Stated system enhanced the vision of the author regarding in-home displays and smart appliances by enabling real life observations related to the benefits of behaviour shifting devices. It was possible to experience (observe from the screen) how the building scale energy demand is shifted during peak periods, so that it showed how informed decisions of customers play a critical role in load balancing in the electricity grid.

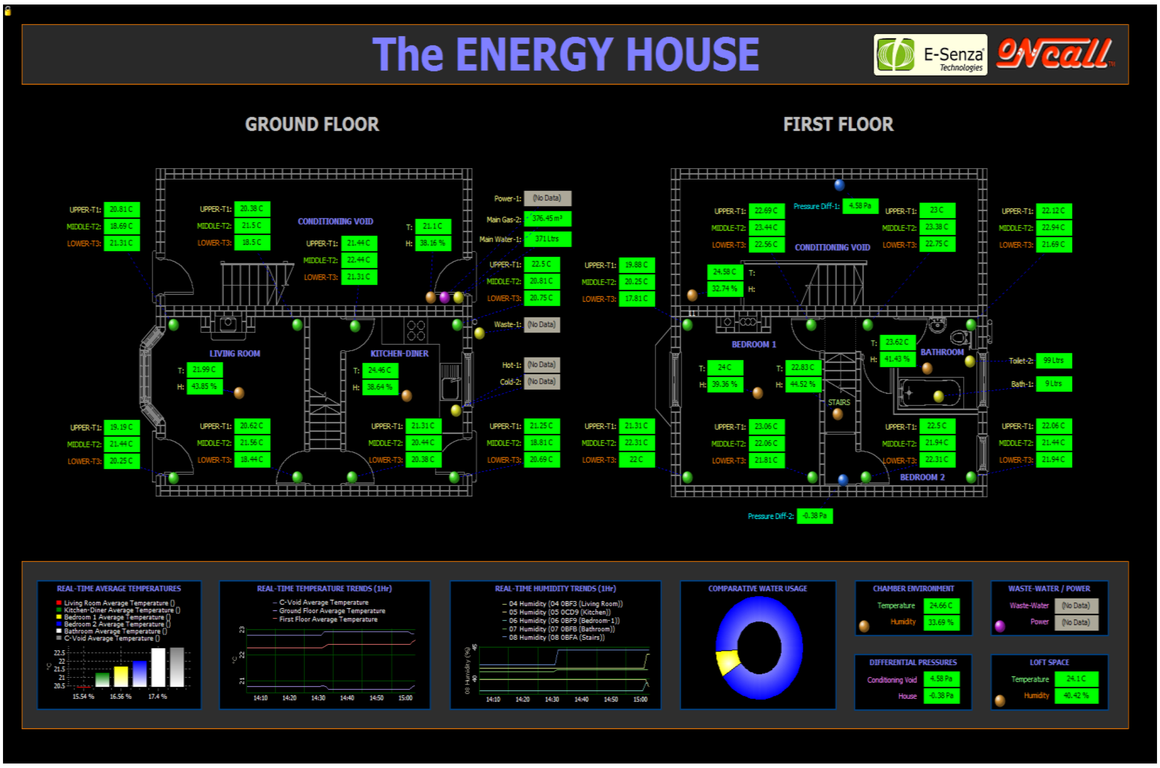


Figure 4.7 Screenshot of Energy House Monitoring System

<u>*Climate Data:*</u> What is meant by ‘climate data’ in this study is the renewable energy potential of a particular neighbourhood. With respect to this statement, Solar and Wind Energy Resource Assessment (SWERA) database has been used as a data source for obtaining climate data regarding to solar and wind energy availability on site. SWERA is a web based GIS database of solar and wind energy ant it is free to access. Additional data set that SWERA offers is HOMER data. Homer is a model for optimizing locally generated power (i.e. via building integrated renewable energy technologies) among a group of houses at a neighbourhood level. Given Figure is a screenshot of stated web based GIS database that covers local renewable energy potential and the utilization potential.

Figure 4.8 Screenshot of SWERA (SWERA, 2012)

Smart Meter Data: Smart meter data will be assessed in terms of availability, in a way that it will be assigned to geospatial platform as 'smart meter installed' and 'smart meter not installed'. UK Ministry of Energy and Climate Change announced that mass roll-out of smart meters will start in late 2014 and is set to be completed in 2019, during which the energy suppliers will be responsible for replacing over 53 million gas and electricity meters, involving visits to 30 million homes and small businesses. As there is no validated data for existing smart meter rollout exists, Smart meter data are produced via assumptions in scenarios. In that sense the proposed DSS model has a great potential for observing and evaluating the degree of influence between smart meter rollout and smart grid implementations. Therefore, the stated DSS model can be used as a test-bed for assessing the smart metering policies.

Smart Appliance Data: This type of data will be assessed in the same manner with the above mentioned smart meter data and it will be assigned to geospatial platform as 'smart appliances exist' and 'smart appliances do not exist'.

Applied data collection, analysis and evaluation stages of the conducted research are further elaborated in the following chapter.

4.2.6.2 Data Collection and Analysis Methods

Referring to research onion model of Saunders, data collection and analysis layer is the last layer, and it deals with techniques and procedures employed for collecting and analysing the data required for the research. As it is highlighted in "research choice" layer, the researcher requires mixed methods. The alternative methods that can be employed are the combination of quantitative (experiments, observations of well defined events, surveys with close ended questions) and qualitative (interviews, observations) methods. These alternatives are critically eliminated by means of validity and reliability, so it is ensured that the same results would be obtained by other researchers who follow the same steps.

Experimenting method, as it is conducted under unbiased scientific measurement environments, is a valid and reliable method, but as discussed earlier in "research strategy" layer it is not a viable method in this study due to the constraints and limitations associated to the research context.

Observations of well defined events (such as counting the number of patients waiting in emergency at a specified time of the day) are also valid and reliable approaches, because under such settings, different observes will obtain the same results. Obtaining similar outcomes is a sign that experimental validity is maintained. Due to types of parameters (local renewable energy potential that needs to be measured and recorded) involved in conducted research, observations of well defined events is an appropriate tool for this study.

Surveys with close ended questions are another quantitative method that can be used as a data collection tool. As the researcher needs data related to prioritisation of neighbourhoods in terms of smart grid applicability, a "rate of importance" indicator among assessment parameters is required. In other words, conditions those build up "priory" need to be investigated. Therefore, a statistical survey has been undertaken with the intention of making a statistical inference. The qualitative opinion of the participants is analyzed in quantitative manner via applying basic statistics.

Interviews are another method of data collection. In quantitative survey research, the researcher applies structured interview comprising standard set of questions and nothing more. On the other hand, in qualitative survey research, in-depth interviews are used. An in–depth interview is an open–ended, discovery–oriented method that is well suited for describing both program processes and outcomes from the perspective of the target audience or key stakeholder. Therefore the researcher adopted semi-structured interviews so that both quantitative and qualitative findings from the interviews are maximised. In order to maintain external validity, interviewees are chosen from high relevance sample to the context, such as academics and industry professionals. Interviews are also used as a cross check examination method for double checking the results to ensure the appropriateness of measured parameters. Construct validity is maintained for this study, as both questionnaire and interview findings show the same tendency.

Analysis of the collected data has been done via basic statistics, and context specific calculations (AHP related calculations). Further details regarding data analysis can be found in chapter 5.

4.3 Research Design

In line with the above introduced research methodology, research design that the author of this research has developed is illustrated in Figure 4.9. The figure itself depicts how the embedded processes undertaken throughout this study overlap with the research themes in addition to the methods/tools engaged with the each stage of the process. Furthermore, after a comprehensive literature review about the research methodology, researcher's adopted research philosophy, approach and method is also demonstrated in the mentioned Figure .

The conducted research is mapped out in given research design which comprises seven main phases. Each phase incorporates relevant elements that are clustered as 'Research Theme', 'Process', and 'Tool/Method'. Process cluster is given in seven consequent stages which are reflections of the research objectives and stated stages are the steps to follow in order to achieve the research aim and find a validated answer to the research question.

Aforementioned phases of the research design are further elaborated as follows:

Phase 1: This is the gap identification phase of the research. Throughout this phase, a comprehensive literature review has been undertaken in order to have a solid understanding of environmental sustainability, climate change, renewable energy sources, present electricity grids and related challenges, smart grid systems and related challenges. Research question is crystallized at this stage and aforementioned research objectives are formed. Additionally, requirements of Research Objective-1 are met.

Phase 2: This phase is the conceptualization stage of the study. Initialisation of the GDSM is done. Literature review and observations took place throughout the phase.

Phase 3: This is the criteria identification phase of the research. A set of indicators are identified via extraction from the related literature covering smart grids and residential energy use in order to fulfil the requirements of Research Objective-2.

Phase 4: This phase covers the data collection and analysis. Questionnaire (see appendices) is adopted as data collection tool for the primary data. Secondary data are collected through open access data bases and observations. Identification of the ontology to be used in the model will be defined in accordance with the data collected. This phase is organized in order to fulfil the needs of Research Objective-3.

Phase 5: This is the phase when the prototyping of the model takes place. Analytical Hierarchy Process and geospatial decision making concepts are covered through literature review. Geospatial decision support model for the selection of optimum neighbourhood in terms of smart grid applicability is proposed in order to fulfil the requirements of Research Objective-4.

Phase 6: This phase comprises testing and validation of the proposed model. Multiple case studies (comprising neighbourhood alternatives) will be conducted in order to implement the model. This phase is carried out in order to meet the needs of Research Objective-5.

Phase 7: The last phase covers the validation of the model. Focus group study will be conducted in order to validate the functionality of the model for smart grid applicability prioritization of neighbourhoods. This phase is to be performed in order to realize Research Objective-6.

It should be noted the term "epistemology" in the "ADOPTED RESEARCH METHODOLOGY" column in the following figure is used intentionally for replacing the original expression of "ontology". The reason for that is to avoid confusions within the text where the term "ontology" has also been used for defining "set of rules".

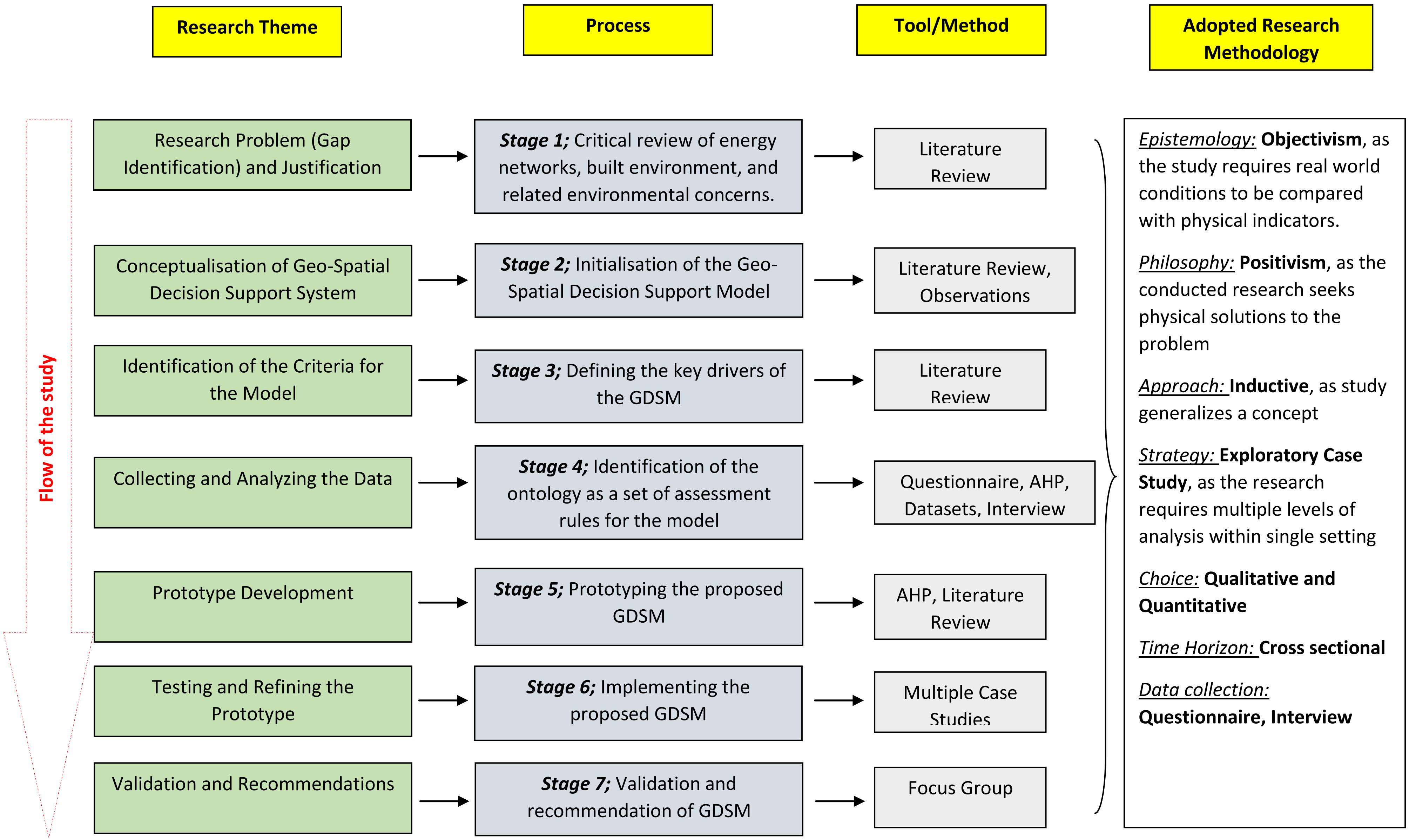


Figure 4.9 Research Design

4.4 Concluding Remarks

In this chapter, research methods and research methodology are elaborated. Research Onion approach has been adopted in order to present the awareness of general aspects of research methodology. That approach can be applied to any kind of research via appropriate selection of the steps involved. In other words, all research projects have their own specific methodology that needs to be formulated according to the needs of the specific research problem.

In line with this, a tailor made research methodology is formed for the research question that seeks an answer to identifying the feasible alternative among neighbourhoods that has the optimum applicability for smart grid implementations. A clear representation of the stated research methodology is mapped out via a research design incorporating research themes (ranging from problem identification to the solution of the problem), and processes and research tools embedded to realize those research themes. An adopted research methodology is extracted from the given research design approach. Briefly, adopted research methodology is developed in the axis of objectivism and positivism, and it is directed within inductive boundaries as the research seeks developing a concept for enabling physical solutions to real life problems. Questionnaires and interviews are used as tools for data collection, and both qualitative and qualitative manners are applied in cross sectional time horizons. Exploratory case studies are used for mastering the proposed solution.

The next chapter of the thesis deals with data collection, analysis and evaluation where adopted research methodology steps regarding to data used in this research are further elaborated.

CHAPTER 5: IDENTIFICATION OF KEY ENABLERS OF SMART GRID APPLICABILITY ASSESSMENT MECHANISM

5.1 Introduction

This chapter of the thesis deals with data collection, analysis and evaluation procedures applied throughout the conducted research. Initially, the criteria identification is justified through comprehensive literature review and a conclusion is drawn out in order to form a robust grounding for the questionnaire. The next step is the handling of the questionnaire survey and analyzing the results in accordance with AHP method. Subsequently, conducted interviews are analyzed in order to validate and refine questionnaire data. The quality matters of the survey by means of reliability and validity are also discussed.

5.2 Criteria Identification for Smart Grid Applicability

Initially, it is worth mentioning that criteria identification for smart grid applicability is a critical writing of researcher's thoughts, and it comprises a process that combines findings from smart grid literature review, analysis of smart grid demonstration projects, and built environment and energy related literature. The criteria are defined from literature review, and smart grid demonstration projects enabled the researcher to identify key features of a typical smart grid implementation project. The overlapping components are the list of criteria specified as the criteria that should be primarily considered as smart grid applicability criteria.

Given Figure 5.1 below illustrates the criteria identification procedure. Stated figure depicts how clusters are brought together in order to form the basis for smart grid applicability assessment criteria.

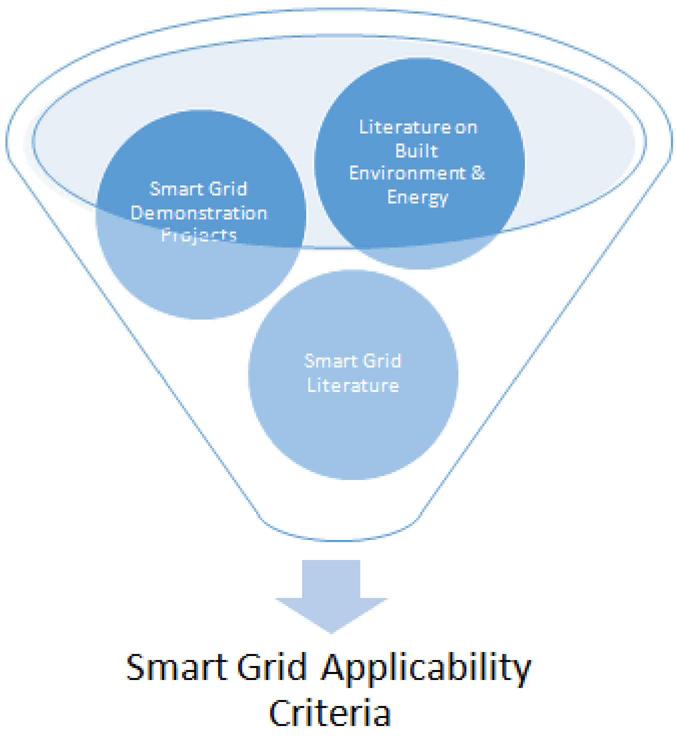


Figure 5.1 Criteria Identification Process

In spite of growing urban populations in most countries, it is important for new cities to adopt smart energy networks that allow greater energy efficiency and greater flexibility in energy use. In addition to the literature review supplied in Chapter 2, it is well worth highlighting the emerging concepts for the interaction of built environment and smart grid concept. Researcher's digest of smart grid concept is previously highlighted as the increased use of renewable energy sources in the energy mix, increased interaction of consumers with electricity grid, and reduced demand for energy in residential buildings.

In the light of abovementioned vision of smart grids, clusters of criteria are identified as building energy consumption related criteria, smart grid technology related criteria, and finally renewable energy criteria. Altiparmakis and Meibom (2011) argue that urban energy requirements are of high interest with efficient use of energy that comprises energy demand, energy supply, and sufficient assisting technology. In accordance with this statement, energy profiles of the buildings (efficiency and demand) should be taken into consideration.

European Union Energy Performance Buildings Directive (EU-EPDB) has been introduced to provide clear guidelines for energy performance of buildings to improve the energetic quality of new buildings and existing building stocks. Aforementioned EU directive is implemented by means of assigning Energy Performance Certificate (EPC) labels to buildings when they are constructed or marketed for sale or rent. It is highlighted by Boardman (2012) that EPC label coverage of UK building stock in terms of regulated energy (space and water heating, cooling, ventilation and fixed lighting) is 82% by the end of 2011. Due to their standardized nature, efficiency indication capabilities, and widespread use EPC labels are chosen as the first criteria for the geospatial decision support model.

It is simplified by Forsström et al. (2011) that, energy efficiency in buildings can be expressed as: *Energy Consumed / Built Area*, in other words it is kilo Watt Hours (or in other units) per square meter of residential buildings. In order to express this criterion in the model, researcher has chosen to use 'electricity meter readings' as an indicator for the proposed model as this is an essential criteria for simplified representation of energy efficiency of buildings.

It is discussed by Boardman (2007) and Eyre et al. (2010) that residential buildings have the potential to utilize at least one of the low or zero carbon technologies some of which displace gas, some electricity and some both. In line with this discussion, from a neighbourhood perspective, aforementioned 'micro-grid' emerges as an enabler platform for realization of low carbon technologies. As the adopted vision of smart grids requires maximization of renewable energy use in the energy mix, researcher has identified renewable energy utilization potential as an indicator for the proposed model. Therefore, climate data (solar potential, wind regime etc.) is added to the model.

Smart grids are not exclusively designed to facilitate balancing of supply and demand but they encourage the elaboration and application of energy or climate- remediation policies (Giordano et al., 2011). It has been observed that among the energy market actors (consumers, generation companies, utilities etc.), smart grids are synonymous with smart meters measuring actual output or consumption in real time. Smart meters are central gateways located on the customer's site that support two-way communication and smart meters bridge the communication gap between consumers and other energy systems' parties by means of information and communication technologies (Kranz and Picot, 2011). Even though it is possible to find smart meters in the market, most of the applications are for accurate pricing purposes and avoid fraud rather than realizing smart grid effectively. The new metering infrastructure is essential for energy efficiency measures, the monitoring and management of grids as well as load balancing and shifting. Therefore, availability of a smart meter is considered as a criterion for the smart grid applicability assessment model.

For the residential buildings, appliances are key parameters of household energy decomposition method which is developed by International Energy Agency energy indicator project (International Atomic Energy Agency, 2005). In this method energy intensity concept is introduced and energy intensity calculated for appliances is given as *Energy / Appliance*. Residential buildings, as main elements of the local energy system's demand side, consist of several appliances which have a certain profile that makes them more or less attractive for smart interaction to renewable energy sources (Mollering and Lowenhag, 2009). Having said that the data from electricity utilities about domestic electricity consumption is aggregated consumption of multiple households without knowledge about the events in individual households, Stamminger et al. (2009) expresses detailed knowledge at household level is a primer necessity for optimising electricity production and consumption. Smart appliances are developed in order to meet the stated need of household end-use data. In line with these, the researcher identified smart appliance availability as a parameter for decision support model.

When the literature regarding smart grids in Chapter 2 is taken into consideration from a built environment perspective, abovementioned criteria (or factors derived from those criteria) appear as critical elements of smart grid technology and/or its functionality.

In a nutshell, following criteria are identified as parameters for the development of geospatial decision support model for prioritization of neighbourhoods by means of smart grid applicability:

- Energy Performance Certificates (EPC)
- Energy Consumption of Buildings
- Climate Data (Renewable resource potential)
- Smart Meter availability
- Smart Appliances

5.3 Questionnaire Survey for Identifying Attitudes of Academia and Industry Towards Smart Grid Applicability

Literature encompass that data collection methods are highly dependent on the researcher's plans. Researchers may commence interviews, undertake questionnaires, conduct experiments and/or make observations or appropriate combinations of stated tools.

For the conducted study, researcher has chosen to carry out a questionnaire with the intention of collecting primary data.

A questionnaire consists of a set of questions presented to a respondent for answers and there are three basic types of questionnaire:

• Closed –ended

• Open-ended

• Combination of both

The researcher has chosen carrying out a close ended questionnaire for obtaining a weighting factor for the aforementioned criteria. The stated questionnaire comprises of a single question that asks the individual rating of importance for five pre-defined criteria (see previous section 5.1 for the identified criteria). The goal of the questionnaire is to draw a tangible result for prioritization of aforementioned set of justified criteria for smart grid applicability.

Piloting has been conducted with three postgraduate researchers from Salford University, and three technical managers from member companies of Turkish Wind Energy Association with the intention of ensuring that the questionnaire supplies the data required, and this lead the researcher in doing minor amendments on the questionnaire.

A confidentiality statement is supplied with the questionnaire in order to make it clear to participants that the questionnaire has been carried on within boundaries of research ethics and the collected data would only be used for academic purposes. Additionally, participants' right to withdraw from the survey at any stage has been reminded.

Researcher has applied 'judgement sampling' in order to select population members who are good prospects for accurate information. In accordance to this, researcher has delivered the questionnaires to people those are engaged to built environment and/or energy related field and are involved in academia (academics/ PhD researchers) or industry. In other words, professionals from industry and academia that are directly concerned with specific content of the research are selected as the population for conducting the questionnaire. Given Table 5.1 and Figure 5.1 below depict the overall response to the questionnaire.

Table 5.1 Overall questionnaire response

Overall questionnaire response	Academia	Industry	Total
Sent	90	90	180
Collected	53	62	115
Rate of Return	58.88 %	68.88 %	63.88 %

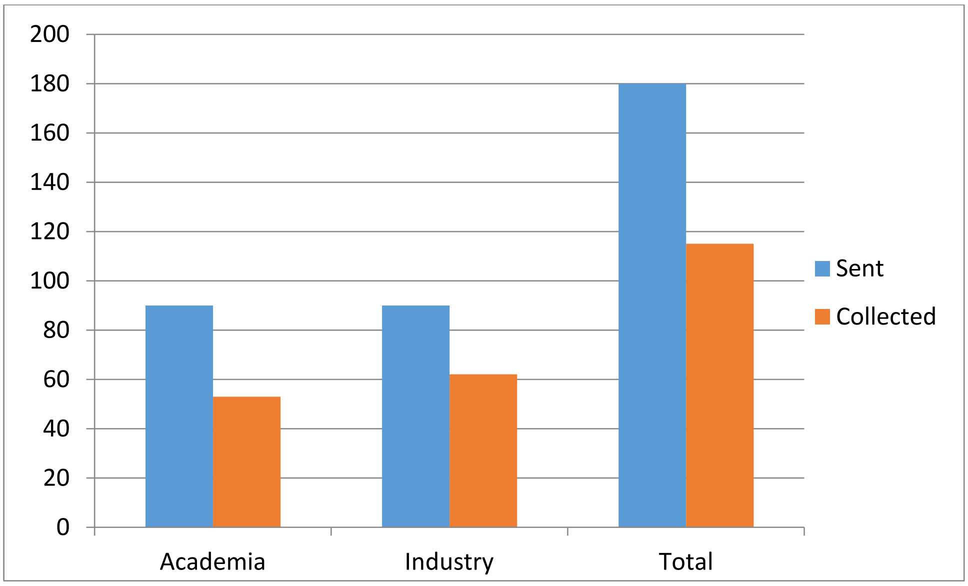


Figure 5.2 Graphical representation of overall questionnaire response

As it is seen from table given 5.1 and Figure 5.2 above, the questionnaire yielded significantly satisfying rate of return both from academia (~59 %) and industry (~69%). Such high ratios can be explained as effectiveness of selecting target group with appropriate expertise.

Academia focus of the stated questionnaire has been conducted in University of Salford in the UK (in School of the Built Environment, and in School of Computing, Science and Engineering), and Eastern Mediterranean University (EMU) in Northern Cyprus (in

Engineering Faculty). There were two main reasons for selecting these universities. First consideration was ease of access and the second concern was the diverse and multinational structure of the stated universities. An official confirmation letter from EMU for conducting the stated questionnaire can be found in appendices. Additionally, active researchers and academicians (mostly the people that are met by the researcher in academic conferences and meetings) that produce publications in related fields are contacted via e-mails, and are invited to participate in the conducted questionnaire.

The given Table 5.2 below depicts the basic numerical figures regarding to participation to questionnaire from the academia.

Table 5.2 Academia response of the questionnaire

Questionnaire carried out in academia	Salford University	Eastern Mediterranean University	Academics approached via e-mails	Total
Sent	30	30	30	90
Collected	23	17	13	53
Rate of Return	76.66 %	56.66 %	43.33 %	58.88 %

The highest participation to the questionnaire within academia is observed to be from Salford University by ~77 %, followed by Eastern Mediterranean University ~57 %, and lastly the academics responded via e-mails ~43 % with respect to 30 questionnaires being sent to each institution.

Figure 5.3 below depicts how responses of individual institutions differ from one another. Additionally, overall sent/collected ratio is represented in the same figure.

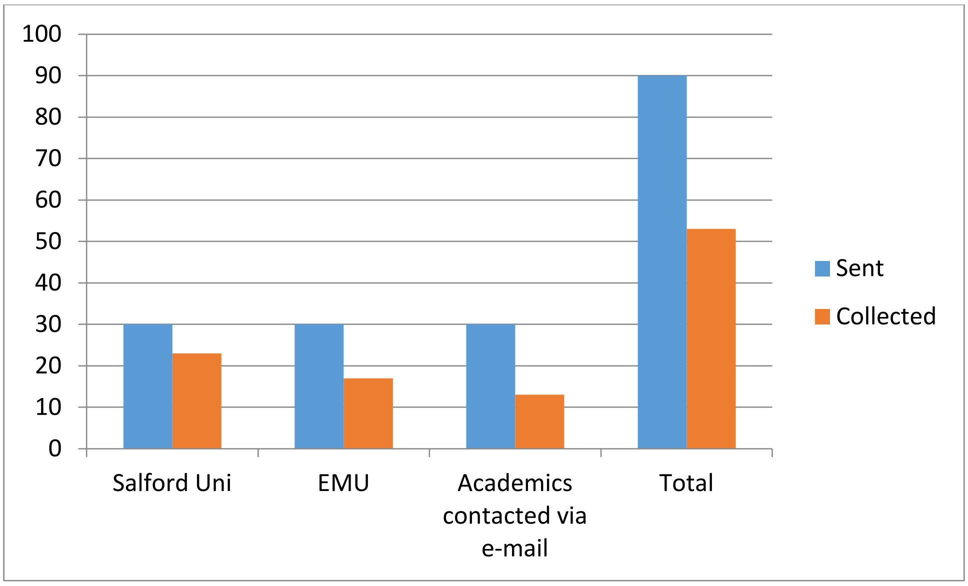


Figure 5.3 Graphical representation of academia response of questionnaire

Industry focus of the questionnaire has been conducted with many energy companies and utilities. 60 questionnaires were delivered at 4^{th} National Energy Efficiency Forum and Fair (Istanbul, January 2013), and 30 questionnaires were delivered to major utilities and member companies of Turkish Wind Energy Association (TWEA).

Table 5.3 Industry response of questionnaire

Questionnaire carried out in industry	Energy Forum and Fair	Utilities and TWEA member companies	Total
Sent	60	30	90
Collected	41	21	62
Rate of Return	67.21 %	70%	68.88 %

60 questionnaires were delivered at the 4^{th} National Energy Forum and Fair that resulted with 41 participants. Participant profile of the stated event comprised of senior managers and senior technical staff of over 120 national and international energy industry

companies/organisations like energy efficiency companies (i.e. Siemens, ISBAK, ErkaMax, Schreder etc.), funding and finance bodies for energy projects (i.e. Development Bank of Turkey, Sekerbank etc), and governmental institutions and initiatives for development and/or approval and licensing of energy projects (i.e. Ministry of Energy and Natural Resources of Turkey, Ministry of Environment and City Planning of Turkey , etc.). In addition, mainstream national utility companies, and national and international member companies of Turkish Wind Energy Association were contacted for their participation in the questionnaire and the responses were 21 out of 30 people that are contacted. See figure 5.4 to see the questionnaire response figures in industry.

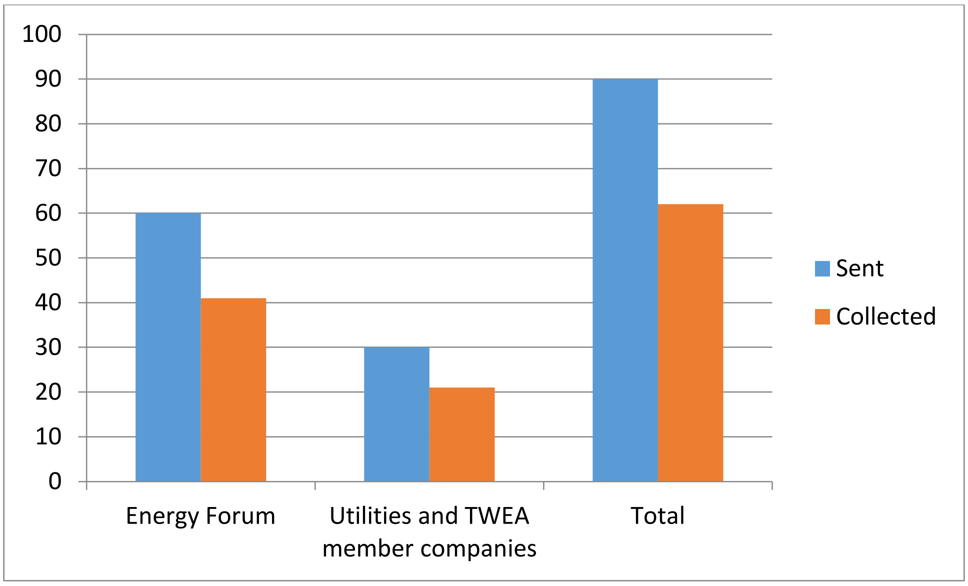


Figure 5.4 Graphical representation of industry response of questionnaire

As it is depicted in the given Tables 5.1, 5.2 and 5.3 above, conducted survey attracts attention of both academia and industry, and therefore a considerably high rate of return is obtained as a consequence. However, the response rate to the questionnaire is remarkably higher among industry when compared to academia. This condition can be explained as energy industry finding benefit to themselves regarding to the conducted academic research in terms of building and reforming their management strategy for smart grid implementations. Such an interpretation is a good example of mutual benefits gained due to collaboration between academia and industry.

Detailed breakdown analysis of questionnaire conducted in academia and industry is depicted in the Tables 5.4 and 5.5 respectively. In the stated tables, criteria are shown as C-1......C-5 in short. Please see below for actual representation of the criteria:

C-1: Energy Performance of Buildings (Energy Performance Certificates)

C-2: Energy use of Buildings (Utility meter readings)

C-3: Climate Data (for renewable energy potential determination)

C-4: Smart Meter (presence of smart meters installed)

C-5: Smart Appliances (availability of smart household appliances)

Criteria are asked to be scored over a nine-point scale individually in accordance with the brief supplied with the questionnaire (see appendices for a copy of the conducted questionnaire) in order to obtain weighting factors for prioritization procedures that take part in Analytical Hierarchy Process (AHP).

Table 5.4 Breakdown of academia response of questionnaire

Academia	Low			Medium			High					
(53 people)	1	2	3	4	5	6	7	8	9	∑	$\bar{x}$	Rank
C-1	-	-	2	2	9	13	13	8	6	346	6.53	III
C-2	-	1	1	4	20	11	14	2	-	301	5.68	IV
C-3	-	-	2	1	6	14	16	8	6	354	6.68	II
C-4	-	-	1	3	3	13	10	13	10	372	7.02	I
C-5	-	4	4	19	14	9	2	1	-	242	4.57	V

The given Table 5.4 comprises distribution of the criteria ratings given by 53 people from academia. The scores are categorized in “Low”, “Medium” and “High” impact clusters. Additional columns indicating total scores and mean values for individual criteria are also supplied. An initial ranking is formed in accordance to the mean values of the criteria with the purpose of obtaining trend of attitude in academia towards realization of smart grid projects.

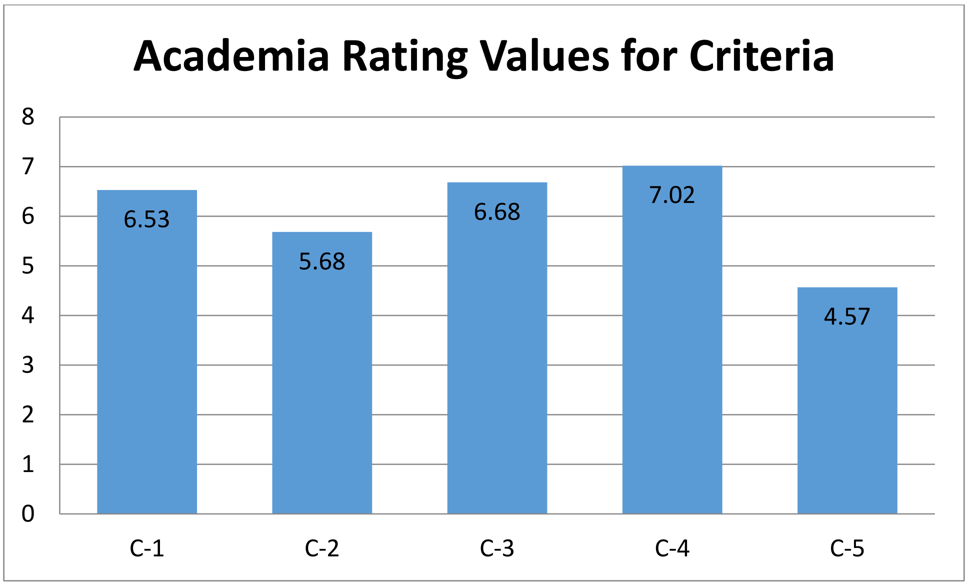


Figure 5.5 Academia rating values for criteria

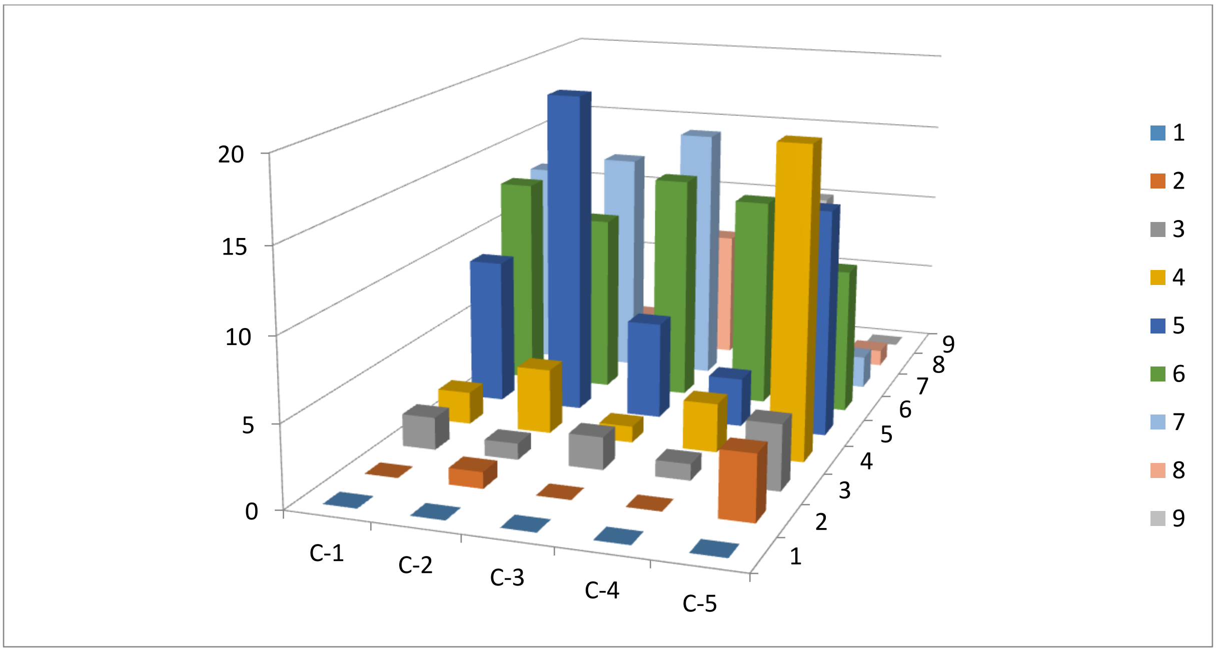


Figure 5.6 Breakdown of academia scores

Figure 5.5 graphically represents the academia rating values for criteria, and Figure 5.6 depicts the breakdown of academia scores. It is digested from the stated figures 5.5and 5.6, and from the table 5.4 that the highest cumulative score is achieved in criterion regarding smart meter availability (C-4), and it is followed by criteria of climate data for renewable energy (C-3), and energy performance of building (C-1) respectively. These are followed by Building Energy Use Criterion (C-2), and the least rating score is achieved by Smart Appliance criterion (C-5).

Given Table 5.5 below depicts the breakdown of the ratings of 62 participants from industry. The stated table is organized exactly in the same structure of Table 5.4 and comprises rating clusters, sum of values of scores for individual criterion, mean values. An additional layer of ranking is also added with the intention of obtaining trend of attitude in industry towards realization of smart grid projects.

Table 5.5 Breakdown of Industry Response

Industry	Low			Medium			High					
(62 people)	1	2	3	4	5	6	7	8	9	∑	$\bar{x}$	Rank
C-1	-	1	3	8	12	14	14	8	2	367	5.92	III
C-2	-	2	5	6	12	18	12	4	3	354	5.71	IV
C-3	-	-	1	1	4	13	19	13	11	441	7.11	II
C-4	-	-	-	2	7	9	11	14	19	457	7.37	I
C-5	-	3	5	13	9	12	11	5	4	343		

Though mean values of scores vary from academia survey, the questionnaire conducted in industry reflects the same tendency in terms of ranking of criteria. Smart meter availability criterion gets the highest score, and smart appliance availability gets the least one. Middle values are Climate Data criterion, Energy Performance of Buildings criterion, and Building Energy Use respectively.

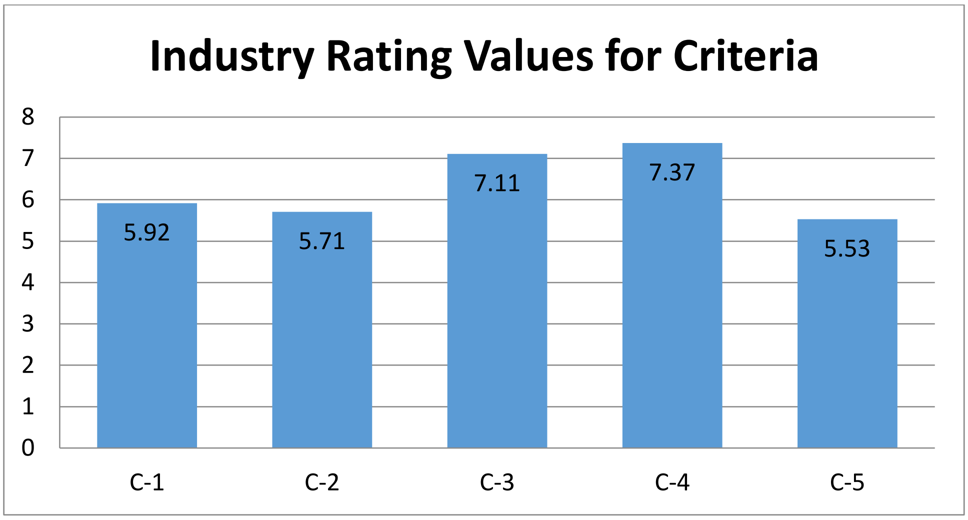


Figure 5.7 Industry rating values for criteria

Figure 5.8 graphically represents the industry rating values for criteria, and Figure 5.7 represents the breakdown of industry scores.

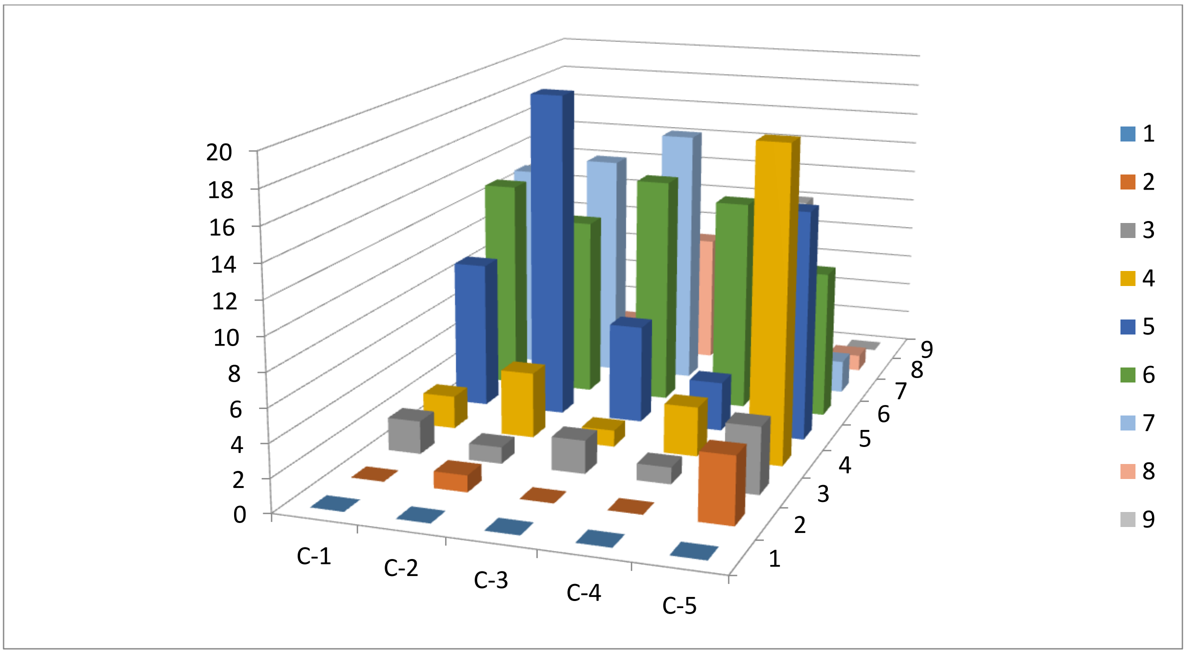


Figure 5.8 Breakdown of industry scores

When the overall breakdown of the questionnaire is considered, as the tendency is similar in rankings of criteria in both domains (industry and academia), the criteria ranking of the overall questionnaire appears to be in the same order as a consequence. Hence the numbers of participants are different in both domains; there is a need for a calculation of weighted average for the cumulative set of participants. Table 5.6 below depicts the aforementioned calculations and tendencies. Additionally, given figure 5.9 graphically represents how ratings of criteria differ from one another.

Table 5.6 Overall breakdowns of questionnaire responses by criterion

Overall Breakdown	∑(Academia) (53 People)	∑(Industry) (62 People)	∑(Cumulative) (115 People)	$\bar{x}$ (overall mean)	**Rank**
C1	346	367	713	6.20	**III**
C2	301	354	655	5.70	**IV**
C3	354	441	795	6.91	**II**
C4	372	457	829	7.21	**I**
C5	242	343	585	5.09	**V**

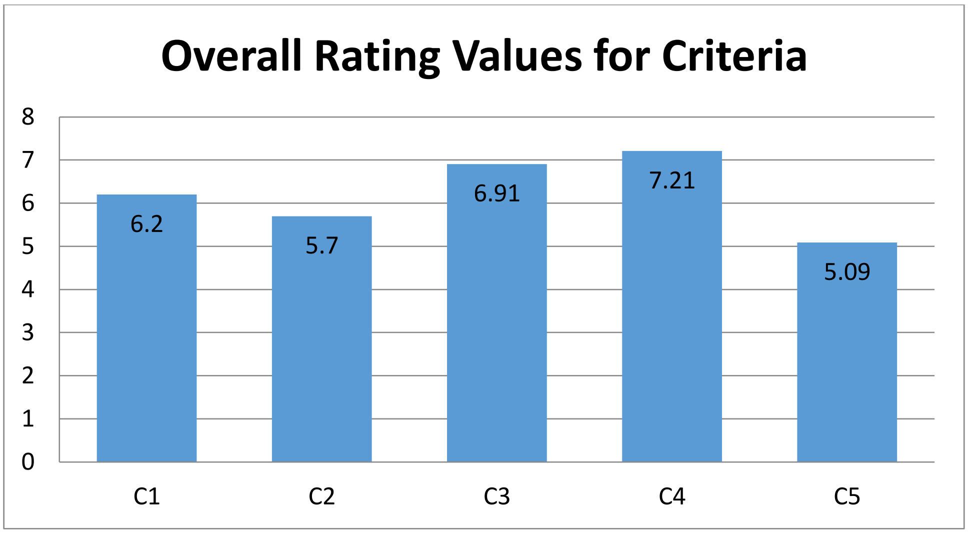


Figure 5.9 Overall Rating Values for Criteria

As the characteristics of each criterion are discrete by nature (such as Climate Data and Smart Appliance), interviews regarding to mentioned criteria are carried out in order to strengthen and deepen the understanding of underlying reasons that lead participants choosing such a score for each individual criterion. See the next section 5.4 of this chapter for details of interviews. By conducting breakdown analysis for domains of academia and industry, ranking values are obtained for AHP analysis for ranking of alternatives. Alternatives, in this case the neighbourhoods, are further evaluated in Chapter 7 that covers the mastering of the proposed DSS model.

5.4 Expert Views on Smart Grid Applicability Assessment

As mentioned earlier in this chapter, open ended interviews are carried out in order to crystallize the understanding of the underpinning reasons that direct perception of survey participants regarding the stated criteria. In fact, conducted interviews not only cover issues regarding extend of the questionnaire, but also the issues regarding to development of the proposed DSS model, and recommendations for further research (See appendices for a copy of interview brief and interview questions).

In this section, parts of the interviews that are related to the questionnaire are covered. Interviewees are chosen in the same manner as it is in the selection of target groups in the questionnaire survey. A total of six individuals are interviewed, of which three of them are academicians, one is an industry professional, and two of them are senior staff of the institutions that act as bridge between academia and industry.

Interviewees are initially asked to fill out the questionnaire and explain their reason. Additionally, interviewees are asked whether they had any recommendations for technical aspects or criterion alternative for further research studies. The outcomes of the interviews are then used as triangulation data for validation purposes regarding questionnaire survey data. The following order is adopted as the structure when presenting the interviews: i) profile of the interviewee, ii) rating of criteria with explanation, iii) comments and recommendations regarding technical issues like any possible criteria for future work. Once all interviews are handled, a conclusion is drawn.

5.4.1 Interview with Academician 1

Profile: The first interviewee from academia is a Professor at University of Salford, School of the Built Environment. He has experience in public, private, academic, and third sectors. Behaviour change and sustainable decision-making, organisational sustainable change, sustainable return on investment for built environment projects are the fields that he specialized in.

Academic 1	Rating	Reason
C-1	7	EPC labels are good signs of energy efficiency potential, and actual usage levels are the cause of load on the grid. These two parameters are important when designing physical parameters of electricity delivery infrastructure.
C-2	8	
C-3	7	Increased utilization of renewable will strengthen electricity supply, help ease delivery loads, and enable keeping track of carbon footprints.
C-4	6	Automatic control potential of a smart meter enables managed operational load management of the grid, on the other hand social studies have shown that smart meters are below the expectations when it comes to user behaviour change.
C-5	2	Programmable features of smart appliances obviously have a

		potential in managing peak loads but the nature of them is transient (they may come and go depending on the occupier) and therefore their effect on how to design transmission grid is minimum. Additionally, energy consumed by appliances holds less than a third of the energy consumed in dwellings.

Recommendations for Physical Parameters: Storage facilities can also be considered because in surplus conditions of micro generation, storing energy and how it is converted back might become a serious issue.

5.4.2 Interview with Academician 2

Profile: The second interviewee from academia is a Professor of Sustainable Urban Development (SUD) at the University of Salford, Manchester, UK, where he has been Director of Design in the School of the Built Environment and of the Urban Quality Research Centre. He led the development of a number of new Masters Programmes in urban design and sustainable building design. He was co-author of the University of Salford's energy research strategy and emphasis on retrofit that has ultimately led to the energy hub facility at the university which enables whole building testing and energy evaluation.

Academic 2	Rating	Reason
C-1	9	Demand side reductions are the most important factors when considering management of grid load from a building perspective.
C-2	8	
C-3	7	Climate data for renewable should be concerned specific to the site. Besides renewable technologies offer cleaner power generations, occupants have limited control on climatic conditions.

C-4	7	Smart meters are important tools that bridge buildings and the electricity infrastructure.
C-5	6	Current legislations and incentives are targeting retrofitting by means of insulation etc., and that situation reduces the possibility of investing in smart appliances by occupiers.

Recommendations for Physical Parameters: Apart from household energy consumption, there is also non-domestic energy consumption in communities (like street lighting). Those issues can be addressed as parameters of loading on the grid that is based on community energy usage needs.

5.4.3 Interview with Academician 3

Profile: The third academician is a Professor at Technical University of Istanbul, where she teaches and conducting research related to renewable energy. She has led numerous renewable energy related research and development projects funded by the university, research bodies, and local government.

Academic 3	Rating	Reason
C-1	7	Energy efficiency is highly tide to building fabric performance.
C-2	5	Building energy use is one of the main reasons of stress on the grid, but regardless of the grid technology, energy use is highly related to energy use behaviour of the end user.
C-3	8	Decentralized power generation via renewable resources will improve energy supply security, as well as maintaining reduced carbon emissions.

C-4	9	Smart meters are gateways that make it possible to implement smart grid concept within built environment
C-5	4	Energy used by appliances is a small proportion of residential consumption when compared to heating and cooling.

Recommendations for Physical Parameters: It is well worth concerning energy storage and backup strategies for maintaining stability and resilience of the grid. Therefore hybrid applications of renewable and conventional energy sources can be taken into consideration.

5.4.4 Interview with Industrial Academic 1

Profile: The first industrial academic is the technical manager of Salford University Energy House. He has a background in Energy Engineering and Building Surveying. His key areas of expertise are energy performance of buildings and monitoring buildings using sensing devices. Additionally, he is a part time PhD student conducting research on energy and buildings.

Industrial Academic 1	Rating	Reason
C-1	7	Energy efficiency in buildings is an important issue at global level. Though being arguably accurate, EPC labels are good indicators for energy efficiency estimations.
C-2	8	When it is the matter of energy supply and demand, you need to know the actual amount of electricity taken from the grid so that the supply can be adjusted accordingly.
C-3	6	Variable and intermittent nature of renewable resources avoids them being the primer source that a grid can rely on.

C-4	9	Smart meter rollout is a vital part of smart grid projects. Smart meters are crucial for data generation and remote controlling.
C-5	5	Smart appliances are not commonly available at the time being.

Recommendations for Physical Parameters: It might be useful to have a look at heat demands of the properties in the UK (a web based GIS based tool called HeatMap UK is available) to get an idea for spatial distribution of energy efficiency of dwellings.

5.4.5 Interview with Industrial Academic 2

Profile: The second industrial academic is a senior engineer at the General Directorate of Renewable Energy, an acting division of Ministry of Energy in Turkey. He holds a PhD in Engineering with a focus on energy studies. He has well over 10 years of experience in renewable energy resource assessment, and wind energy feasibility studies. Moreover he is the vice president of Turkish Wind Energy Association.

Industrial Academic 2	Rating	Reason
C-1	6	Energy performance of the buildings and energy use of the buildings together form the demand side of grid operations.
C-2	6	
C-3	8	Smart grid philosophy implies cleaner grid operations, and therefore renewable energy is very important for maintaining a cleaner energy supply.
C-4	9	Without smart meters, smart grids cannot be put into practice.
C-5	4	Smart appliances require a considerable duration of time to become widespread.

Recommendations for Physical Parameters: From the point of view, present electricity infrastructure suffers brownouts; therefore a robust backup mechanism is required. Suitability of storage technologies can be included in smart grid applicability assessment process.

5.4.6 Interview with Industry Professional

Profile: Interviewed industry professional is a senior engineer at a private energy company in Istanbul, Turkey. He has been professionally involved in energy projects for more than five years, and he holds an MSc in wind energy resource modelling.

Industry Professional	Rating	Reason
C-1	6	EPC labels are valuable indicators energy efficiency in buildings.
C-2	5	Energy used in buildings is a direct indicator of electricity demand, but it should be considered that energy demand is highly related to consumption behaviour of the occupant. On the other hand, cumulative energy use of a neighbourhood is crucial for estimating the total demand.
C-3	7	As conventional resources are depleting, renewable energy becomes more important for energy supply security, regardless of the grid technology.
C-4	8	Smart meters are the enablers of two way interaction between the grid and the consumer by means of energy and data flows.
C-5	5	From context of Turkey, smart appliances are not likely to become common within time scale of smart meter rollout.

Recommendations for Physical Parameters: None

5.4.7 Overall assessment of interviews

When the conducted interviews are digested, it is seen that some minor difference of opinions due to subjectivity appeared. As all the interviewees are of different expertise in energy field regarding dimensions of smart grid issues, differentiation in their perception of smart grids is reasonable. Despite the minor variations in rating of the criteria, incompatibility has not been encountered. It can be said that acceptable consistency in tendency is maintained within boundaries of specific context. Therefore interviews yielded robust understanding of how the criteria are individually evaluated by means of their value to potential stakeholders.

In brief, the following perceptions for the criteria are extracted from the interviews:

Energy performance of buildings: It is well appreciated by the participants that energy performance of the buildings is an important parameter that has a finger in stress over the grid. Energy Performance Certificate (EPC) labels are endorsed as adequate parameters for representation of energy efficiency of buildings when conducting smart grid applicability process for the built environment domain.

Energy use of buildings: Similar to EPC, actual energy used in buildings is agreed to be an important factor of energy demand that causes stress over the grid.

Climate data for renewable energy: Interviewees are like minded on utilization of renewable energy that it offers cleaner grid operations as well as offering increased security of energy supply.

Smart Meter: Dominating view regarding smart meter is that it is a vital element of implementing a smart grid.

Smart appliance: As being a technology at its experimental stage with very limited availability in the market, smart appliance ranked the least criterion that affects smart grid prioritization applicability process by consensus of interviewees.

Table 5.7 below depicts the average values for the interview outcomes, and additionally figure 5.10 graphically represents the stated scores. The ranking order is only for validation purposes of the questionnaire survey results, and it is used as a triangulation tool for cross examination of the tendency in questionnaire. It is seen that same tendency is achieved with the outcomes of interviews and the questionnaire survey.

Table 5.7 Average scores of interview outcomes

INTREVIEWS	$\bar{x}$ *(Overall mean)*	***Rank***
C-1	7	***III***
C-2	5.71	***IV***
C-3	7.66	***II***
C-4	8	***I***
C-5	4.33	***V***

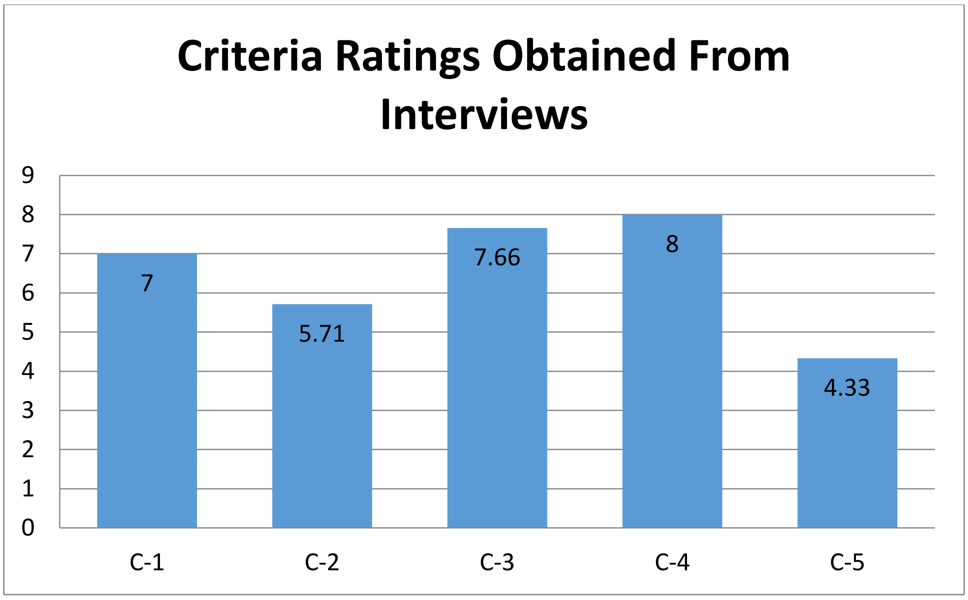


Figure 5.10 Criteria ratings obtained from interviews

When it comes to comments received, energy storage technologies are commonly raised as recommendation for physical aspects of the study, but it is noteworthy to mention that storage technologies are beyond the scope of the conducted study.

Figure 5.11 below is the concept map of interviews conducted among experts. Expert views on smart grid applicability regarding 5 criteria (Building Energy Performance, Building Energy Use, and Climate Data for Renewable Energy, Smart Meter, and Smart Appliance) are mapped out in a clustered manner. Overall rating for each individual criterion is supplied. Additionally, recommendations of experts for any possible technical issue are highlighted.

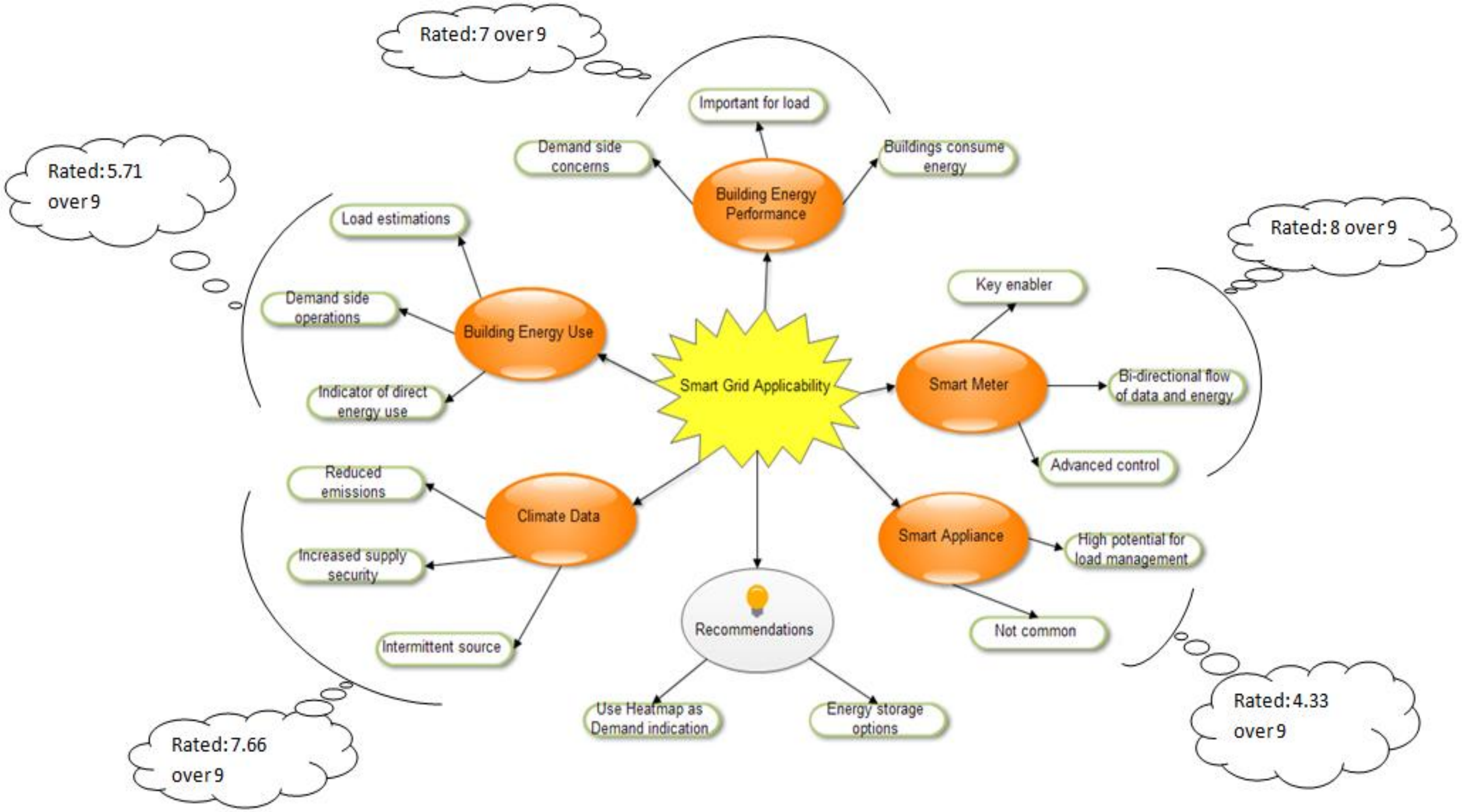


Figure 5.11 Concept map of smart grid applicability interviews with experts

5.5 Reliability and Validity of the Analysis for the Identification of Smart Grid Applicability Criteria

In this section, the quality of the conducted survey is elaborated by means of reliability and validity. Addressing the reliability and validity issues regarding the conducted study are supplied where appropriate. Reliability and validity are the vital elements of measurement methods. Reliability and validity are strongly related to one another, because something that is not reliable cannot be validated and vice versa (Lyberg et al, 2012).

Reliability, in short, is the consistency of outcomes harvested from a research procedure by being common on iterative trials. Although it is inevitable to avoid subjectivity as every participant would have his/her own opinion, reliable practices would tend to yield consistent outcomes with minor fluctuations. For the conducted research questionnaire, the survey yielded the same ranking on trials both in academia and industry. Additionally, conducted interviews that depict the views of experts in the field, point out similar outcomes. Therefore, it can be said that reliability is obtained for the aforementioned questionnaire survey.

Validity in research studies implies the degree of harvesting ability of a research approach that is claimed to be designed for (Ciolkowski et al, 2003). The following approaches are implemented to maintain validity in conducted survey (compiled from Ibid):

Internal Validity: It is the method that ensures whether the study allows drawing appropriate conclusions. For the conducted survey, piloting study has been carried out as a tool for measuring internal validity. Piloting study comprised of three postgraduate researchers from Salford University and three technical managers from member companies/organisations (Ataseven Energy Group, Borusan Holding, and General Directorate of Renewable Energy) of Turkish Wind Energy Association- TWEA. The participants were asked whether the questionnaire design is capable of picking up the relevant information regarding identification of criteria importance order, and the consensus of the group was that the questionnaire meets the goal by measuring rate of importance via a 9 point rating scale. Therefore, it can be said that internal validation of the questionnaire is maintained.

External Validity: It is the method that seeks how representative the surveys are. In short, it is ensured by external validity that appropriate target of participants are chosen for the specific context of a survey. For the conducted research, participant profiles are of high relevance to the context. Target group of the questionnaire survey comprised of academicians and industry professionals that are linked to fields that are sub components smart grid applicability. For that reason, representation capability of the survey for the desired outcomes can be approved to be externally valid.

Experimental Validity: It is an approach of validation that is highly tide to external validation. It relies on the mechanism that different samples do not produce different results. In other words, a similar trend in outcomes is maintained for the replication of surveys for varying sample groups. When the conducted research is taken into consideration, it can be extracted from “Rank” columns of Tables 5.4 and 5.5 that target groups of academia and industry that are to different sample groups, yield the same trend for ranking of specified smart grid applicability criteria. Therefore, it can be said that experimental validity of the survey is maintained.

Construct Validity: It is an approach that seeks whether the research tool measures the right things. For the conducted study, triangulation is used as “cross examination” method for double checking the results to make sure that the appropriateness of measured parameters. Interviews are conducted for triangulation purposes and it is seen that the outcomes of the interviews point out similar trends with questionnaire results. Consequently, triangulation denotes that construct validity is achieved.

5.6 AHP – Pairwise Comparison Matrix Analysis for the Prioritisation of the Identified Key Criteria for Smart Grid Applicability

Once the visions of academia and industry on smart grid applicability criteria are obtained, it is then time to run AHP methodology in order to crystallize prioritization of the stated criteria. Referring to Figure 3.4 depicting decomposition of AHP, criteria weights are obtained by conducting pairwise comparisons of rated criteria for obtaining Importance Matrix (IM). Importance Matrix produces refined values of criteria in terms of rate of importance. Normalization of Importance Matrix yields criteria weights. Structure of Importance Matrix (paired matrix) is as follows:

	C1	C2	.....	Cn
C1	1			
C2		1		
.....			1	
Cn				1

From the context of the conducted research, weights of individual criterion are the components of rating mechanism that alternatives (neighbourhoods) are assessed with.

When the criterion rating values of the conducted questionnaire (shown in figure 5.8) are considered for pairwise comparison, the following matrix is obtained, and the eigen vector (Weights of criteria) is calculated accordingly as follows:

1	1.0877	0.89725	0.85991	1.21181
0.919371	1	0.82489	0.790568	1.11984
1.11452	1.21228	1	0.95839	1.35756
1.16291	1.26491	1.04342	1	1.4165
0.825214	0.892985	0.736616	0.705965	1

Weights (Eigen Vector)
0.199094
0.183228
0.222123
0.231767
0.163788

The following Figure 5.12 shows the normalized criteria weight of importance. Sum of all criteria is equal to 1.

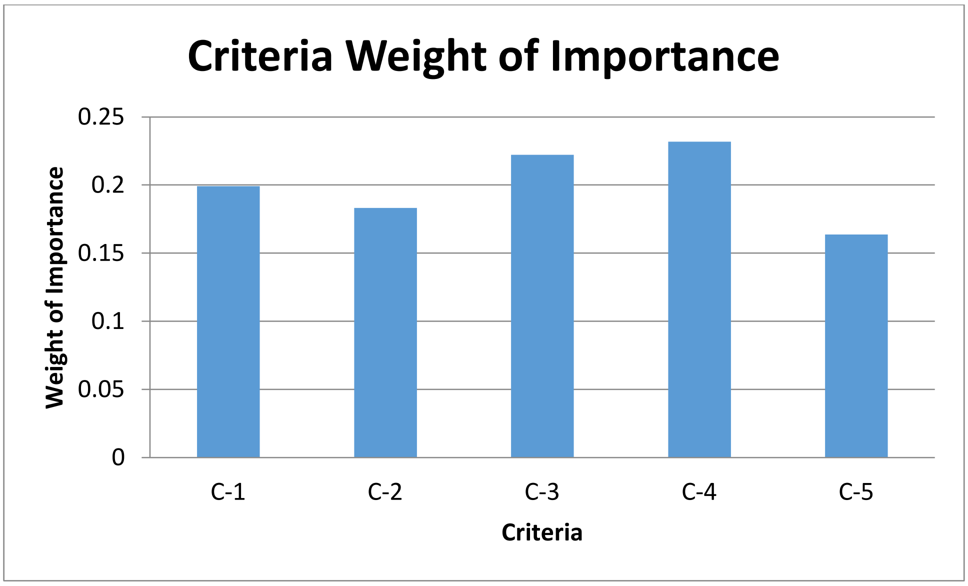


Figure 5.12 Criteria Weight of Importance

It is seen from the results that, the initial ranking order depicted in Table 5.6 is repeated. Normalized criterion weights emerged as C-4 being the most important criterion by weighing 0.231767 out of 1, and C-5 being the least important criterion by weighing 0.163788 out of 1. Saaty (2001) highlights that consistency of a data set (ranked in accordance with 9 – point AHP scale – also known as Saaty scale) adopted in AHP methodology can be checked via calculating the consistency ratio (CR). The consistency ratio (CR) represents the key check of inconsistency of the subjective values of a matrix so that if CR is ≤ 0.1, the values of subjective judgment are considered acceptable.

Consistency ratio CR is calculated as follows:

$$CR = CI / RI \qquad (5.1)$$

Referring to the formula given above, CI is consistency index, and RI is the randomness inconsistency.

$$CI = \frac{\lambda_{\max} - n}{n-1} \qquad (5.2)$$

Consistency index is the process of checking consistency in terms of maximum eigen value. Maximum eigen value λmax (with inclusion of error factors due to significant figures) is calculated as “5”, and when it is applied within the equation given above, CI is calculated as “0”. On the other hand, if errors due to significant numbers are eliminated, and CI for the pairwise comparison matrix is calculated via MATLAB computation software, the result is calculated as 7.9486e-07.

Randomness index is derived from order of a matrix, and it is the average of CI for random matrices using the 9 point scale. RI values for the matrices comprising N elements are shown below (where N is the order of a matrix) (Saaty, 2001):

N	1	2	3	4	5	6	7	8	9	10
RI	**0.00**	**0.00**	**0.58**	**0.9**	**1.12**	**1.24**	**1.32**	**1.41**	**1.46**	**1.149**

As the order of pairwise comparison matrix considered in this study is 5, RI value of the stated matrix is 1.12.

Considering computed CI and RI values of the questionnaire survey data set, consistency ratio of the comparison process can be calculated as:

$$CR = CI / RI = (7.9486e\text{-}07) / (1.12) = 7.09696429e\text{-}7$$

Calculated CR is much less than 0.01, therefore it can be said that consistency is maintained and validated throughout comparison calculations.

AHP processes regarding alternative neighbourhoods are further elaborated in following Chapter 6.

5.7 Concluding Remarks

The main concern of this chapter is data collection, analysis and evaluation procedures regarding conducted research. Throughout the chapter, key enablers of smart grid applicability assessment mechanism are elaborated in detail. Initially, the criteria that form the basis of the assessment are identified and justified from the literature on the topic of smart grids. The stated criteria comprise five elements listed respectively: Energy performance of buildings, energy use of buildings,climate data for renewable energy, smart meter availability, and finally smart appliance availability.

Subsequently, stated criteria are used for designing a questionnaire survey which seeks to find out how important the individual criteria are in terms of smart grid applicability. Conducted questionnaire is analysed via applying pairwise comparison procedure of AHP in order to obtain weighting factors of stated criteria. Additionally, interviews comprising the same topic with the questionnaire survey are conducted with the intention of obtaining expert views on priory of the stated smart grid applicability criteria.

The quality of the results obtained through questionnaire survey is cross examined by means of reliability and validity by applying triangulation via conducting interviews, and it is observed that consistency is highly maintained throughout questionnaire survey. Once the results of the questionnaire survey are validated, it is seen that smart meter availability is the prominent criteria for smart grid applicability, and it is followed by climate data for renewable energy, energy performance of buildings, and energy use of buildings, and smart appliance availability respectively. Obtained weighted ranking of criteria in terms of their priory on smart grid applicability is intended to be used in formulation of the structure of the geospatial decision support model that is proposed in Chapter 6 of this thesis.

In a nutshell, criteria of smart grid applicability are justified, and then their importance on smart grid implementation process is derived through AHP pairwise comparison procedures applied to results of conducted questionnaire surveys and interviews with experts. Findings are to be used for profiling and ranking of alternative neighbourhoods.

The following Chapter 6 attempts to develop and structure an assessment process for alternative neighbourhoods in accordance with their eligibility for smart grid applicability. A geospatial decision support model is proposed and elaborated for strengthening the management of smart grid implementation projects.

CHAPTER 6: CONCEPTUALISATION OF GEOSPATIAL DECISION SUPPORT MODEL FOR SMART GRID APPLICABILITY (GDSM4SGA)

6.1 Introduction

This chapter of the thesis deals with formulation and structuring of smart grid applicability assessment mechanism. The scale of this study is limited to neighbourhood level; therefore neighbourhoods are the alternatives that are assessed.

As an initial step, general structure of a typical DSS and the need for a spatial decision support system for smart grid applicability prioritization is briefly discussed. Next step covered in this chapter is general structure and main functionality of the proposed model. Subsequently, inputs, assessment mechanisms, and expected outputs of the proposed model are elaborated. Finally, the workflow behaviour of the overall model is expressed by means of activity diagrams.

6.2 Decision Support Requirements in Smart Grid Projects

In this section of the chapter, decision support systems and their derivation in spatial domain (spatial decision support system) are briefly covered. Subsequently, smart grid projects are evaluated from a spatial perspective, and the decision support requirements of such projects are discussed.

6.2.1 Spatial Decision Support Systems

Decision support systems (DSS), as discussed earlier in Chapter 3, are interactive computer based solutions that are developed with the intention of supporting decision making and problem solving activities. DSSs amalgamate theory and knowledge regarding a wide range of topics comprising cognitive science, artificial intelligence, finance, management science, scientific modelling, and many more.

When it comes to problems within spatial domains, geographically anchored data becomes a critical element of formulation of the process that offers solution to the problem. Decision support systems that are dealing with spatial problems are called Spatial Decision Support Systems (SDSS). Vacik and Lexer (2001) highlight that the following features are the primary distinctions of such spatial DSS:

I. Having been designed to solve ill-structured problems
II. Having an effective and user friendly user-interface
III. Enabling the user to combine data and models/methods in a flexible manner
IV. Assisting the user in evaluating the decision space and the available options
V. Adaptability to specific situations
VI. Providing mechanisms and tools for the input and storage of geospatial data
VII. Inclusion of processes for geospatial analysis and query
VIII. Presenting output in spatial forms (e.g. maps)

In accordance with the abovementioned expressions of SDSS, it can be said that SDSSs are appropriate and rational propositions to any decision maker who is in charge of making decisions regarding to a complex problem within a geospatial context.

6.2.2 Site Selection as a Problem in Smart Grid Deployment

As it is highlighted in initiatory chapters of this thesis, thanks to the environmental and socioeconomic benefits offered, smart grids are becoming vital cases in environmental agenda of governments. Policy initiatives forecast that transition in grid technology from present infrastructure to smart grids is to be completed by 2050.

As forecasted by EPRI (2011) and agreed by economists and energy business professionals, abovementioned transition in grid technology requires 400 billion dollars in United States only. Time, cost, and quality are the three corners of a triangle that forms the essence of project management. Wasted time can never be recovered, money is always scarce, and replacement of low quality is always very expensive.

Energy industry is fragmented by nature as many actors ranging from finance, generation, distribution, and transmission processes are involved in the value chains of energy industry. Therefore, required resources to conduct transition process in grid infrastructure are logically needed to be supplied by all the actors involved in the market. As it is well agreed by the energy industry that there is scarcity in terms of resources where in this case are the money and qualified workforce for conducting transition process in grid infrastructure and operations. Therefore, allocation of resources becomes crucial in such projects.

In the light of abovementioned restriction of resources, this research offers geographical segmentation throughout project timeline in a way that available resources are allocated to a sub-region so that the overall project can be conducted in a timely and cost effective way. To make that concept clear to one's perception, when a smart grid project is assumed to be analogous with a jigsaw puzzle, each sub-region represents individual pieces of the puzzle. Once the geographical segmentation has been completed, it is time to identify where to kick start the project and how to move on to the next-region. In order to achieve that, a knowledge base comprising spatial indicators regarding smart grid applicability must be well established. This knowledge base should be designed in a way that it supplies decision makers the information regarding to sub-regions by forecasting and reflecting their performance assuming intended transition process is completed. In other words, a forecasting and simulation effort is required for identification of performances of alternative sub-regions likely to occur as if smart grid project has been utilized. Stated approach would enable identifying the most suitable sub-region to kick start the project in terms of smart grid applicability. Such manner in management of smart grid projects enables harvesting maximised benefits offered by that particular sub-region for a longer duration whilst progress with the transition process is being carried out among other sub-regions till the overall project is completed. For that reason, it can be said that site selection in a manner of prioritization of alternatives in terms of smart grid applicability is a vital milestone in smart grid project realizations.

Smart grid realization projects fall into the category of “ill-defined problems” as they are comprised of unclearly defined constraints and they possess multiple criteria (such as local renewable energy availability on site, and smart meter installations) for evaluating solutions. Moreover, aforementioned site selection adds another layer of complexity to realization of such projects that are represented by ill-defined problems. Therefore, rendering a decision in such complicated mediums requires a solid and well formulised approach. As their strength in dealing with ill-defined spatial problems, and flexible nature in combining spatial data with appropriate modelling tools, spatial decision support systems (SDSSs) emerge as essential assistive technology for smart grid projects carried out within spatial domain.

6.3 Proposed Conceptual GDSM4SGA

This section of Chapter 6 describes and discusses the specifications of spatial decision support model that is built with the intention of assisting decision makers on the identification of priory areas for smart grid applicability. Initially, functionality of the stated model is handled in order to make it clear about what is dealt with the model. Secondly, data requirements of the model are introduced. Subsequently, structure of the proposed model is presented. Lastly, data flow modelling is undertaken for the proposed SDSS by means of standardized general purpose modelling language ‘UML’.

6.3.1 Functionality of GDSM

Proposed SDSS is called Geospatial Decision Support Model for Smart Grid Applicability (GDSM4SGA). As its name implies, the model is designed for assessing areas by means of spatial enablers (or assets) for identifying suitability of smart grid applications. Previously identified criteria are spatially anchored to the alternative areas in order to form a base layer for assessment.

In this study, Analytic Hierarchy Process is adopted as the main data processing and analysis tool. As mentioned in previous chapters, the Analytic Hierarchy Process (AHP) is a quantitative technique for multiple criteria decision making. It provides a way to quantify the qualitative aspects thus eliminating subjectivity in the outcome. The technique begins by clearly identifying the objectives, criteria and alternatives for a given problem situation (Saaty, 2008). For each of the criteria (qualitative or quantitative) a vector is created that gives the relative ranking of its alternatives. In this study, weights of the criteria's are determined from the questionnaire survey and interviews. Adequate statistics are applied to collected questionnaires in order to obtain pairwise importance weights, and these inputs are then used to relatively rank the alternative neighbourhoods.

From a practical perspective, bridging AHP with the conducted study is depicted in the Figure where objectives, factors, attribute map layers and ranking of alternatives are illustrated for AHP. Moreover the given figure depicts the geospatial process for rating the alternatives.

Factors given (i.e. F1, F2....Fn) are the set of rules derived from aforementioned criteria, and these factors (or derived versions of "functions" and "tasks" in ontology) are applied to attribute maps of the neighbourhood alternatives. These factors are forming the basis for the ontology all together and they are formed either by criteria on its own or by bridging any criteria via semantic relations. Additionally, observations that are carried out in the Salford

Energy House assisted the crystallization of factors, and strengthened the vision obtained through literature regarding the identification of assessment criteria. Stated factors are:

F1: Classify “Energy performance rating of buildings”
F2: Classify “Energy consumption of the buildings”
F3: Classify “Smart meter availability”
F4: Classify “Renewable energy potential”
F5: Classify “Smart appliance availability”

Geospatial rating of alternatives comprises rating the attribute layer maps in accordance with the weighting factors obtained through questionnaire.

Abovementioned AHP algorithm is basically composed of two stages:

1. Determining the relative weights of the decision criteria (See Figure 6.2)

2. Determining the relative rankings (priorities) of alternatives (locations/neighbourhoods) (See Figure 6.3, Figure 6.4and Figure 6.5)

Calculation of criteria weights is the first stage of the stated AHP algorithm, and the process of calculating criteria weights is described in detail in previous chapter five. In given Figure 6.2 below, decomposition of criterion weights in order to achieve the overall goal is illustrated. As a next step, each location/neighbourhood is assessed by means of the identified criteria individually. Figure 6.3 shows how individual criteria and individual alternative neighbourhoods are matched to each other. Figure 6.4 given below depicts how priority vectors for alternatives in terms of individual criterion are obtained. The process is a matrix calculation and the resultant vector is the priority vector of alternatives for the particular criterion. This process is repeated for each single criterion.

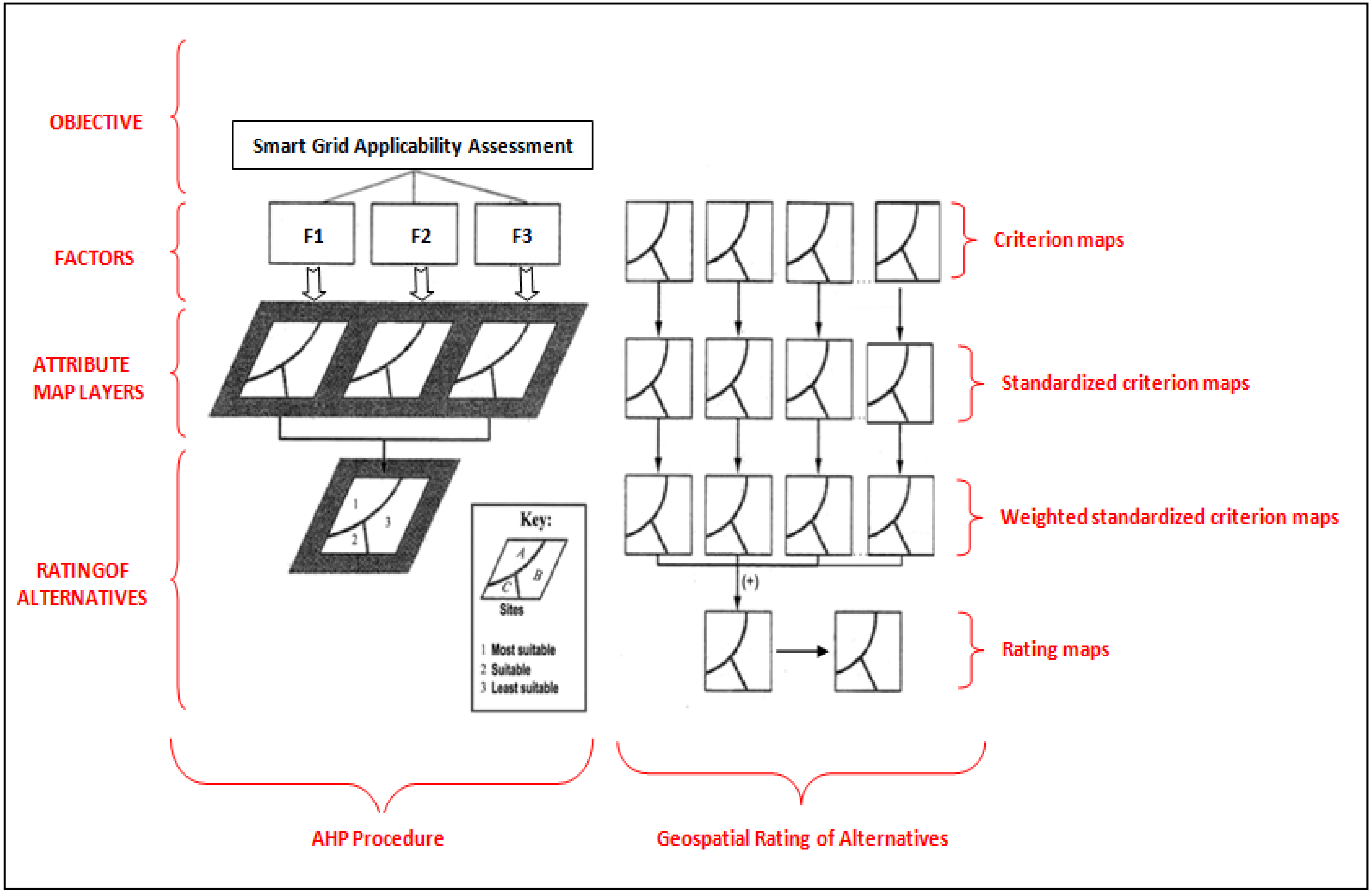


Figure 6.1 Geospatial MCDM process for the model

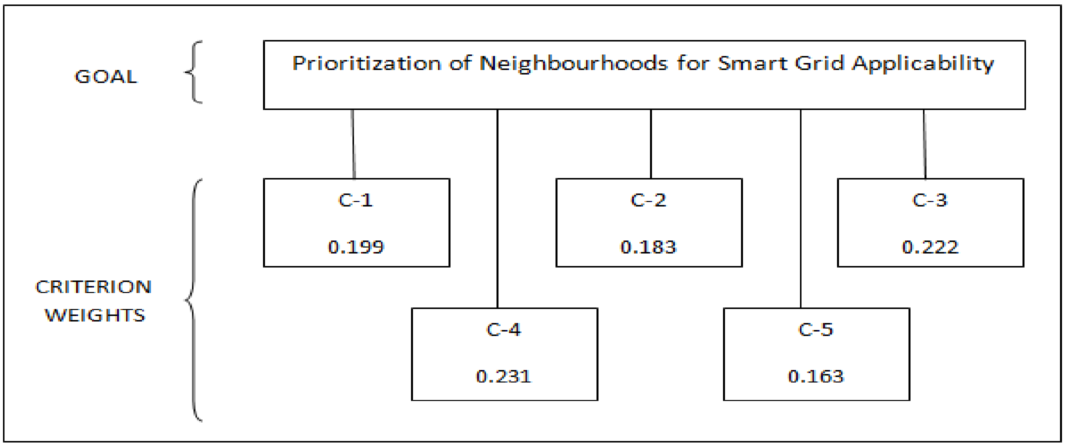


Figure 6.2 Relative Weights of Decision Criteria

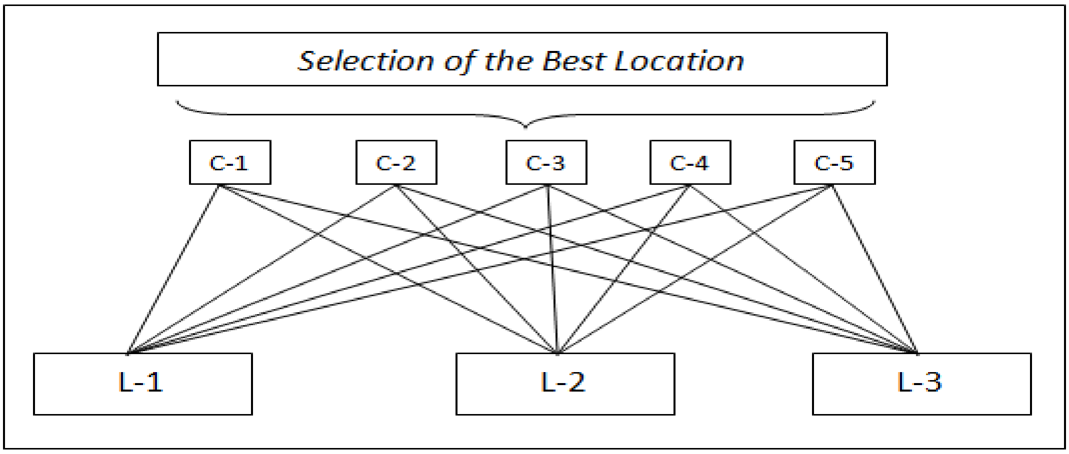


Figure 6.3 Location selection mechanisms

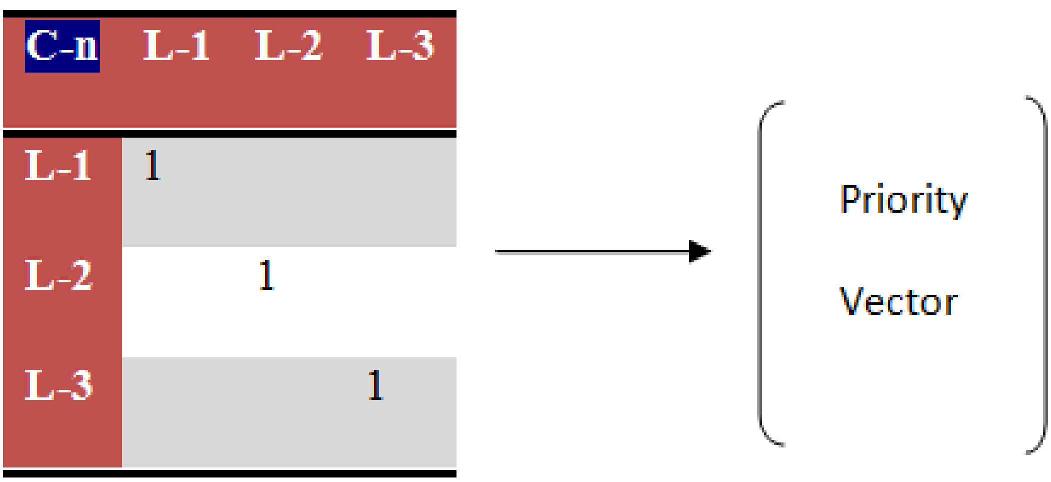


Figure 6.4 Priority Vectors of Alternatives for Criterion “n”

Following the calculations of priority vectors of alternatives in terms of individual criteria, the last step of aforementioned AHP algorithm is to combine all of the obtained priority vectors in order to reach a final vector of overall rankings. As it seen in the following Figure 6.5, it is linear algebraic process which is multiplication of priority matrix (which is formed by aforementioned priority vectors) and vector of criteria weights. The output of this calculation is the vector that indicates ranking of alternatives. Stated calculations are further elaborated with location specific data in the following Chapter 7 “Mastering GDSM4SGA”.

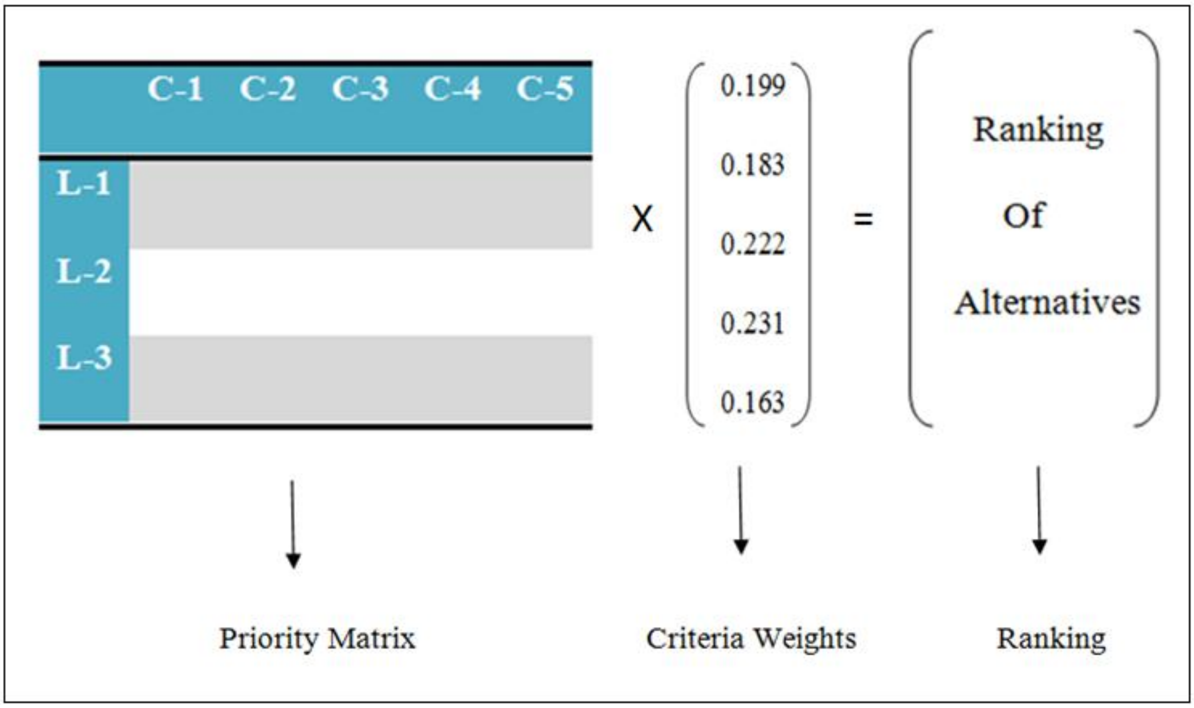


Figure 6.5 Calculation of ranking of alternatives

6.3.2 Data Requirements of GDSM

Previous chapter 5 of this thesis has dealt with primary data that is collected, evaluated, and analysed by the researcher. The stated primary data plays a critical role in designing the assessment mechanism that ranks alternative neighbourhoods in terms of smart grid applicability. In order to conduct such assessments, profiling of the alternative areas/ neighbourhoods comprising spatial elements of identified criteria should be well established.

Thus, utilization of data that supply appropriate spatial base for profiling of alternatives emerged as a vital requirement. Such requirements are fulfilled via previously generated data by others. Therefore these data are clustered as secondary data. The following are the spatial derivations of criteria-related secondary data:

6.3.2.1 Topography

In order to develop a spatial model, any GIS platform would logically require a topography layer as a base map that other data can be appended and anchored. In this study OS MasterMap Topography Layer has been adopted as the base layer. Stated layer provides a highly detailed view of Great Britain's landscape including individual buildings, roads and areas of land. In total, it contains in excess of 400 million individual features.

6.3.2.2 Energy Performance of Buildings

EPC labels regarding postcode boundaries of alternative neighbourhoods are integrated to model data base. An EPC label is an indicator of building energy efficiency; therefore EPC is used in the model as a representation of building energy performance criterion. A typical EPC label comprises address details, dwelling type, floor area, energy efficiency rating, environmental impact rating, energy use, carbon emissions, and fuel costs. Additional elements such as advice on improvements etc are also supplied with an EPC label but those are beyond the scope of this research. Please see appendices for a copy of an EPC label.

6.3.2.3 Energy Use of Buildings

Actual energy use in residential buildings is an indicator of energy demand. The following tools are embedded to the model as data enablers of energy demand.

The National Heat Map: It is a web based tool hosted by Department of Energy and Climate Change (DECC, UK). The national heat map provides high resolution maps depicting address-level modelling of heat demand. The tool enables visualisation, reporting and exporting spatial heat demand ranging from a single dwelling scale to country scale. Please see appendices for detailed capabilities of The National Heat Map.

UK Sub-National Energy Consumption Statistics: It is a data set supplied by UK Department of Energy and Climate Change, and the stated data set indicates country wide energy consumption statistics spatially.

6.3.2.4 Local Renewable Energy Potential

Local renewable energy potential is an indicator of clean energy generation potential that can be integrated into the energy loop. Tools specified below are used for local determination of renewable energy potential:

Solar and Wind Energy Resource Assessment (SWERA): SWERA is a data source that is mainly supported by United Nations Environment Programme (UNEP), as well as many other international organizations. The Solar and Wind Energy Resource Assessment (SWERA) brings together solar and wind energy resource data sets and analysis tools from a number of international organizations in a dynamic user-oriented environment. The information and data provided on the site are freely available to the public and intended to support the work of policy makers, project planners, research analysts and investors. Due to its strength in data quality for local renewable energy potential estimation, SWERA is adopted as one of the data sources. Detailed specifications of SWERA can be found in appendices.

IRENA Global Atlas for Solar and Wind: The Global Atlas is the comprehensive information platform on the potential of renewable energy. It provides resource maps from leading technical institutes worldwide and tools for evaluating the technical potential of renewable energies. Therefore, IRENA Global Atlas is used as a data source for determining local renewable energy potential. Further details regarding to this tool can be found in appendices.

JRC PVGIS: This web based photovoltaic potential assessment tool is developed by European Commission Joint Research Centre Institute for Energy and Transport. Photovoltaic Geographical Information System (PVGIS) provides a map-based inventory of solar energy resource and assessment of the electricity generation from photovoltaic systems in Europe, Africa, and South-West Asia. As this tool offers an indication of solar electricity supply, it is adopted as one of the data sets for this study.

6.3.2.5 Smart Meter Availability

Smart meters offer the key technology that makes it possible to obtain smartness in electricity infrastructure by enabling bi-directional flow of data and energy between generation and end use. As it is highlighted in “scope and limitations” of this study, not every data is easily accessible. Spatial data for smart meter deployment is not accessible at the time being, therefore it is based on assumptions made in accordance to case studies which are further evaluated in the next chapter of the thesis.

6.3.2.6 Smart Appliance Availability

Just like smart meters data, spatial data for smart appliances is not available at the time being; therefore data regarding smart appliance availability is based on assumptions made in accordance to cases that are further evaluated in the following chapter.

6.3.3 Ontology

Gruber (1995) defines ontology as “specification of conceptualisation”. In other words, ontology is the structural framework developed for organizing information. Ontology denotes knowledge as a set of concepts within a domain, and the relationships between pairs of concepts. It can be used to model a domain and support reasoning about concepts.

It is expressed by Jung and Sun (2010) that ontological commitments are required for development of a successful information system in order to make sure that data objects, concepts, and relationships adhere to the chosen ontological specifications. As SDSSs are structured information systems, ontologies have been adopted by SDSSs to support the decision making process, mainly to represent the data and to support their processing for taking decisions. Therefore, an ontology requires describing the domain knowledge, including concepts, properties (i.e. relations between concepts), and instances (i.e. an object of the concept), in a standard and machine-readable format (like standard Ontology Web Language - OWL), which can be understood by machines to discover relevant concepts and instances (i.e. web services).

In this research, aim of developing decision ontology is to form a basis for representing, modelling and analyzing decision making process. Stated decision ontology is developed in two steps. The first step is the development of the geospatial function ontology that formulates semantic linkages between data sources and geospatial operations. The second step is the task ontology in which geospatial problems are represented by subcategories of tasks and related geospatial functions. Formation and notation of the stated ontology is based on the industry standard package ArcToolbox 9.3 (developed by Environmental Systems Research Institute - ESRI) that enables an environment for performing geo processing operations.

Geospatial function ontology portrays the input and output data type, requirements, and effects of geospatial functions. The geospatial function ontology depicted below in figure 6.6 the data types for input data are points (Address/building data), line (boundary), or polygons (area/neighbourhood data); the data type for output data is polygon (area/neighbourhood data).

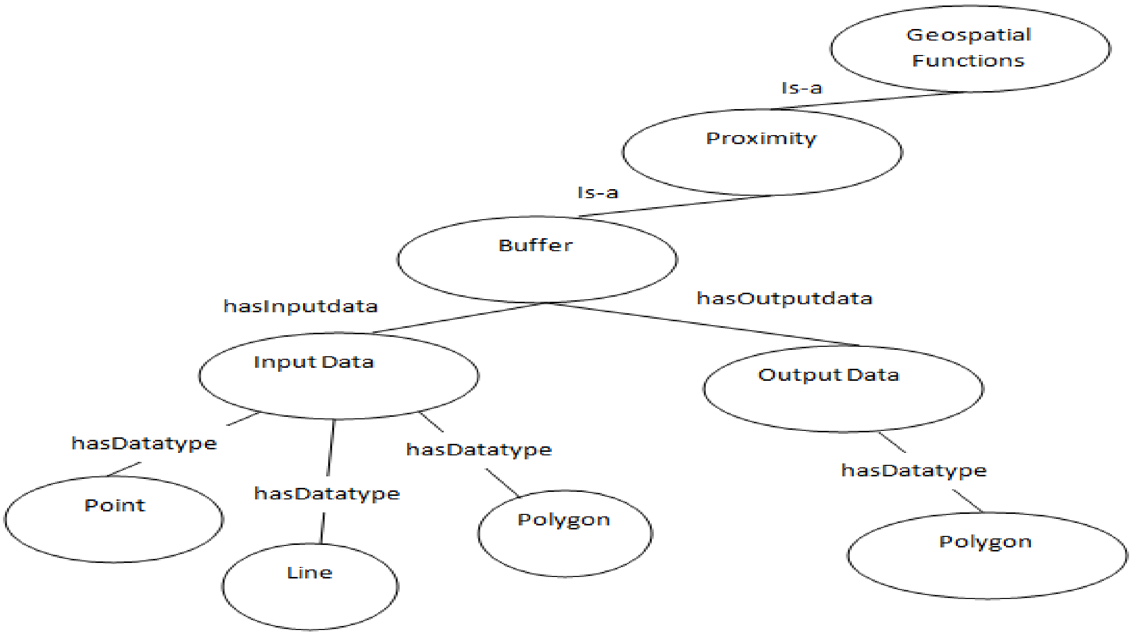


Figure 6.6 Geospatial Function Ontology

When it comes to the second step which is "task ontology", it can be said that it specifies problem solving processes and presents the knowledge of tasks in a domain by specifying concepts and relations appearing in a concerned task (Seta et al, 1996). Special annotations from ArcToolbox are used for linking the objects. Given Figure 6.7 depicts how tasks decompose and how the functions are connected to one another.

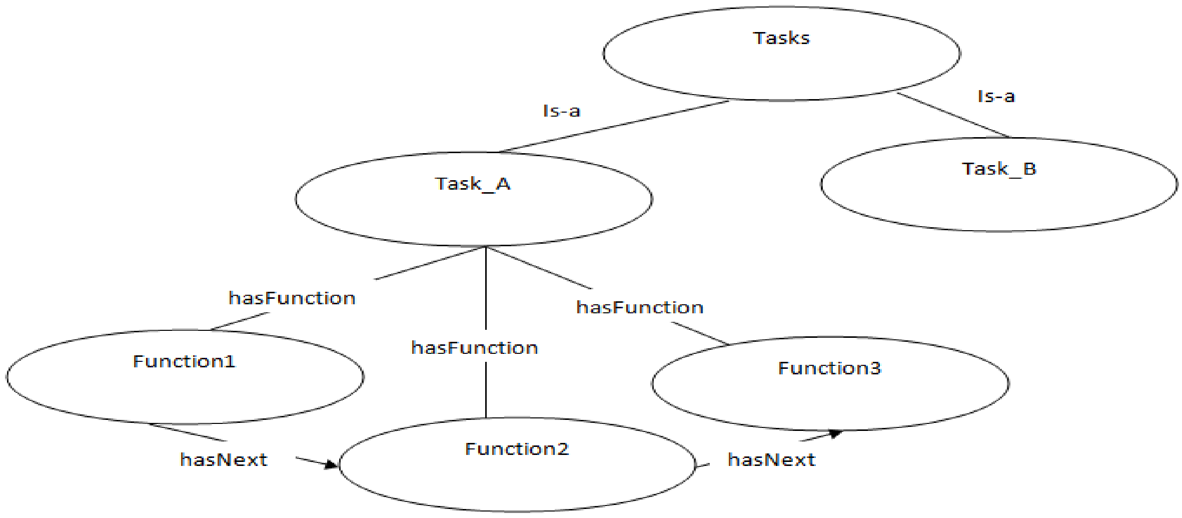


Figure 6.7 Task Ontology

Abovementioned steps of ontology are the overall representation of the decision ontology developed for the proposed Geospatial Decision Support model. Mentioned geospatial functions are derivations of identified criteria, and they represent the basis of how the aggregate criterion attribute maps are obtained. Task ontology developed for the proposed model depicts the formation of aggregate criteria maps that are formed by engaging layers of attribute maps (in terms of functions) to one another.

Each task in the proposed model is assigned for individual criteria (i.e. Task_A is assigned for Building Energy Performance (C-1), and Task_B is assigned for Building Energy Use (C-2), and so on). Functions described under each task are repeatedly used and adopted according to the related data type (i.e. smart meter data, renewable energy data etc.), and they are given as follows:

Function 1: "Create point density mapping". This function aggregates the number of data points within specified range.

Function 2: "Extract by Attributes". This function extracts the cells of a mapped data grid based on a logical query. Data sets used in the model are classified in a way that data are clustered in a 9 point scale (AHP 9 Point Scale), where minimum value is assigned to integer 1 and maximum value is assigned to integer 9 and mi-values are assigned to integers ranging from 2 to 8 accordingly. The reason for that is to maintain compliance with Analytic Hierarchy Process. Stated function consists of a logical query that clusters data set in a form of a 9 point scale.

Function 3: "Run Weighted-overlay". This function enables assigning a percentage of influence (weighting factor) to the aggregated data points and extracted attribute data sets.

Those functions are run within the model respectively in order to locate suitable areas in terms of individual criterion.

6.3.4 Structure of GDSM4SGA

Up to this point in this chapter, functionality, data requirements, and underlying ontology are described in detail. In this section, how those functionality, data, and ontology are brought together under the umbrella of GDSM4SGA is explained.

The model is elaborated in two different approaches. First approach us the "component" approach that lists main components and general structure of proposed model. Mentioned components are i) "Information Base" that serves as the data source and comprises geospatial databases regarding identified criteria, ii) "Toolbox" component that serves as the processing unit/mechanism (in this case it is the AHP algorithm), iii) "Spatial decision support generator" component that serves as a shell where the assessment process of alternatives is being carried out, iv) "Graphical User Interface" (GUI) component that serves as the medium for the users to interact with the model and enables the users to supply input, obtain output in a visualized form. GUI component's other function is to act as a "data visualisation" tool in order to enable knowledge transfer to decision makers in a more comprehensible way.

Component approach that breaks down the general structure and the main components of proposed model "GDSM4SGA" is depicted in Figure 6.8.

Second approach used for describing the structure of the model is "conceptual model" approach in which main input, embedded processes, and main output are shown in a conceptual framework. In this case, data layers and alternative neighbourhoods are matched and processed within a GIS engine. Aforementioned AHP algorithm and ontology are embedded in the stated GIS engine. Figure 6.9 illustrates the proposed model from a conceptual point of view.

Last but not least, it is well worth highlighting the data layers used in the assessment mechanism. Stated data are highlighted previously in the data requirements section, and as depicted in Figure 6.10, used data layers are:

- Topography layer that acts as a base plate to geographically link other layers
- Building energy performance layer, and Building Energy use layer that comprise point data regarding buildings within the neighbourhood
- Layers of wind and solar energy that indicate local renewable energy potential
- Smart meter, and Smart appliance data layers that comprise point data regarding related component availability in the neighbourhood
- A combined data layer that brings together all the mentioned data layers with the intention of supplying a base for overall assessment of alternative neighbourhoods

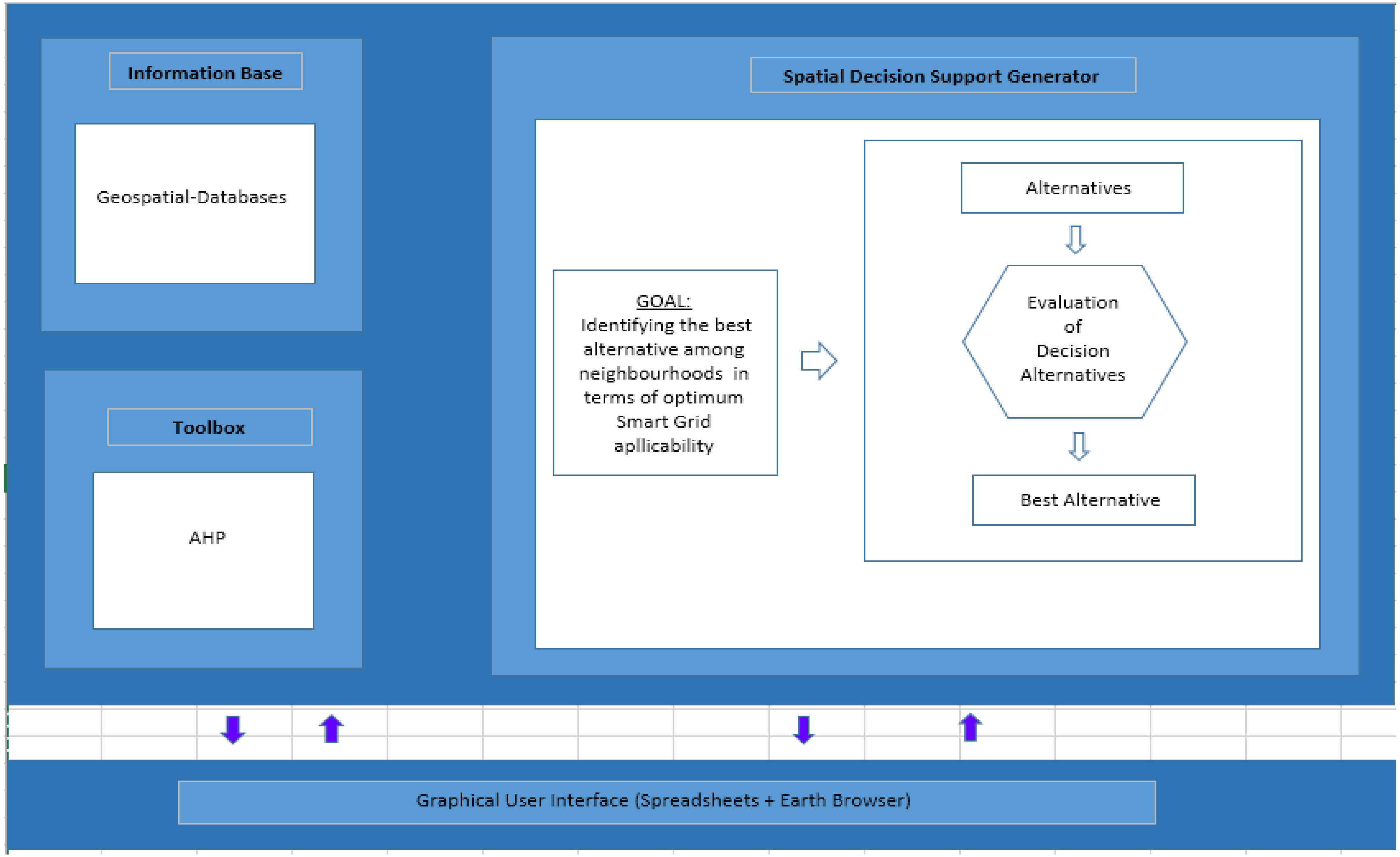


Figure 6.8 Main Components and General Structure of Proposed Geospatial Decision Support Model for Smart Grid Applicability (GDSM4SA)

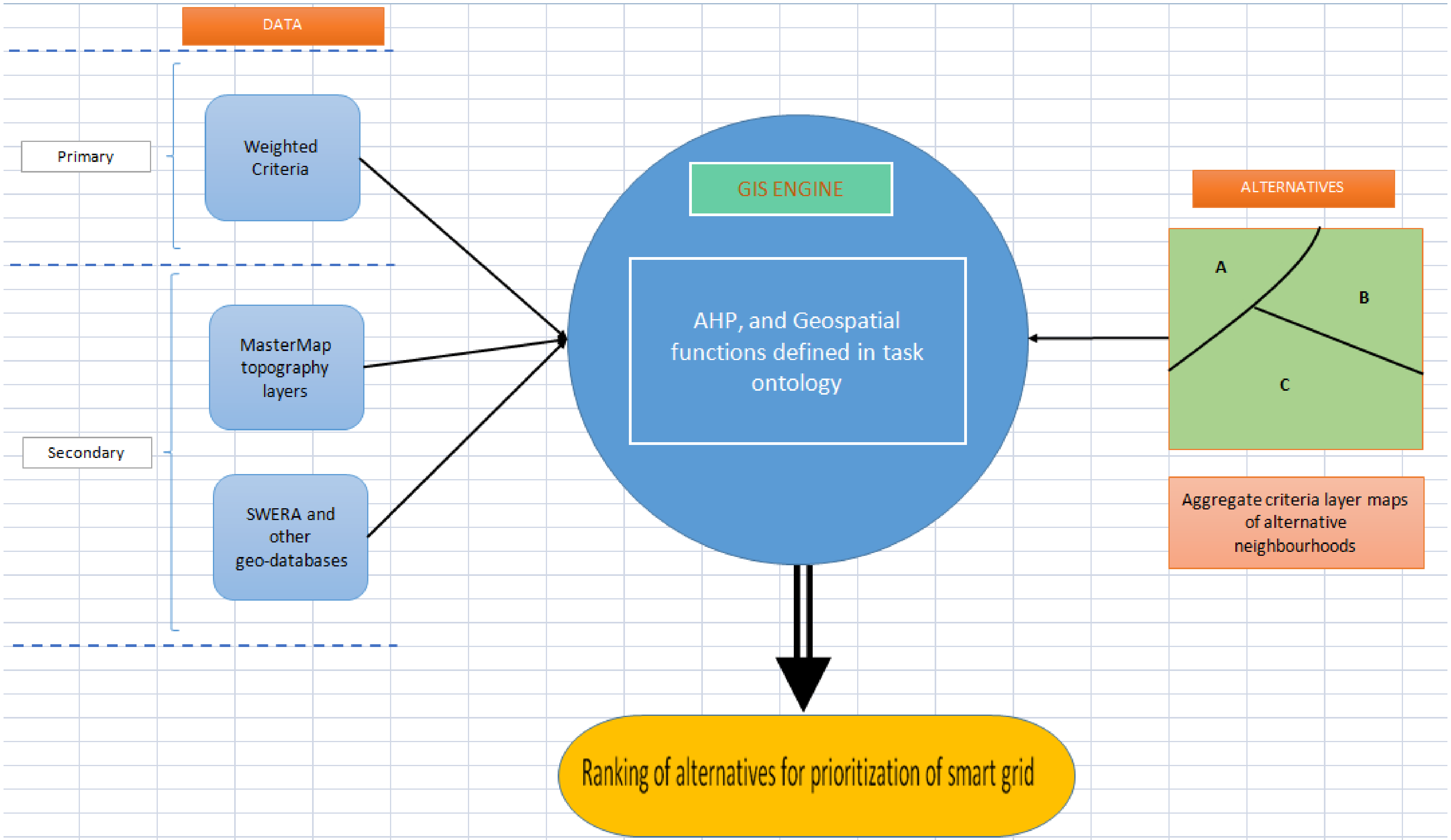


Figure 6.9 Proposed Conceptual model for GDSM4SG

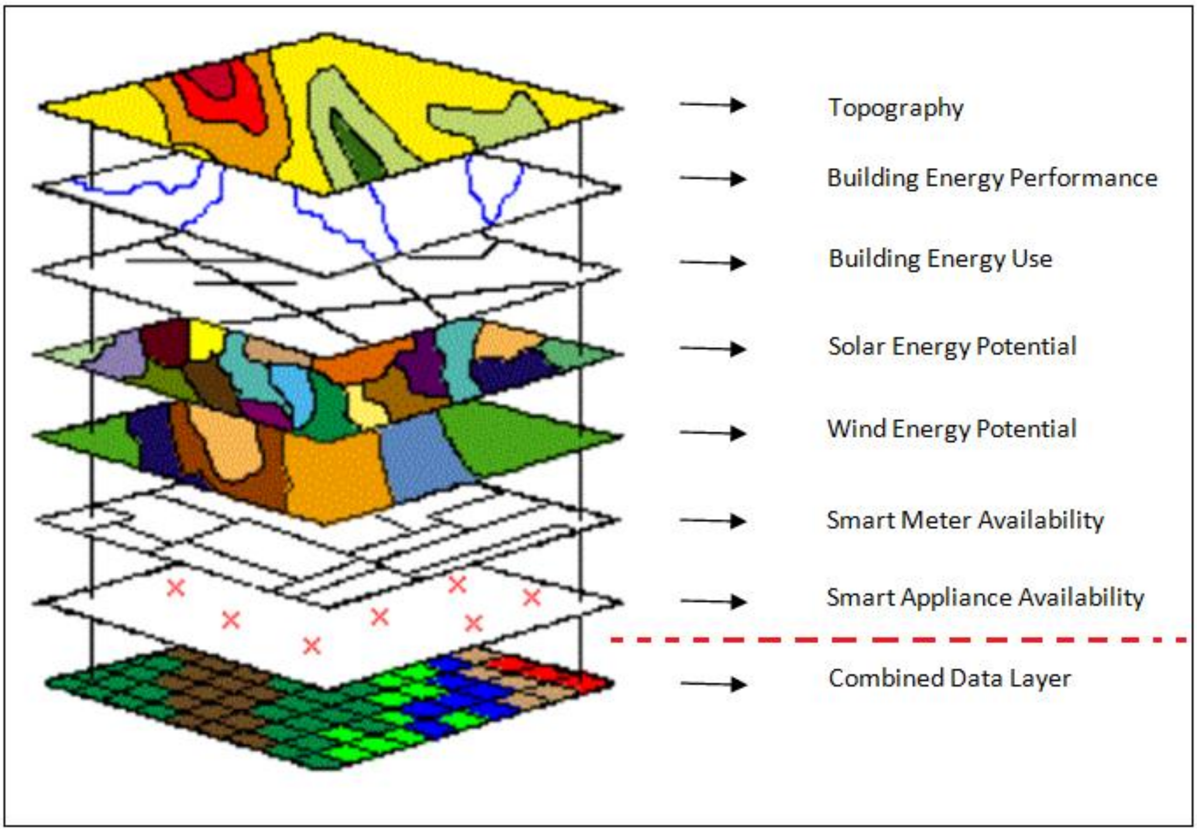


Figure 6.10 Data Layers Embedded in GIS platform

6.4 Data flow modelling

6.4.1 Modelling of GDSM

A model is the phenomenon when something is used in any way to represent something different. The term "conceptual model" refers to models which are developed to represent conceptualization processes and related semantics. It is highlighted by Parent et al (2008) that conceptual modelling offers numerous benefits to geospatial applications such as eliminating or minimizing the need for computational expressions. As the intention in this study is to develop a generic decision support model, conceptual modelling emerges as a viable approach for systematic representation of the overall mechanism.

Data flow modeling (DFM) is a basic conceptual modeling technique that graphically represents elements of a system, and it is one of the most comprehensible methods for the system representation. Emphasized by Bhattacharjee and Shyamasundar (2009), Unified Modeling Language (UML) provides a technology independent framework that can be used to model and specify composition of processes, and it is primarily designed for reducing the complexity of software intensive system design. UML is the industry standard notation for software systems, and its straightforward nature is the reason why many researchers adopted UML in their research regarding to geospatial issues ranging from forest management (Vacik and Lexer, 2001) to wildfire damage reduction applications (Spiros et al,2003), and river system behaviour representations (Janssen and Dokas, 2008). Distinctions offered by UML in improving the quality and readability of the software diagrams, making them easier to understand and to work with makes it a preferable modelling tool for the system proposed in this research.

6.4.2 Adoption of Unified Modeling Language

6.4.2.1 Unified *Modeling* Language

Unified Modeling Language (UML) is a standardized general purpose language with graphical expressions for visualisation, specification, construction, and documentation of models (Booch et al, 2005). Reinhardt (2011) highlights that; UML is developed with the intention of creating a platform independent of particular programming languages. Diagrams are the key enablers for graphically representing a system via UML approach. UML diagrams represent two different views of a system model comprising structure and behavioural aspects, therefore the stated diagrams are clustered as structure diagrams and behaviour diagrams. The structure diagrams depict static structure of a system by using objects, attributes, operations, and relationships. On the other hand, behaviour diagrams depict dynamic behaviour of the system by indicating collaborations between objects. Given Figure 6.x gives a picture of UML diagrams and their breakdown among clusters.

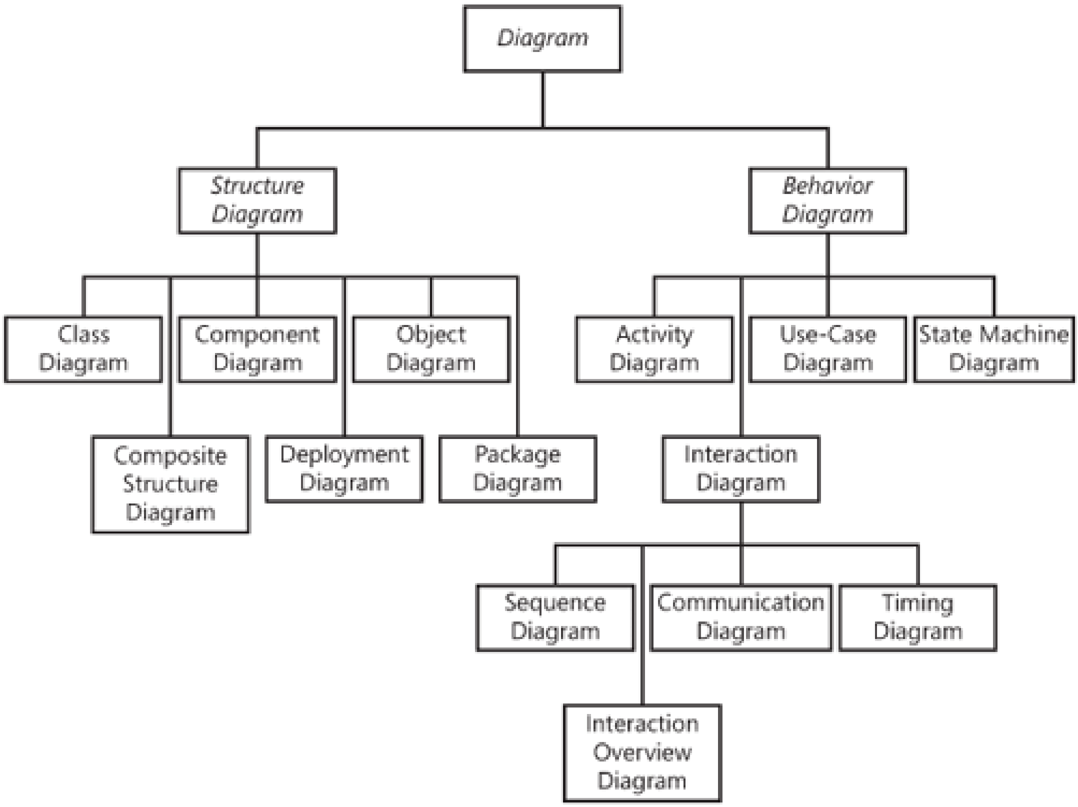


Figure 6.11 UML Diagrams (Booch et al, 2005)

UML diagrams do not only differ from each other by their systematic functions, but also by their purpose of utilization. Given Table 6.x below shows how UML diagrams are categorized and how their purposes vary.

Table 6.1 UML Diagrams explained (Booch et al, 2005)

Diagram	Category	Purpose
Activity	Behavior	Shows the flow of operations in an activity
Class	Structure	Shows classes, interfaces, and relationships within a system
Communication	Behavior	Shows the interaction between objects
Component	Structure	Shows components and their dependencies
Composite structure	Structure	Shows the internal structure of a class
Deployment	Structure	Shows how components are mapped to hardware resources
Interaction overview	Behavior	Shows sequences and activities
Object	Structure	Shows a view of the system at a particular time
Package	Structure	Shows how classes are split into logically related groups
Sequence	Behavior	Shows the interaction between objects
State machine	Behavior	Shows how the state of objects changes after events
Timing	Behavior	Shows the behavior of objects in a period of time
Use case	Behavior	Shows what actors perform which action in the system

Structure wise software intensive modelling for the proposed system is beyond the scope of this study. Therefore structure diagrams are not handled for conceptualisation of the model. Intention of conceptualising the proposed SDSS is to represent it as lean as possible and make it comprehensible for the potential users and developers alike. In the light of stated argument, dynamic behaviour of the system emerges as the point that needs to be explored in order to make apparent the interactions of actors and operations taking part within the system. Therefore UML behaviour diagrams are chosen as the key enablers of conceptualisation in this study. The proposed system comprises functions (different operations within activities), and actors interacting with the system. For that reason, utilizing use case diagrams and activity diagrams comes to the forefront for conceptualization of the proposed model (See Table 6.1).

6.4.2.2 UML Use Case Diagrams

Use cases capture the functional requirements of a system and describe interactions between various actors and the system. The term “actor” means an individual, a system, or an organisation that has a goal in using the system.

The following figure 6.12 depicts the use case diagram for the proposed model.

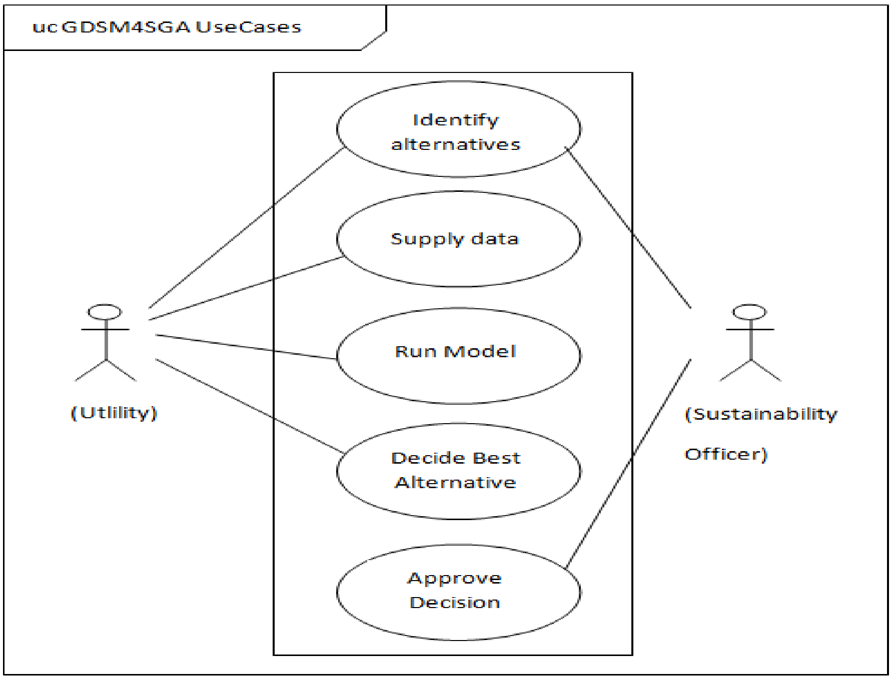


Figure 6.12 Use Case Diagram for Smart Grid Applicability decision making mechanism

Actors defined in the abovementioned Use Case Diagram are i) Utilities, and ii) Sustainability officers of decision making stakeholders (in this case governmental certifying bodies).

Role of Utilities is to identify alternative areas for smart grid applicability, and supplying relevant data to run the proposed model. Additionally, as it is well agreed that DSS extends decision makers capabilities but it does not replace their judgment, deciding on the most suitable location among alternatives is the last but not least duty of the utility actor.

The other actor involved in the stated use case is the "Sustainability Officer". Mentioned actor is a staff or division of an organization that is in charge of certifying/accrediting/approving the smart grid transition projects. Stated actor in given use case is involved in phases of identification of alternative locations, and approval of the projects.

6.4.2.3 UML Activity Diagrams

A UML Activity Diagram is a special case that is used for describing internal behaviour of a method or system, and it represents a flow driven by internally generated actions. Activity diagrams represent processes and sequential activities taking place in a system. Given Figure 6.13 illustrates the UML Activity Diagram of proposed GDSM4SGA.

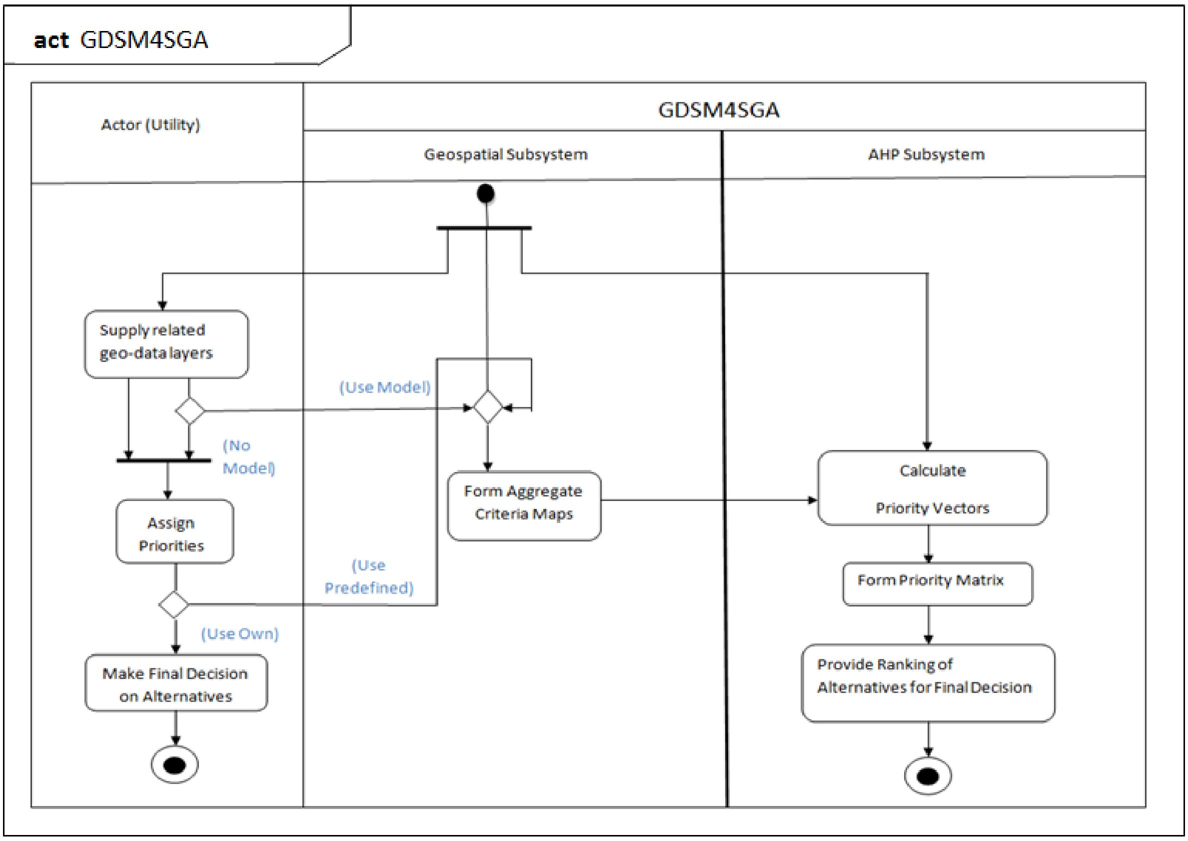


Figure 6.13 UML Activity Diagram of proposed GDSM4SGA.

In given activity diagram of the system, the design is divided into two main partitions by lines that are known as swim lanes. These partitions depict the responsibility area of the systems and actors. In GDSM4SGA system design, actor (utility) and GDSM4SGA assessment mechanism are two main responsible players. GDAM4SGA system is also divided into two subsystems as geospatial subsystem and AHP subsystem. Workflows are depicted in the figure given above.

"Utility" is an actor whose duty is to feed the mechanism with relevant data. If the actor chooses to use the proposed model, than predefined priority weights needed to be assigned to data. On the other hand, actor might choose to assign its own priorities and make judgements on the alternatives regarding stated "own priorities" in order to make a final decision. In the event of proposed model is being used, than it is time to describe the stated subsystems. Geospatial subsystem is responsible for forming the aggregate criterion maps that are vital for the AHP procedures to be carried out. Responsibility of AHP subsystem is to conduct linear algebraic computations in order to obtain ranking of alternatives which is a solid indicator of the priory of alternative locations.

6.5 Concluding Remarks

The main concern of this chapter is the conceptualisation of the proposed Geospatial Decision Making for Smart Grid Applicability – GDSM4SGA. In this respect, proposed system is discussed from functionality and data requirements perspectives, and suitability of proposed Smart Grid applicability assessment mechanism is elaborated for site selection problems. Additionally, embedded AHP algorithm and decision ontology are examined thoroughly. Two different approaches are developed for clarifying the structure of the proposed model. The first approach is the “component” approach that breaks down the main components of the model. The second approach is the “conceptual model” that comprises overall data flows, and highlights the embedded mechanisms.

In order to offer more comprehensible and systematically standardized representation of the proposed model, modeling effort has been carried out via Unified Modeling Language (UML). In this regard, Use Case Diagram (illustrates relations of actors and actions within the system) and Activity Diagram (illustrates flow of operations) are produced.

In a nutshell, conceptualisation of the proposed model has been investigated in a rational way.

The following chapter handles mastering of the proposed model. Additionally, location characteristics in terms of the identified criteria are presented, and the assessment mechanism is run accordingly. Lastly, output of the system is displayed.

CHAPTER 7: MASTERING THE PROPOSED GEOSPATIAL DECISION SUPPORT MODEL

7.1 Introduction

This chapter of the thesis deals with testing phase of the proposed model GDSM4SGA. Initially, three different locations, which are used as the case study locations, are selected randomly as shown in red circles in figure 7.1 below.

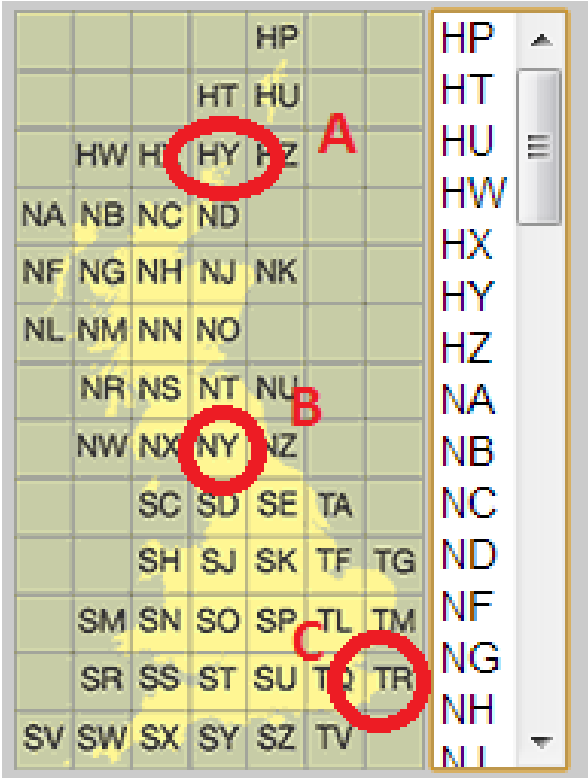


Figure 7.1 Geographical Positions of Alternative Neighbourhoods (Retrieved from OS National Grid Reference Squares)

The figure given above depicts national grid references for the UK, and each grid comprises 1:10000 scale street level colour, digital raster mapping.

The next step is to assign criteria related data to the digital maps, and then apply the smart grid applicability mechanism that has been elaborated thoroughly in chapter 6. When the calculation algorithm given in figure 6.5 is decomposed to individual location level, the following formulation is achieved for each location:

$$\mathbf{SGAS = [\{(L_nC_1)*(0.199)\} - \{(LnC_2)*(0.183)\} + \{(LnC_3)*(0.222)\} + \{(LnC_4)*(0.0.231)\} + \{(LnC_5)*(0.163)\}]} \quad (7.1)$$

Where SGAS stands for “Smart Grid Applicability Score”, and “n” is the location identifier (where in this case n= 1 or 2 or 3) and “L” stands for the Location (Neighbourhood), and C is the criterion, and the numbers in parenthesis are the criteria specific weighting factors that are clearly explained previously in chapter 6. It should also be kept in mind that assigned data to the neighbourhood polygons are converted into AHP nine point scale, so that uniformity among magnitudes with different units is maintained. When applying the formula given above, higher the result better the area performance is. The scores (SGAS) are then ranked to identify and compare the smart grid applicability of individual neighbourhoods.

An important issue that needs paying attention regarding abovementioned formula is the plus/minus notations that point out the addition/subtraction of relevant term. Terms with positive effect on smart grid applicability are added to one another, whereas the ones whose amplitude make negative effect are subtracted from the accumulation of terms. In the grand scheme of things, SGAS comprises five terms each associated with related criterion. Following table addresses the mentioned terms are as follows:

Table 7.1 SGAS Equation Terms

TERM	INDICATION	IMPACT ON SGAS	REASON
1st	Energy performance of buildings	Positive	Higher EPC values contribute to energy saving
2nd	Energy demand	Negative	Higher demand, causes stress over the grid
3rd	Renewable energy	Positive	Higher share of renewable in the energy mix enhances energy security reduces Carbon emissions
4th	Smart meter	Positive	It is key enabler of SG
5th	Smart appliance	Positive	Essential for load management

It is crucial to mention at this point that, from a managerial perspective, it can be said that the worst performing location is more in need of implementing a smart grid. Depending on this statement, the priory ranking is the reverse of the SGAS matrix formed by all alternatives. In other words, the worst performing area is logically the initial point to kick start the project.

In brief, testing phase of the proposed model comprises site selection, data allocation, and employing the SGAS algorithm phases. Very lastly, the obtained rank should be reversed in order to identify the appropriate rank for the priory areas for smart grid applicability.

7.2 Characteristics of Alternative Neighbourhoods

The term "neighbourhood" used in this study denotes the areas comprising of approximately 1000 dwellings within its borders. The case study neighbourhoods employed in this study are randomly selected, provided that they are within the UK territory and they are located on different longitudes. Condition regarding longitudes is set in order to ensure variations in local solar power potentials.

In the following figures 7.2, 7.3, and 7.4, geographical positions of case study Neighbourhoods A, B, and C are depicted. The distinction between the longitudes is clearly observable.

Figure 7.2 Geographical Position of Neighbourhood-A

Figure 7.3 Geographical Position of Neighbourhood-B

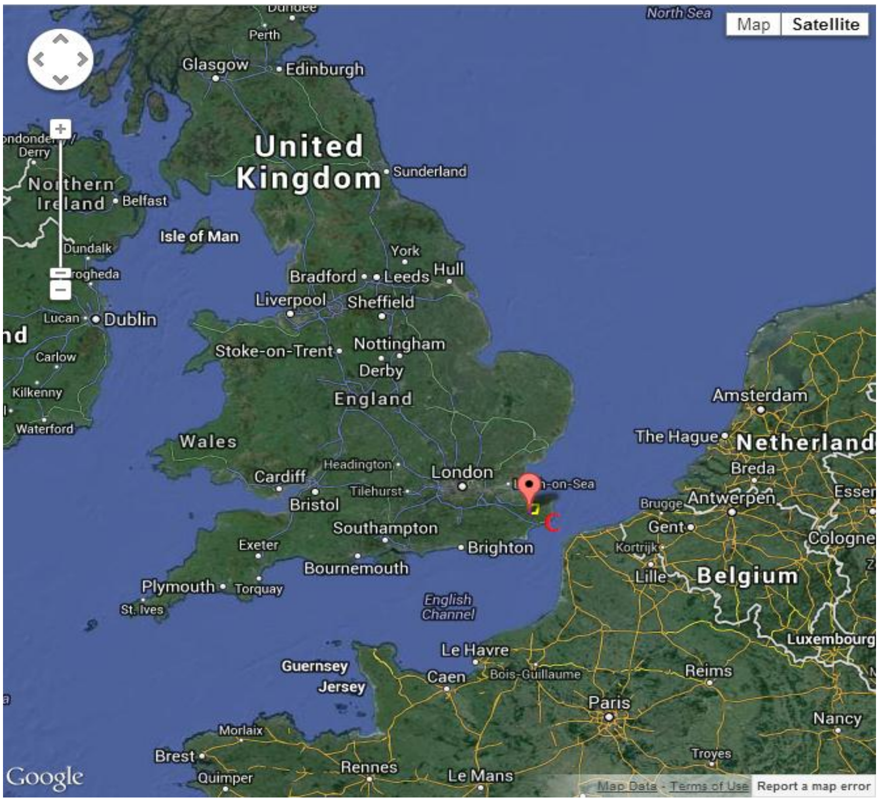


Figure 7.4 Geographical Position of Neighbourhood-C

Neighbourhood A is located at the north of Scotland, and it covers the National Grid Reference Square HY41, nearby Kirkwall.

Neighbourhood B is located at the north of England, and it covers the National Grid Reference Square NY53, nearby Penrith.

Neighbourhood C is located at the south-eastern England, and it covers the National Grid Reference Square TR15, nearby Canterbury.

Data assigned to the stated grids, as previously discussed in chapter 6, comprised of the data sets regarding to the identified criteria for smart grid applicability. Smart meter data and smart appliance data are the exceptions to the abovementioned clause, as assumptions are required to be made due to difficulties in accessing the sufficient data.

7.3 Case studies for Testing the GDSM4SGA

7.3.1 Restructuring Data for AHP Compliance

As mentioned earlier in this chapter, criteria related data require conversion in a way that they become compatible with AHP method. In other words, data is restructured so as to match up to AHP nine-point scale. Stated conversions are supplied via the tables given below:

EPC:

Energy performance certificate values range between 0 and 100.

The following AHP scale conversion has been applied.

Table 7.2 Scale Conversion: EPC ~ AHP

AHP	1	2	3	4	5	6	7	8	9
EPC	0~20	21~30	31~40	41~50	51~60	61~70	71~80	81~90	90~100

BEU:
Building Energy Use (Based on UK National Heat map) is classified in accordance with AHP scale as follows:

Table 7.3 Scale Conversion: BEU ~ AHP

AHP	1	2	3	4	5	6	7	8	9
BEU (kWh/m2)	<550	550~600	600~700	700~800	800~900	900~1000	1000~1100	1100~1200	1200+

Renewable Energy (Solar) potential:
In this study, only spatial variations of solar energy have been concerned. Aforementioned spatial data bases are used as the data enablers. The following AHP scale conversion has been applied.

Table 7.4 Scale Conversion: Solar potential ~ AHP

AHP	1	2	3	4	5	6	7	8	9
Global Horizontal Irradiation (kW/m2)	<750	800	850	900	950	1000	1050	1100	1100+

Smart Meter Availability:
This data is based on assumptions, and the original scale indicates percentage of smart meter deployment. The following conversion has been applied for AHP compliance:

Table 7.5 Scale Conversion: Smart Meter Availability ~ AHP

AHP	1	2	3	4	5	6	7	8	9
Smart Meter Availability (%)	0~15	15~25	25~35	35~45	45~55	55~65	65~75	75~85	85~100

Smart Appliance Availability:

Similar to Smart meter data, appliance availability is also based on assumptions. AHP conversion is designed as follows:

Table 7.6 Scale Conversion: Smart Appliance Availability ~ AHP

AHP	1	2	3	4	5	6	7	8	9
Smart Appliance Availability (%)	<5	5~10	1~20	20~30	30~40	40~50	50~60	60~70	70+

7.3.2 Data Profiles of Alternative Neighbourhoods

After exploring selected neighbourhoods, an extraction from grid reference postcode coverage has been made with the intention of identifying the number of dwellings among stated locations. EPC registrations are then searched by address (postcodes) with the help of data bases enabled by Landmark Information Group. Building energy use, and on-site renewable energy potential (solar) are obtained from the geospatial databases that are elaborated in chapter 6 (SWERA, JRC-PVGIS, SWERA, UK National Heat map) and exported to spreadsheets for identifying the general average values for each alternative neighbourhood. The scope of this study is assessing neighbourhood scale smart grid applicability, but initial spreadsheets contain building scale (point) data. Thus, in order to represent the neighbourhood scale, average values for related point data that lies within boundaries of selected reference grids (polygons) are calculated. This point forward in this chapter, the spreadsheets are presenting average values of the reference grid polygons (neighbourhoods). In this regard, the following table is formed with the intention of depicting the profiles obtained for the alternative neighbourhoods:

Table 7.7 Profiles of Alternative Neighbourhoods

NEIGHBOURHOOD	***GRIDREF***	***Dwellings***	***EPC (Actual; AHP)***	***BEU (Actual; AHP)***	***Renewables (Actual; AHP)***	***Smart Meter (Actual; AHP)***	***Smart Appliance (Actual; AHP)***
A	HY41	978	(51.2; 5)	(1020; 7)	(800; 2)	(60; 6)	(2; 1)
B	NY53	1007	(46; 4)	(920; 6)	(900; 4)	(60; 6)	(6; 2)
C	TR15	1016	(56; 5)	(900; 6)	(1000; 6)	(70; 7)	(9; 2)

7.3.3 Case Study for Smart Grid Applicability of Neighbourhoods

The case study that aims to examine the practicability of the proposed GDSM4SGA comprises multiple case studies (for each alternative neighbourhood A, B, and C) within a single setting. In this respect, SGAS for each alternative neighbourhood has been calculated initially. Once the SGAS are obtained, a spreadsheet is designed in the way that has been depicted in Table 7.7, but this time with an extra column indicating SGAS values.

As "Google Earth", GUI enabler of the proposed model, is a mainstream geo visualization tool that is widely used in geospatial applications, stated spreadsheet is then geo-processed via using a "Spreadsheet to KML" converter in order to convert the dataset into a form that can be displayed in Google Earth. KML (Keyhole Mark-up Language) is an XML (Extensible Mark-up Language) notation for expressing geographical annotation and visualization within Internet based 2D maps and 3D Earth browsers.

Stated spreadsheet is designed by using "OFFSET Function" (in Excel), so that the calculations, and output charts and graphs can dynamically respond to alterations in dataset. In other words, any amendments made to the inputs are immediately reflected to the outputs (calculations and graphs). The following figures are the screenshots that depict the offset function enabled spreadsheets for dynamic charts:

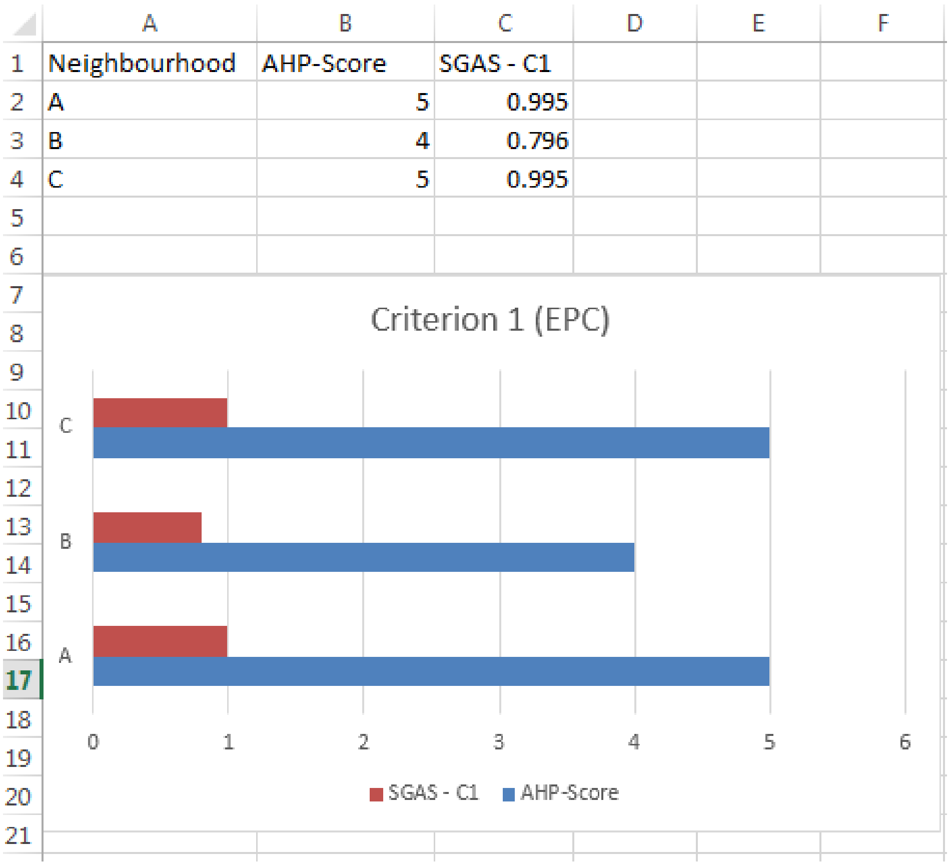


Figure 7.5 EPC component of SGAS

Depicted in given figure 7.5, SGAS component EPC has been calculated in accordance with the related AHP conversion. Obtained AHP scores are multiplied with criterion weight or let's say criterion coefficient (in this case it is 0.199) (See SGAS equation in part 7.1 for details). Neighbourhood A obtained the highest score and it is followed by equal scores of B and C.

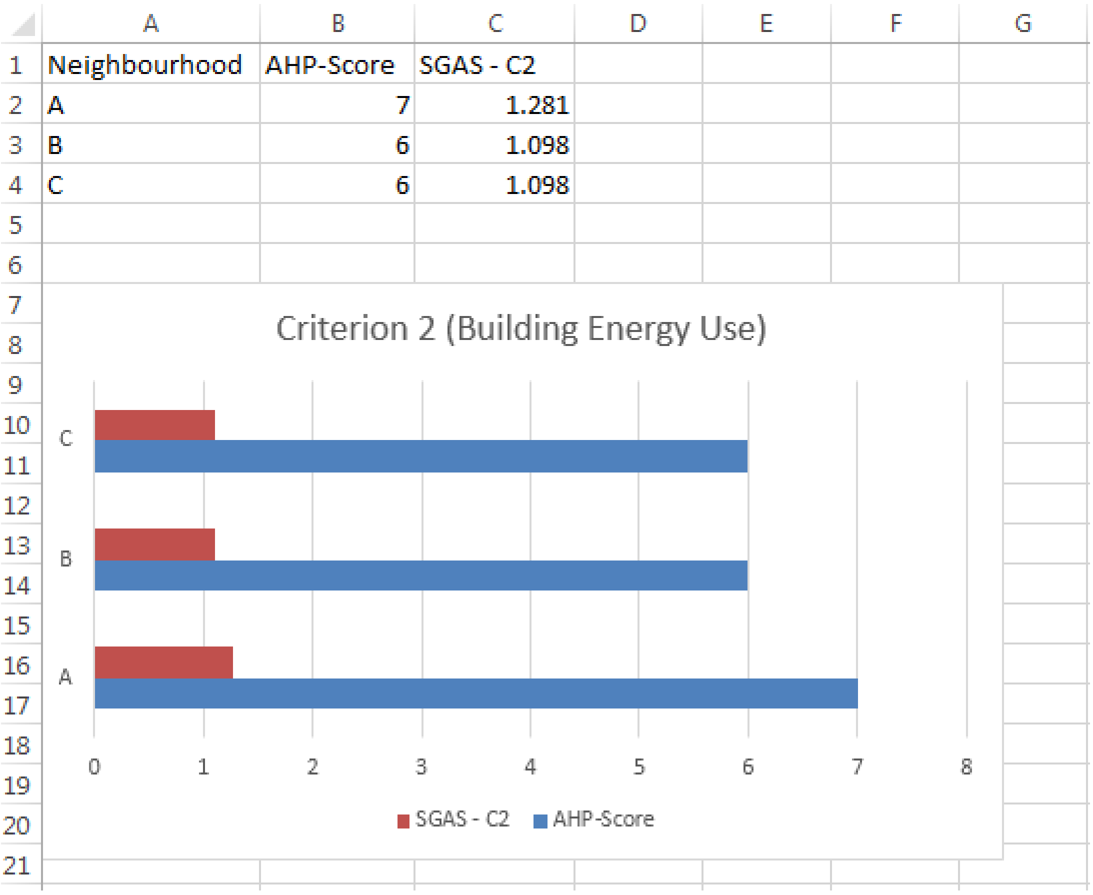
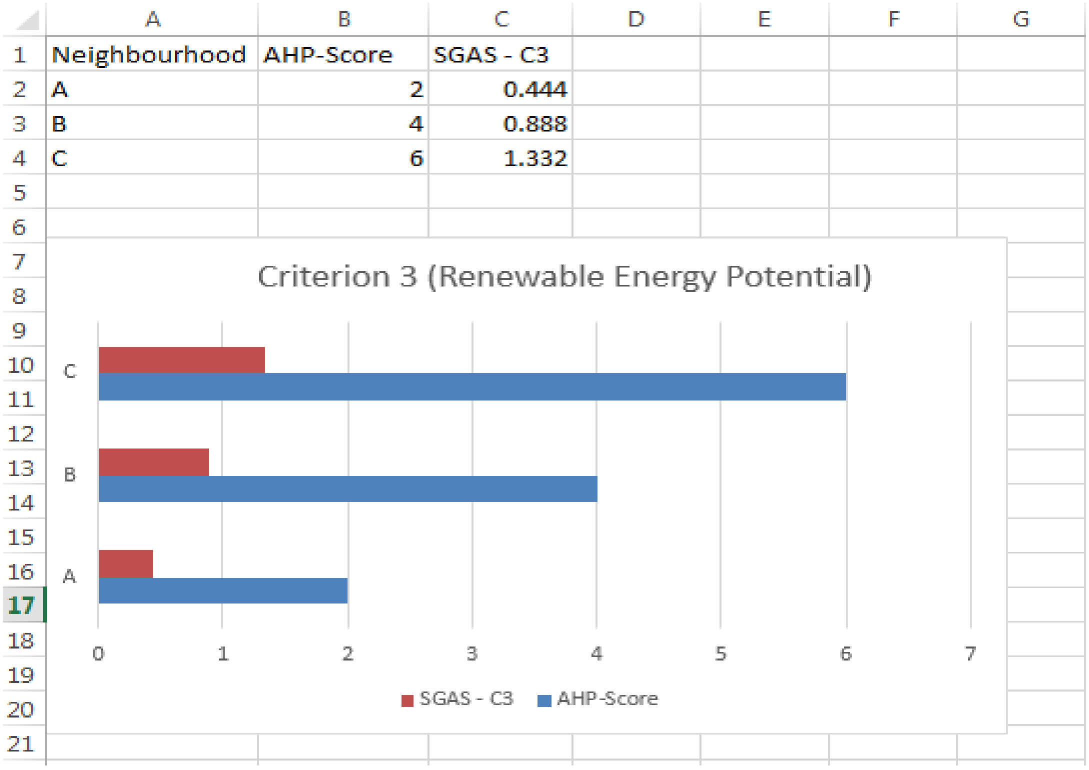


Figure 7.6 BEU Component of SGAS

As shown in figure 7.6 above, SGAS component BEU (Building Energy Use) has been calculated in accordance with the related AHP conversion. Obtained AHP scores are multiplied with criterion weight (in this case it is 0.183) in order to get the matrix vector regarding second term of smart grid applicability score (SGAS). Highest score is achieved by Neighbourhood A.

Figure 7.6, given below illustrates the calculation of renewable energy potential of alternative sites, and presents the results individually for each neighbourhood. The coefficient (criterion weight) used is 0.222. Neighbourhood C obtained the highest score followed by B and A.



Neighbourhood	AHP-Score	SGAS - C3
A	2	0.444
B	4	0.888
C	6	1.332

Figure 7.7 Renewable Energy Component of SGAS

Following figures 7.8 and 7.9 depict the “Smart Meter”, and “Smart Appliance” components of SGAS respectively. Normalized coefficients used in calculations are 0.231 and 0.163 respectively. Neighbourhood C performs the best in terms of both criteria, and it is followed by the equal values of A and B.

Neighbourhood	AHP-Score	SGAS - C4
A	6	1.386
B	6	1.386
C	7	1.617

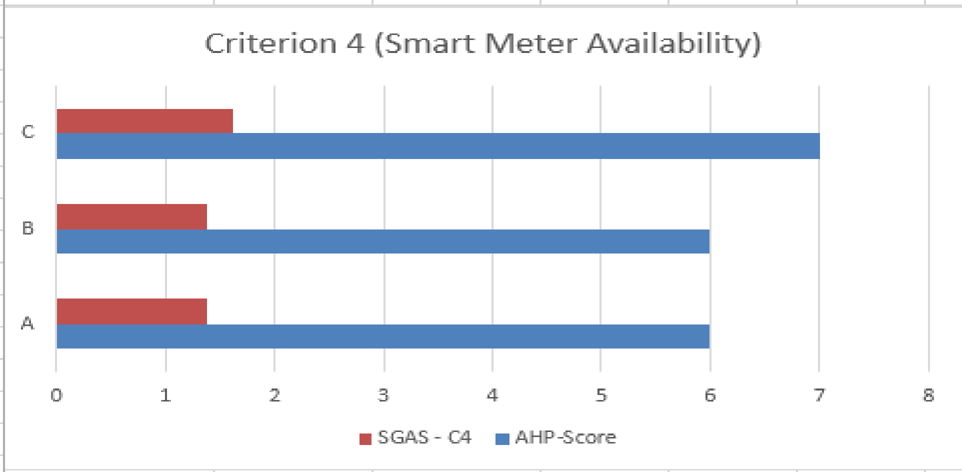


Figure 7.8 Smart Meter Component of SGAS

Neighbourhood	AHP-Score	SGAS - C5
A	1	1.386
B	1	1.386
C	2	1.617

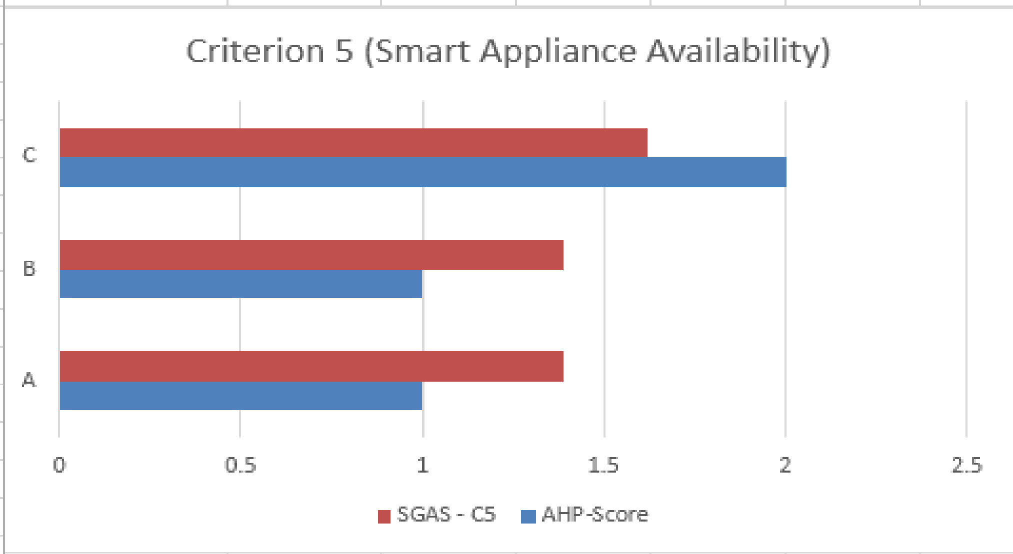


Figure 7.9 Smart Appliance Component of SGAS

7.3.4 Solving Smart Grid Applicability Score (SGAS) Equation

Abovementioned figures are depicting individual component scores. In order to achieve the overall SGAS, SGAS equation should be solved. In a simplified way, the SGAS equation can be represented as follows:

SGAS = {EPC*(Weight1)} – {BEU*(Weight2)} + {Renewables Potential*(Weight3)} + {Smart Meter *(Weight4)} + {Smart Appliance *(Weight5)}

Results of implementing mentioned SGAS equation for each alternative neighbourhood are presented in the following figure 7.10. Additionally, criteria distribution among neighbourhoods is also supplied via the stated figure.

	EPC	BEU	RenewableEnergy	SmartMeter	SmartAppliance	SGAS
A	5	7	2	6	1	1.707
B	4	6	4	6	2	2.298
C	5	6	6	7	2	3.172

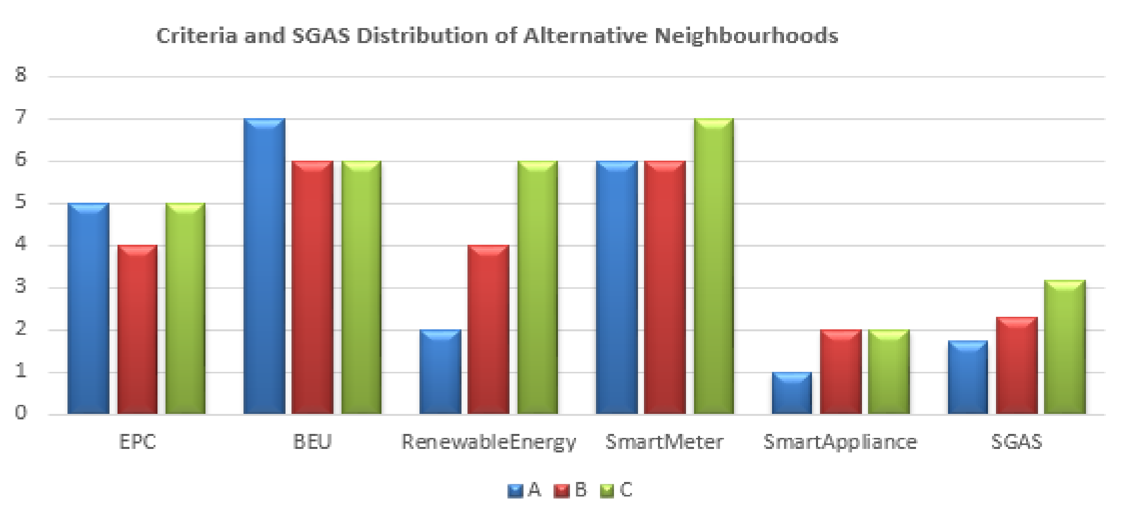


Figure 7.10 SGAS and Criteria Distribution among Neighbourhoods

The SGAS scores calculated are: SGAS (A) =1.707, SGAS (B) = 2.298, and SGAS (C) = 3.172.

From this point forward in this section of the chapter, geo-visualization of dynamic spreadsheets (offset function enabled) are to be presented. In other words, files obtained through "Spreadsheet to KLM" conversions that comprise geo-coded data are run in an Internet base earth browser (in this case Google Earth). Initially, spreadsheets are geo-coded (structured in a way that data is understandable to conversion tools), and then they are converted into KML files. Figures given below depict locations, profiles, and SGAS values regarding alternative neighbourhoods A, B, and C. It should be noted that, when combining data layers, geospatial function ontology (See Figure 6.6), and Task Ontology (See figure 6.7) are taken into consideration.

Following Figure 7.11, is a screenshot of earth browser, and it illustrates the locations of National Grid Reference Squares that comprise case study neighbourhoods.

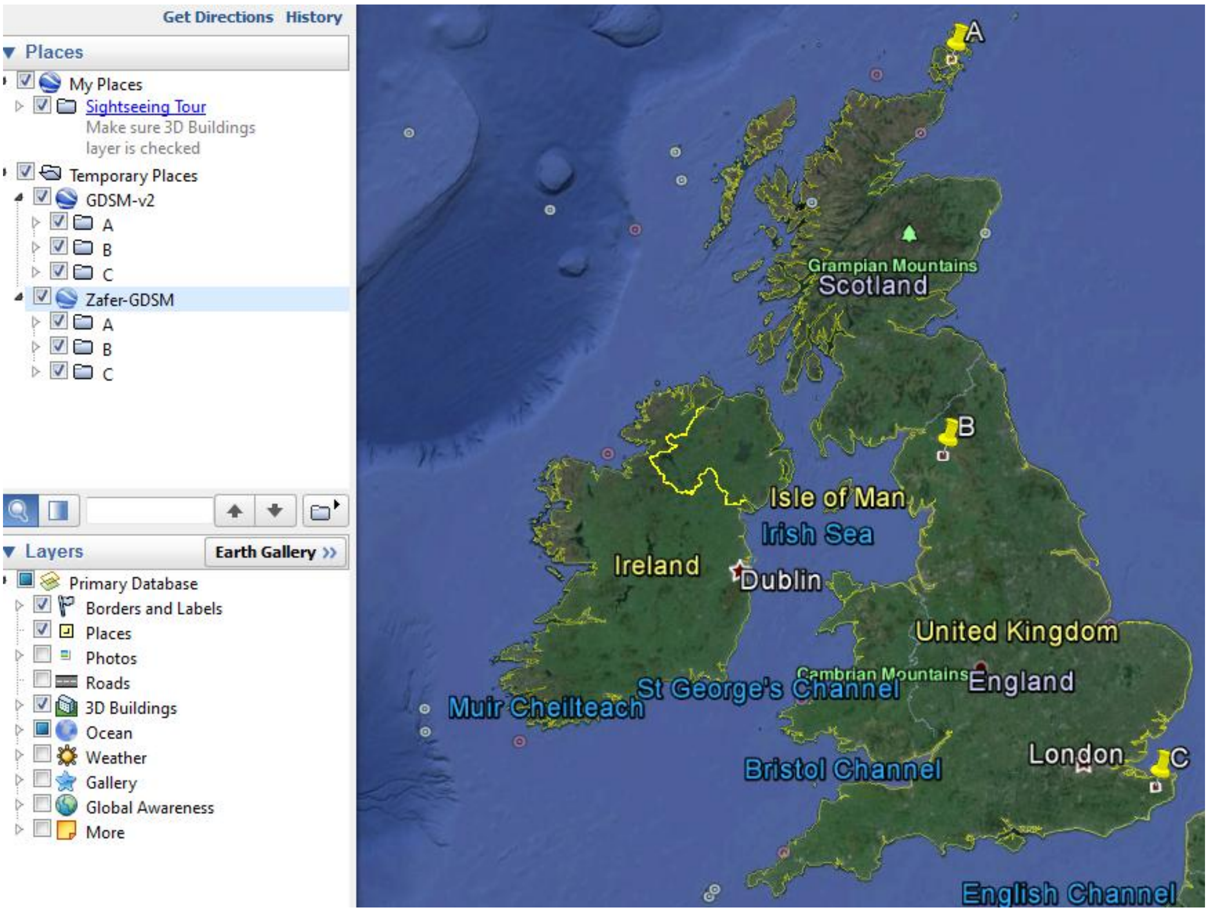


Figure 7.11 Geographical Locations of Case Study Neighbourhoods

Following figures 7.12, 7.13, and 7.14 depict the profiles and SGAS of alternative neighbourhoods respectively.

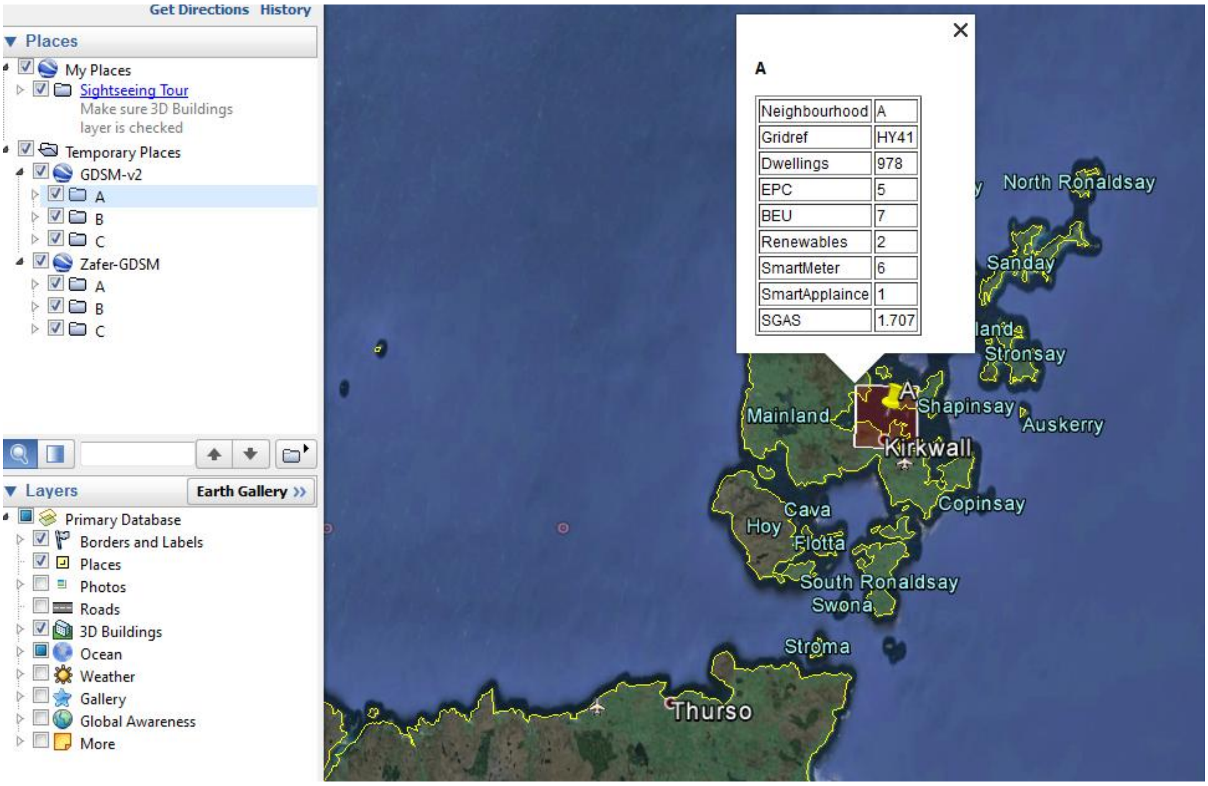


Figure 7.12 Profile and SGAS of Neighbourhood A

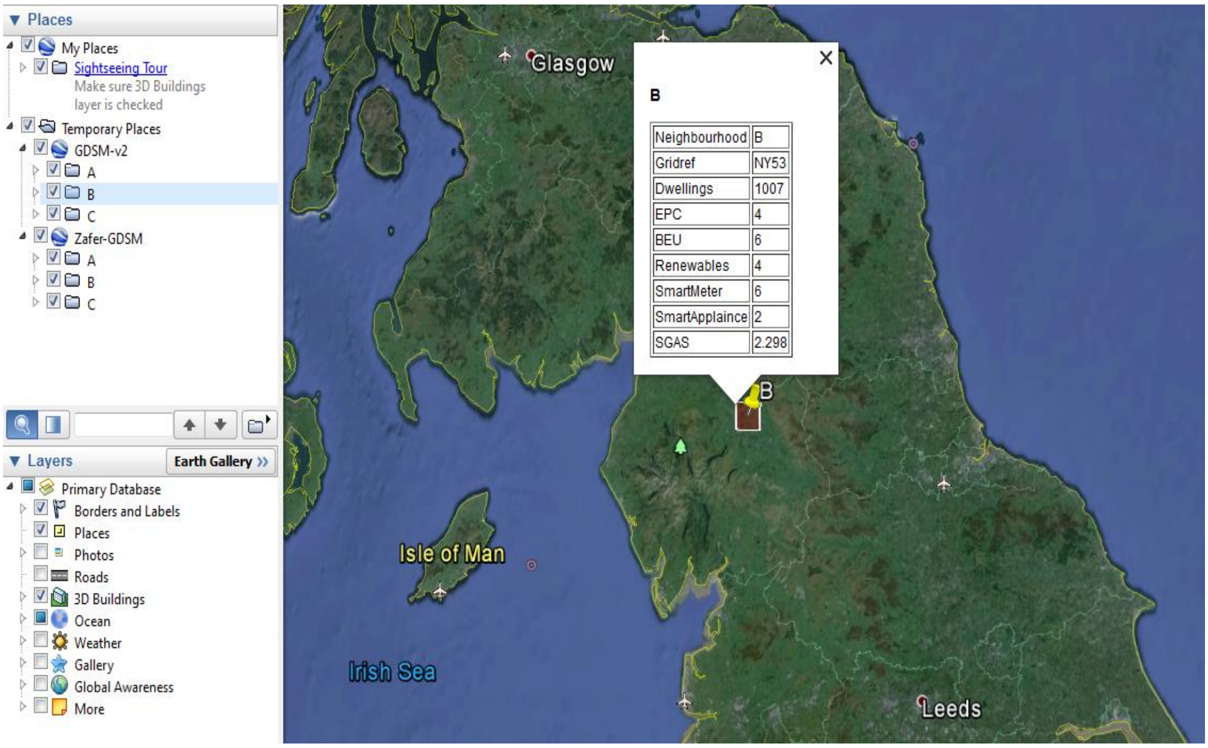


Figure 7.13 Profile and SGAS of Neighbourhood B

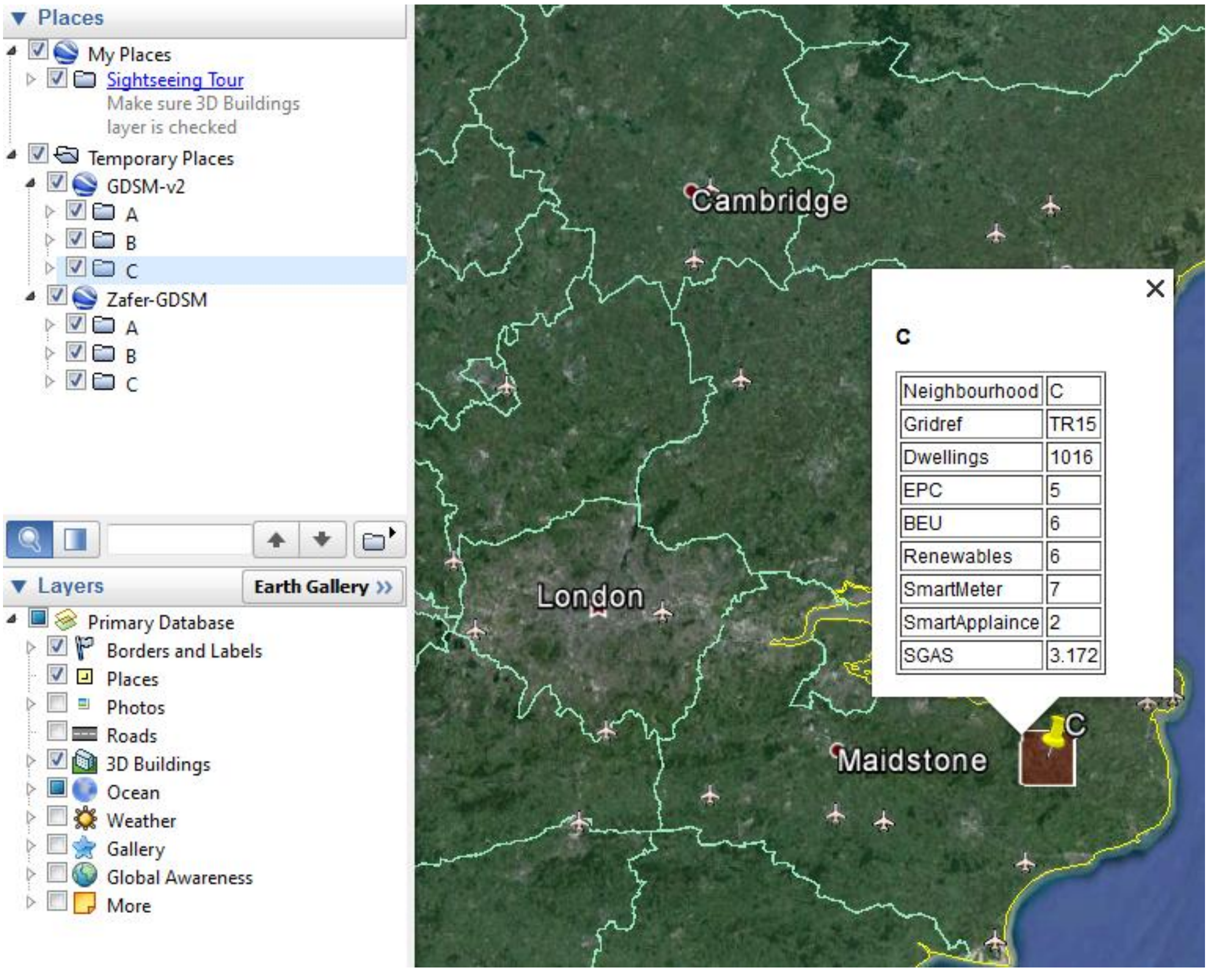


Figure 7.14 Profile and SGAS of Neighbourhood C

Grid Reference squares are tiled as polygons that cover case study areas, and data representing the tiles are attached accordingly. In short, spreadsheet data is visually anchored to grid reference squares.

7.3.5 Ranking of Alternative Neighbourhoods

Given SGAS equation is a representation of performance of neighbourhoods against the smart grid applicability criteria. Higher scores indicate better performances. SGAS for Neighbourhoods A, B, and C are 1.707, 2.298, and 3.172 respectively. Thus, SGAS ranking among neighbourhoods is: C is the first, B is the second, and A is the third and the last.

As elaborated earlier in this chapter, priority ranking for smart grid applicability should be the reverse of SGAS ranking, so that the areas in performing worse than others can be elevated to a better standard. When the SGAS ranking is reversed, the prioritized ranking for the alternative neighbourhoods is obtained for planning and scheduling of allocation of resources when implementing smart grid projects. The restructured (reversed) ranking is: Neighbourhood A is the initial point to kick start the project, followed by Neighbourhood B, and lastly Neighbourhood C.

7.4 Sensitivity Analysis

Sensitivity analysis, as highlighted in Chapter 3 of this thesis, is an important element in multi criteria decision making (MCDM) processes. Sensitivity analysis briefly is the study of determining the influence of parameters on the output of decision procedures. A wide range of sensitivity analysis methods are available: partial derivatives, variation of inputs by one standard deviation and by 20%, a sensitivity index, an importance index, a relative deviation of the output distribution, partial rank correlation coefficients, standardized regression coefficients, rank regression coefficients, the Smirnov test to name a few but many more (Saltelli et al, 2004).

The author of this thesis has chosen to apply "Sensitivity Index" as the sensitivity analysis tool to be applied to parameters. Sensitivity Index is a simple method offered by Hoffner and Gardner (1983) that is used for determining the sensitivity of a parameter by calculating the percentage difference in output when the selected parameter is varied from its minimum value to its maximum value. Stated sensitivity index is calculated as follows:

$$SI = (D_{max} - D_{min}) / D_{max}$$

where D_{max} is the output result when the parameter in equation is set at its maximum value and D_{min} is the result for the minimum parameter value. In cases where comparisons between different models are not important, the following even simpler sensitivity index can be perfectly adequate (Ibid):

$$SI = (Dmax - Dmin)$$

The researcher has chosen to apply simplified SI for case study neighbourhood C. Obtained results are depicted in the following Figure 7.15

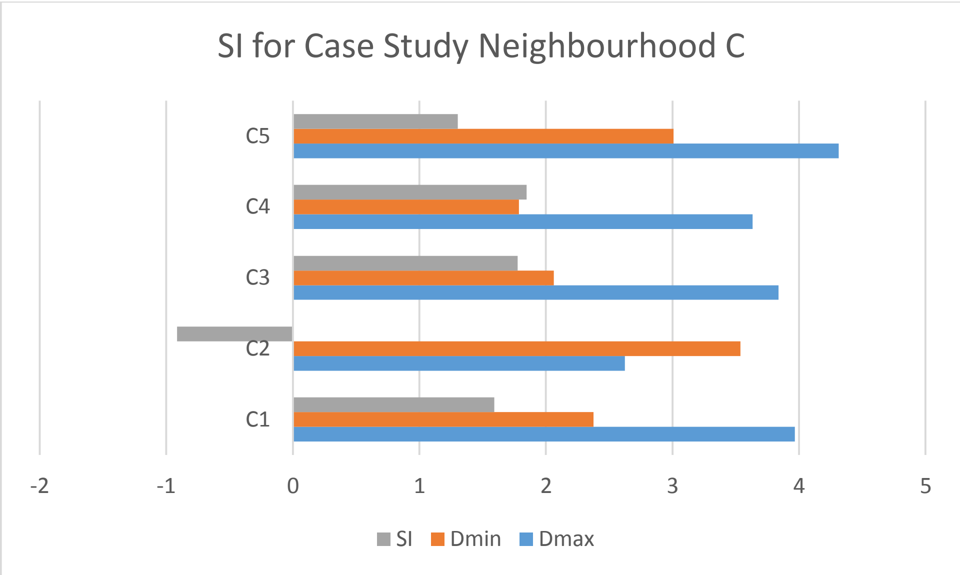


Figure 7.15 Sensitivity Index for Neighbourhood C SGAS equation

As seen from the figure given above, highest sensitivity is observed in the fourth parameter which is the smart meter criterion. On the other hand, the lowest values for sensitivity index are obtained in the second criterion that is the building energy use parameter.

7.5 Concluding Remarks

In this chapter, prototyping and testing of the proposed GDSM4SGA has been elaborated. Initially, three different neighbourhoods are chosen as case study locations. Subsequently, an SGAS (Smart Grid Applicability Score) equation has been identified. The SGAS is the structured assessment mechanism elaborated in chapter 6 of this thesis.

The running phase of the model requires tiling of data layers in accordance with the geospatial specifications of selected neighbourhoods, and then applying the SGAS equation individually for each of the case study neighbourhoods in order to identify the smart grid applicability profiles. Data layers are geocoded and converted to KML in order to visualize the spatial average values of case study neighbourhoods. For prototyping purposes purpose-made spreadsheets are used as data processing and graphing tools, and a web-based earth browser is used for enhanced visualisation.

As outcome, ranking of SGAS scores are obtained for the case study. This is simply the area profile that indicates the performance of selected neighbourhood in terms of selected criteria. This rank should be reversed in order get the priority ranking for smart grid deployment, so that the benefits (especially the environmental ones) offered by smart grids can be utilized in an optimized way.

In order to enable decision makers the elasticity they may require whilst making their judgements, each SGAS term is presented individually. Additionally, a sensitivity analysis for each parameter has been carried out so that decision makers are aware of the impact of each criterion on the output of the smart grid applicability assessment.

The next chapter comprises a focus group study conducted for validation purposes of the proposed GDSM4SGA mechanism. Views of experts regarding the functionality and structure of the model are reflected, and they are presented in a SWOT style analysis approach.

Chapter 8: VALIDATING THE PROPOSED GEOSPATIAL DECISION SUPPORT MODEL

8.1 Introduction

This chapter of the thesis addresses the views of experts on the proposed model. Presented material in this chapter comprise the outcomes of a focus group study which had been held with the purpose of obtaining feedback regarding the validity of the model. Four experts joined the focus group study three of whom are previously interviewed (experts mentioned in sections 5.4.3, 5.4.5, and 5.4.6) for data collection purposes (see Chapter 5 for details).

The new member of the focus group is an industrial academic with a background in electrical engineering, and he holds a PhD degree in power management. He has more than 15 years of international experience in electricity transmission with roles ranging from senior engineering to managerial positions in private sector (international) and governmental departments (Turkey).

Throughout the focus group study, the underlying mechanism is thoroughly explained, and a demonstration had been performed to present the proposed model. Experts are then asked to evaluate the model by performing a SWOT (Strengths, Weaknesses, Opportunities, and Threats) style assessment.

8.2 Expert Views Regarding the Proposed Model (GDSM4SGA)

In this section, SWOT style assessments of experts regarding GDSM4SGA are individually presented. The following layout has been designed for the presentation of individual findings.

8.2.1 Assessment of Expert 1

Expert 1 is a professor at Istanbul Technical University and she has track record in renewable energy projects at both national and international platforms. Her feedback is as follows:

Strengths:

- The model is pretty comprehensible
- The underlying mechanism is reasonable, and supported with widely accepted scientific methods

Weaknesses:

- Lacks financial dimensions that are of main interest of the power companies

Opportunities:

- Model has a high potential to be adopted by local governments when developing energy intensive urban regeneration schemes
- Model can enable Smart Grid companies to conduct pre-feasibility studies for checking the project viability

Threats:

- Nuclear power is in the agenda of many developing countries, but its integration is neglected for the model

8.2.2 Assessment of Expert 2

Expert 2 is a senior engineer working at energy industry, and has expertise in the field of renewable energy technology deployment. His feedback regarding the model is as follows:

Strengths:

- Though requires extensions, model addresses critical elements to the point (like smart metering, local renewable energy supply potential)

- Numerical data and their geographical representations are combined and presented in an unsophisticated form (data visualisation) so that the output makes sense for non-technical decision makers as well

Weaknesses:

- Lacks GHG reduction potential indications

Opportunities:

- Model's integration to decision making operations would definitely be of help to project management teams of utilities in refining their strategies

Threats:

- Electric Vehicle deployment should not be neglected, as EVs tend to be one of the key elements of near-future energy markets.

8.2.3 Assessment of Expert 3

Expert 3 is an industrial academic that held senior engineering and managerial positions in renewable energy policy making within governmental institutions and sectorial associations. His impressions regarding GDSM4SGA are as follows:

Strengths:

- Straightforward and clear methodology to assist Smart Grid projects with the allocation of resources

Weaknesses:

- Storage is a key point for maintaining energy security, therefore it would be a positive feature for the model to include energy storage options

Opportunities:

- An improved interface and improved coverage (energy storage etc.) may turn the model into a commercial product which will assist meeting the feasibility needs of the stakeholders involved in Smart Grid projects.

Threats:

- Fragmented nature and complex dynamic structure of energy industry might limit the use of model to conceptual level.

8.2.4 Assessment of Expert 4

Expert 4 is the very last member of the focus group study, and he is the industrial academic described in the introduction section of this chapter. His opinions on the proposed model address the following:

Strengths:

- Proposed model offers straightforward and systematically developed mechanism for prioritizing areas in terms of smart grid applicability

Weaknesses:

- Model lacks combinatory analysis for ranking the alternative neighbourhoods. Individual ranking of alternatives may vary when compared to pairwise combinations.
- Environmental cost benefit analysis is excluded.

Opportunities:

- If environmental CBA features are improved, the model has the potential to take place in Smart Grid related emission trading projects.

Threats:

- Project financing models (BOT, PPP etc.) make a huge impact on realization of energy projects. Associated risks (political risks, technical risks etc.) might limit the acceptability of the model.

8.3 Overall Outcomes of the Model Evaluation

Figure given below is the illustration that categorizes the prominent outcomes of the focus group conducted for validation purposes of the model.

STRENGTHS	*WEAKNESSES*
• Comprehensible and straightforward method • Grounded on widely accepted scientific methods	• Lacks environmental CBA • Lacks energy storage
OPPORTUNITIES	***THREATS***
• Conceptual design of the model is promising. Improvements would enable the model to become esoteric to smart grid field	• Risks associated with financial models may limit the acceptability of model • Due to complex nature of industry, model might be stuck to conceptual applications only

Figure 8.1 Focus Group Prominent SWOT Outcomes

The participants of the focus group are of the same mind and they reflect credit on GDSM4SGA. All the experts agree that the straightforward mechanism offered by the proposed model shows promise in creating added value for smart grid project realizations. SWOT style feedback obtained throughout focus group meetings capture the improvement possibilities to the model. Furthermore, stated feedback address and justify that there is a need for such an assessment methodology in smart grid realization field. Additionally, highlighted opinions regarding weaknesses, opportunities and threats are the ones that are strongly linked to scope and limitations highlighted to a high degree in initiatory chapters, but they would in return are very useful guidance for further research directions. It is appreciated by the experts that, model is flexible in nature by ability to allow amendments regarding stated issues by adding relevant data layers and redefining criteria weights accordingly, in condition that the guidance provided by proposed UML activity diagram has been followed.

In brief, when the proposed model is assessed within boundaries of scope and limitations of this research, experts agree that the proposed model acts as a straightforward and comprehensible support mechanism for scheduling resource allocation spatially in smart grid project management.

8.4 Concluding Remarks

This chapter of the thesis presents to outcomes of the focus group study that has been carried out with the intention of obtaining expert views regarding the proposed GDSM4SR model. Participants are asked to evaluate the model and present their evaluations by employing a SWOT analysis approach. The findings of the focus group study address that the participated experts reach a consensus on the usability of the proposed model. In a nutshell, provided that the associated limitations are kept in mind, the proposed model has been approved by the experts for prioritization of areas when conducting smart grid deployment projects.

The overall summary of the thesis, results and recommendations are detailed in the conclusion chapter, which is the next chapter.

CHAPTER 9: SUMMARY AND CONCLUSIONS

9.1 Introduction

In this study, a research effort has been made with the intention of developing a model that assists decision makers in smart grid field with scheduling and allocating the key resources. The stated model targets neighbourhoods, but it is designed in a way that it can be expanded to larger scales.

Throughout this thesis, maturing of the conducted research has been elaborated step by step through a logical path that starts with literature reviews, followed by research aim crystallization, a subsequent act of designing an appropriate methodology, data collection and analysis, and lastly model conceptualization –testing-validation phases respectively.

This is the conclusion chapter of the thesis and it covers the summary of the research, the contributions made to knowledge, the main findings and conclusions of the research and the recommendations for the future research activities regarding smart grid deployment.

9.2 The Summary of the Research

At the beginning of the thesis, global environmental concerns and built environment's role and share in such concerns are addressed. The environmental concerns are than narrowed down to energy related problems, and lastly to infrastructure level energy issues. Chapter 1 of this thesis draws a picture of the environmental problems and points out the policy actions taken to cope with the stated concerns. Transition in grid technology is highlighted as one of the key drivers of environmental policy. Deployment strategy of smart grids is observed to be a "gray area" as there is no solid methodology exists. In the light of this argument, the researcher has identified there is a gap in smart grid deployment. Once the frame of the topic area has been drawn, the research question is crystallized, and research aim and objectives are identified accordingly. Additionally, a research methodology that governs the overall research is briefly introduced (See Chapter 4 for in-depth research methodology guidance). Lastly, chapter 1 is concluded with addressing the scope and limitations of the research, and a brief guidance to the thesis.

After framing the research in Chapter 1, a two-step background research has been carried out with the intention of forming a solid knowledge base. The first step (Covered in Chapter 2), is conducting a comprehensive literature review in order to gain insight into energy related environmental problems, and challenges in electricity grid infrastructure. Smart grid concept is examined in detail as it has been addressed as a solution to stated environmental concerns.

Moving on with the second step in background research (elaborated in Chapter 3), decision making concept is reviewed and an appropriate decision making method (in this case it is AHP) has been identified with the intention of meeting the decision making requirements addressed with the aim of this research. As the conducted research lies within spatial context, geospatial dimensions are also addressed. Additionally, visualisation of data is found out to be a suitable method for disseminating knowledge regarding geospatial decision making.

After gaining adequate background knowledge on the milestones of conducting a decision making study regarding smart grid applicability in spatial domain, it is time to plan and structure the way to conduct the proposed research. In other words, a suitable methodology has been formulated (See Chapter 4). Mentioned methodology presents all phases of research ranging from philosophical stance, to characteristics of adopted data collection and analyses methods. In brief, researcher's approach to the conducted research overlaps with "objectivism" and "positivism", and research methodology addresses that exploratory case studies are conducted and quantitative methods are observed as the dominant tool for data collection and analysis. It is important to highlight that, qualitative methods are also used where appropriate, such as in analysis of focus group study conducted for validation purposes. Questionnaires and interviews are carried out for gathering data in an inductive way.

In Chapter 5, data requirements of the study is fulfilled. Initially, criteria required for smart grid applicability are identified. Stated criteria are as follows:

- Energy Performance Certificates (EPC)
- Energy Consumption of Buildings
- Climate Data (Renewable resource potential)
- Smart Meter availability
- Smart Appliances

The next step is to conduct a questionnaire survey targeting experts from industry and academia with the intention of obtaining criteria weights (Rate of Importance). Additionally, interviews are carried out with experts in order to strengthen the data obtained through questionnaire surveys. Data reliability and validity has been maintained via applying relevant indices and triangulation of data sources. The criterion with the highest weighting score appears to be smart meter criterion, whereas on the other hand smart appliance criterion achieved the least weighting score.

In Chapter 6, site selection problems in smart grid deployment projects are covered, and geospatial decision support models are addressed as the assisting technology. In this regard, a Geospatial Decision Support Model for Smart Grid Applicability (GDSM4SGA) has been proposed in order to assist decision makers when making decisions on the priory of locations for smart grid deployment. An AHP algorithm for the overall assessment is elaborated, and presented via mathematical expressions. A conceptual model comprising use of AHP as the main selection mechanism, linking data layers obtained through data bases and questionnaire surveys, and ranking of alternative neighbourhoods is presented. Ontology regarding linking data layers are developed. Additionally, standardized representations of the stated GDSM4SGA are prepared via Unified Modeling Language (UML), so that specifications of the proposed model are modeled in a way that it is independent from any particular programming languages.

In Chapter 7, proposed GDSM4SGA has been run. A case study comprising assessment of each alternative neighbourhood has been conducted with the intention of mastering the model. A further iteration of AHP algorithm has been supplied, and in turn a formula for obtaining Smart Grid Applicability Score (SGAS) is developed. Polygon (neighbourhood) average data are restructured in accordance with AHP scale, so that SGAS formula can be applied to alternative neighbourhoods. As a next step, SGAS are calculated for each neighbourhood and a ranking has been obtained. It is highlighted that SGAS ranking is the rank of area profiles, and it should be reversed for obtaining priority ranking. As a final step, geo-visualisation of polygon data has been supplied with the use of an earth browser.

Lastly, the proposed model (GDSM4SGA) has been validated. In Chapter 8, presented work covers the output obtained from a focus group study that has been held with the intention of model validation purposes. After explaining the model and underlying assessment mechanism, a demonstration of the GDSM4SGA (via spreadsheets and earth browser) has been made. In return, experts participated in the focus group study are individually asked to evaluate the model by applying a SWOT analysis. Obtained feedbacks indicate that the model is straightforward, and simple, and yet it has sound scientific footing. Addressed issues like lacking environmental and socioeconomic parameters are all beyond the scope of this study, and they are highly related to the predefined limitations. On the overall, GDSM4SGA has been validated as a viable tool for assisting decision makers on the allocation of key resources in smart grid projects.

9.3 Contribution to Knowledge

Having conducted a comprehensive literature review, it is observed that many specific studies had been carried out highlighting and proposing technologies and the benefits brought by smart grids. Additionally, it is observed that environmental policies are being developed by governments in order to cope with climate change. This research effort draws abovementioned benefits and policies together, and shows that their combination reveals the requirement for a management strategy for smart grid deployment. GDSM4SGA proposed throughout the study brings a new dimension to smart grid implementations by combining "existing concepts" (like smart metering, and EPC) and "generated data" (criteria weights) in order to formulate a new management strategy that seeks optimization of decision on priory areas in terms of applicability. Novel contribution of the "Smart Grid Applicability Assessment" research effort is the holistic approach brought to allocation of resources in smart grid realization projects. In this regard, Analytic Hierarchy Process (AHP) technique has been re-contextualized within smart grid deployment settings. Its ability to handle the problem has been tested via case studies, and validated by experts.

Las but not least, primary data that has been collected both from academia and industry, in other words potential stakeholders, is analyzed and presented so that their stance for smart grid realization and deployment is introduced to literature. Moreover, this stated knowledge forms the basis of smart grid applicability assessment.

9.4 Main Conclusions

Based on the multiple analyses and evaluations together with the literature reviews, the following conclusions are drawn for the smart grid applicability research effort:

i. Literature addresses that transition in grid technology towards smart grids would bring a variety of benefits comprising environmental, economic, and social issues. Additionally, global policy trends indicate that stated transition is already on the way. Combining these statements, research effort initially justifies the need for developing a robust vision and strategy for smart grid deployment.

ii. This research has been conducted within boundaries of residential energy use and neighbourhood scale smart grids. Therefore, the author of this thesis digested following expressions as elements of a smart grid definition. In this regard, a smart grid is a concept that offers:

   - Increased consumer engagement to the grid (via smart meters)
   - Increased utilization of local renewable energy sources
   - Reduced demand for energy in households in order to reduce the stress over the grid to balance the supply

iii. Scheduling and planning of projects that concern multiple locations is an important issue in project management. Therefore, it can be said that allocation of resources (skilled labor for instance) arises as one of the key parameters in smart grid deployment. This research effort attempts to develop an optimization approach that helps allocating resources by enabling priority rankings among locations in accordance with smart grid deployment requirements.

iv. Keeping project scope and limitations in mind, a set of criteria are derived from the literature as the required parameters in smart grid deployment. See the following item for details.

v. Analytic Hierarchy Process (AHP), has been identified as the main tool for prioritization of locations. The following criteria weights are identified through questionnaire surveys and interviews in order to apply AHP procedures:

- Energy performance of buildings (0.199)
- Building energy use (0.183)
- Local renewable energy potential (0.222)
- Smart meter availability on site (0.231)
- Smart appliance availability at households on site (0.163)

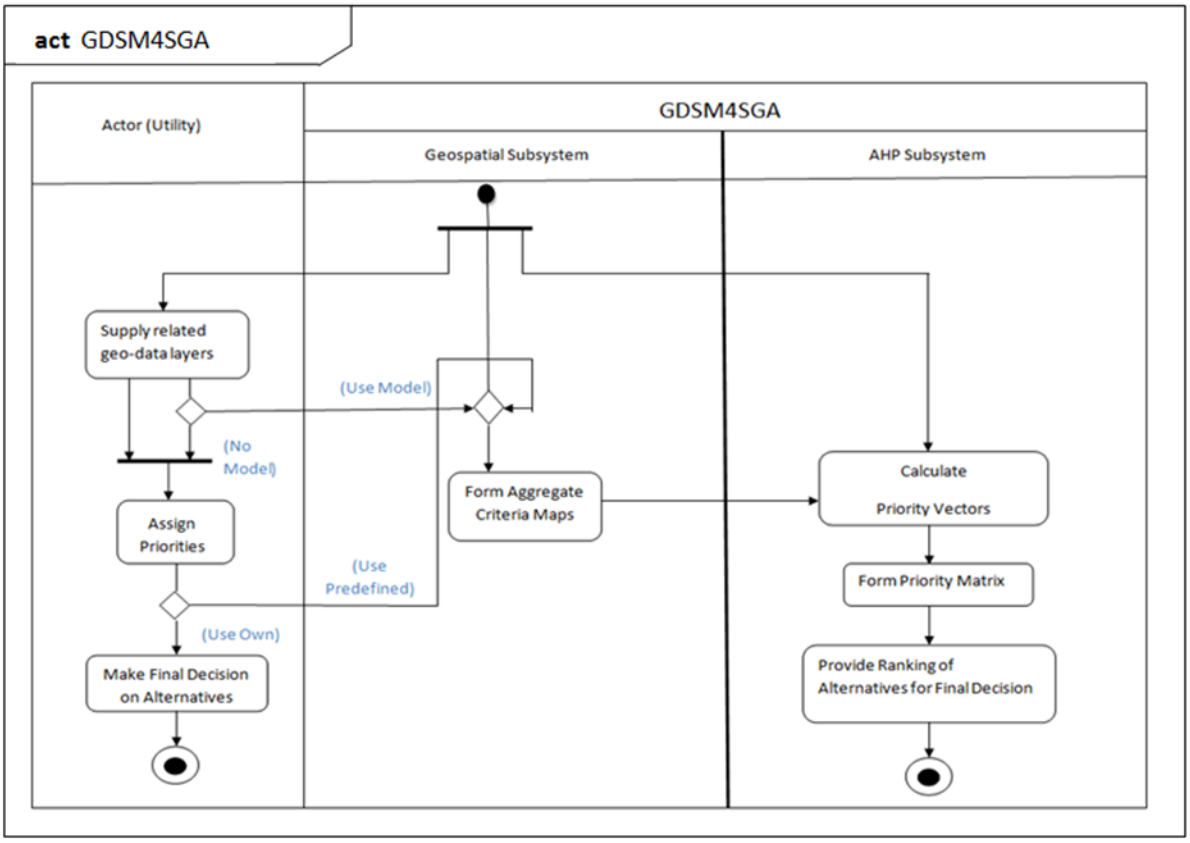
Despite some quantitative differentiations in criteria weights, stance of academia and the industry are identified are found to reflect the same tendency.

vi. The following Smart Grid Applicability Score (SGAS) equation has been developed and formulated as the underlying assessment mechanism :

SGAS = [{(LnC1)*(0.199)} - {(LnC2)*(0.183)} + {(LnC3)*(0.222)} + {(LnC4)*(0.0.231)}+ {(LnC5)*(0.163)}]

Where “n” is the location identifier and “L” is the location (Neighbourhood), and C is the criterion, and the numbers in parenthesis are the criteria specific weighting factors

vii. A conceptual model called GDSM4SGA has been proposed in order to assist decision making with making decisions regarding resource allocations. In a nutshell, GDSM4SGA comprises application of SGAS equation at spatial domains, geo-visualisation of SGAS scores for each location, and finally the ranking of alternative sites in accordance with SGAS. In the proposed model, role of SGAS is to act as an enabler for AHP subsystem. The following UML Activity Diagram has been offered as a solution for representing the conceptual model in a structured way:



UML Activity Diagram of proposed GDSM4SGA

viii. A prototype of GDSM4SGA has been run for a case study comprising three alternative neighbourhoods, and in return SGAS has been successfully calculated and geo-visualised for the case study areas. Additionally, stated model has been evaluated by experts and found as a viable mechanism for assessing locations in terms of smart grid applicability.

All in all, completion of theoretical stages of development, implementation and testing of the proposed Geospatial Decision Support Model for Smart Grid Applicability denote a promising potential for its usability and acceptability in smart grid deployment projects.

9.5 Recommendations for Future Improvements

In this study, an effort to develop a geospatial decision support model for smart grid applicability has been made. Due to duration constraints and technical limitations associated with the conducted research, it was not possible to cover other dimensions. The following recommendations are made for future research:

1) The criteria set used in the model can be extended (such as inclusion of energy storage, and on-site availability of other renewable energy types, and cost related parameters etc.) in order to enhance the decision support capabilities.
2) A "what-if" scenario testing functionality can be added to the model so that the decision makers would be able to test their smart grid deployment strategies.
3) The proposed GDSM4SGA can be implemented in future smart grid projects. A real-life practice of the model would complement theoretical evaluation and validation with empirical evaluation outcomes.
4) The model can be restructured by adopting a different decision making method other than AHP, so that it would be possible to compare the variations in outputs.
5) The user interface of the model can be improved so as to enhance the usability of the model.

9.6 Concluding Remarks

This final chapter of the thesis finalizes the conducted study. The overall research has been briefly discussed, main conclusions are supplied, and contribution made to knowledge has been highlighted. Lastly, recommendations for further research studies are made.

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APPENDICES

Appendix-1 Questionnaire

University of Salford MANCHESTER

Questionnaire for identifying the priority of criteria required for implementation of Smart Grids at neighbourhood scale

This questionnaire is a part of data collection process of a PhD study conducted by Zafer Ozturk, who is a third year PhD Student at the School of the Built Environment, University of Salford. Overall title of the reseach is "*Smart grid applicability prioritisation of Neighbourhoods by developing a geospatial decision support model*".

The questionnaire will take approximately 5 minutes to complete.

Please carefully read the brief in the following page and move on to the actual questionnaire.

Your participation and contribution is highly appreciated. Thank you for your support.

Should you need any further information, please do not hesitate to contact me.

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Confidentiality Statement:

Your participation in this research study is voluntary. All the collected data will be used only for academic purposes and the data will be used in a form that makes it impossible to determine the identity of individual respondents. Research Ethics of Salford University will be strictly applied

Research Brief:

Conducted research study seeks to develop a model for sustainable integration of smart grids to the built environment at a neighbourhood scale. The stated model will incorporate 5 criteria that are extracted and justified from the related literature. The aim of this questionnaire is to find out the rate of importance of the mentioned criteria.

Simplified definitions of key terms and related criteria:

Smart Grid: The smart grid is the roadmap for enhancing the infrastructure of every segment of the energy delivery system. This includes generation, transmission, distribution and consumption.

Though elements of smartness also exist in many parts of existing grids, the difference between a today's grid and a smart grid of the future is mainly the grid's capability to handle more complexity than today in an efficient and effective way.

A smarter electric power grid promises greater efficiency, reliability and security leading to greater use of renewable energy sources that positively impact our environment.

From a built environment perspective, below specified criteria (that excludes ICT and transmission specific technology) emerge as the main drivers of a sustainable implementation of smart grids at neighbourhood scale that seeks maximization of renewable energy utilisation and minimizing the demand for energy use in residential buildings:

Energy Performance of Buildings: This indicator covers how energy efficient the buildings are (This includes physical properties like insulation, glazing etc.)

Energy Use of Buildings: It is the amount of energy consumed within the building (for example: amount of electricity and/or gas)

Climate Data: This indicator shows the availability of renewable energy sources (solar/wind etc.) at a particular site

Smart Meter: A smart meter is often refers to an electricity meter that connects the building to the electricity network. It does not only measure the consumed electricity, but also it enables connecting renewable power to the main grid. Additional a smart grid exchanges data between electricity supplier and the household.

Smart Appliances (Smart fridge/dishwasher/washing machine etc): Smart appliances are an important element in realizing the benefits of smart grid technologies. Smart appliances connected to the grid offer extensive load management as they are programmable according to the peak times of pricing and load properties of the grid. Whether it is the use of renewable sources or load management, smart appliances allow energy consumers to contribute to more efficient management of energy resources while at the same time reducing carbon emissions.

Step 1: Please tick to confirm that you are:

☐ • **Academic or PhD level student in a Built Environment and/or Energy related field**

☐ • **A professional from the industry that is related to Built Environment and /or Energy**

☐ • **Other (Please specify)**............ ....

Step 2: In light with the brief, please rate each of the following criteria independently from 1 to 9, where 1 is the least important criteria and

9 is the most important criteria for sustainable implementation of smart grids at neighbourhood scale.

Please tick the appropriate in the following table according to the given scale:

Intensity of Importance	LOW	MEDIUM	HIGH
Scores	1 < 2 < 3	4 < 5 < 6	7 <8 < 9

	1	2	3	4	5	6	7	8	9
Energy Performance of Buildings									
Energy Use of Buildings									
Climate Data									
Smart Meter									
Smart Appliances									

Date: ....

Participant Consent Form (Questionnaire)

Research Brief:
The smart grid is the roadmap for enhancing the infrastructure of every segment of the energy delivery system. This includes generation, transmission, distribution and consumption. From a built environment perspective, sustainable implementation of smart grids is a strategy that seeks maximization of renewable energy utilization and minimizing the demand for energy use in residential buildings. Conducted research study seeks to develop a model for sustainable integration of smart grids to the built environment at a neighbourhood scale. The stated model will incorporate 5 criteria that are extracted and justified from the related literature.

Purpose of the Questionnaire:
Purpose of this questionnaire is to derive rate of importance of the given smart grid related criteria. Identifying rate of importance (or in other words criteria weights) will enable the researcher to build up analytical relations among the given criteria and will lead the researcher to formulate a deployment strategy for smart grids. This study is part of a PhD thesis conducted in University of Salford School of the Built Environment, under the supervision of Dr. Yusuf Arayici.

Procedure:
If you agree to be in this study, you will be asked to fill out the questionnaire which requires approximately 5 minutes to complete.

Benefits to Participant:

Participants will strengthen their knowledge and vision on smart electricity grids and will help the contribution of the body of knowledge in management of smart grid deployment.

Voluntary Nature of the Study/Confidentiality:
Your participation in this questionnaire is entirely voluntary and you may refuse to complete the study at any point during the questionnaire, or refuse to answer any questions with which you are uncomfortable. In case you refuse to carry on the questionnaire answers you have given until that stage will be disposed and you will not be considered as a respondent. You may also stop at any time and address the researcher any questions you may have. Your name will never be connected to your results or to your responses on the questionnaires; instead, a number will be used for identification purposes. Information that would make it possible to identify you or any other participant will never be included in any sort of report. The data will be accessible only to those working on the project (researcher and supervisor) and it will not be shared with any other organization or individual.

Contacts and Questions:
At this time you may ask any questions you may have regarding this study. If you have questions later, you may contact Zafer Ozturk at 0044 7778289157 or z.ozturk@edu.salford.ac.uk. If you have any concerns or complains about the conducted questionnaire you may contact his faculty supervisor, Dr. Yusuf Arayici at 0044 161 295 6296 or **y.arayici@salford.ac.uk**.

Statement of Consent:

I have read the above information and I consent to participate in this study.

Name of Participant: ____

Date: __________

(please print)

Signature of Participant ____

Age: _______
(Note: You must be 18 years of age or older to participate in this study.)

Thanks for your participation!

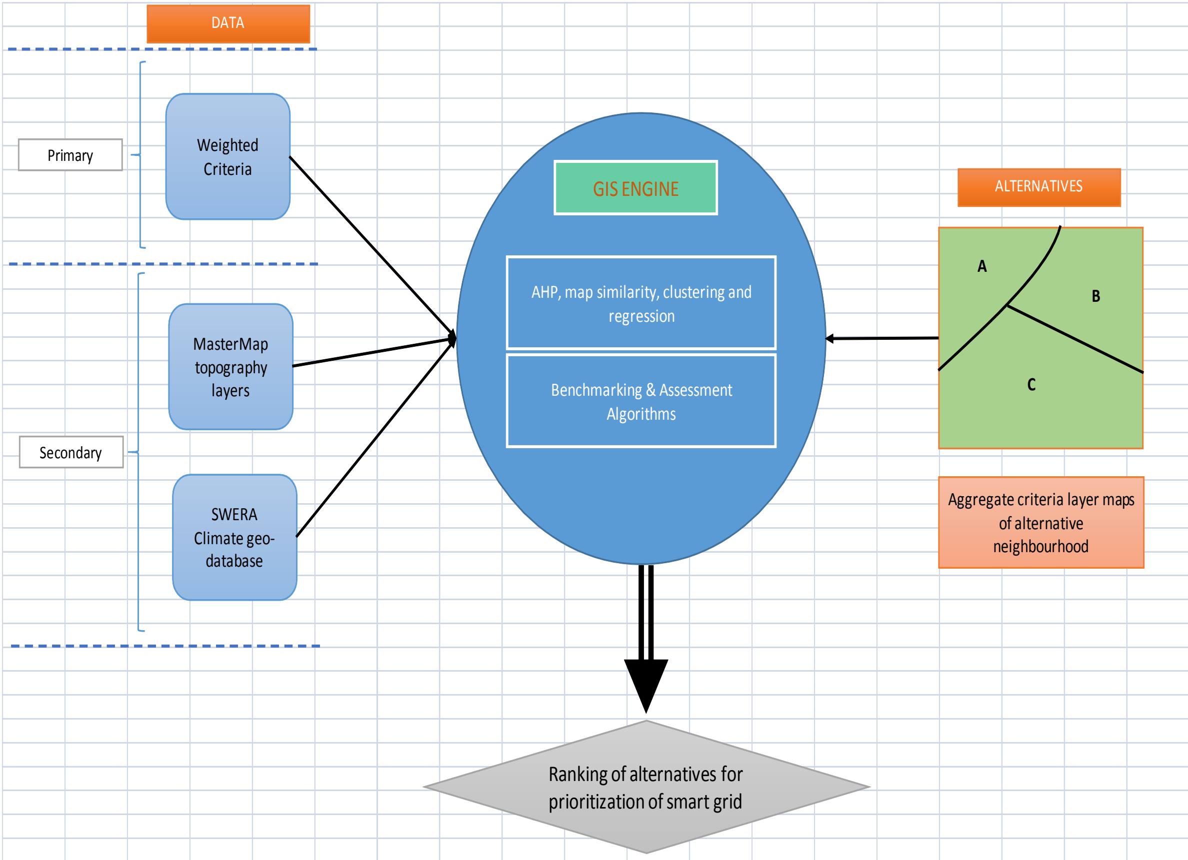
Structure of the interviews

- Consent form will be verbally presented to the interviewee.
- Interviewee will be asked to fill out the questionnaire.
- Interviewee will be asked to explain his/her reason for each of the question that he/she answered as part of the questionnaire.
- Interviewee will be asked to address any recommendations or criticism regarding smart grid related criteria. (Any other criterion to consider?)
- Notes will be taken by the researcher.

Structure of the focus group study

- Consent form will be verbally presented
- Attendee will be asked to evaluate the proposed model in a "Strengths, Weaknesses, Opportunities, and Threats" manner.
- Notes will be taken by the researcher.

Stated model will be the software form of the following data flow diagram:



Appendix-2 EMU Questionnaire Confirmation Letter

Doğu Akdeniz Üniversitesi
Eastern Mediterranean University

İnşaat Mühendisliği Bölümü / *Department of Civil Engineering*
Mühendislik Fakültesi / *Faculty of Engineering*

"Uluslararası Kariyer İçin"
"For Your International Career"

27 September 2012

To whom it may concern,

This is to confirm that Zafer OZTURK of Salford University has conducted a questionnaire titled 'Questionnaire for identifying the priority of criteria required for implementation of Smart Grids at neighbourhood scale' at Eastern Mediterranean University. The survey took place between 27 August 2012 and 7 September 2012.

For further information please do not hesitate to contact us.

Ö. Eren

Özgür Eren

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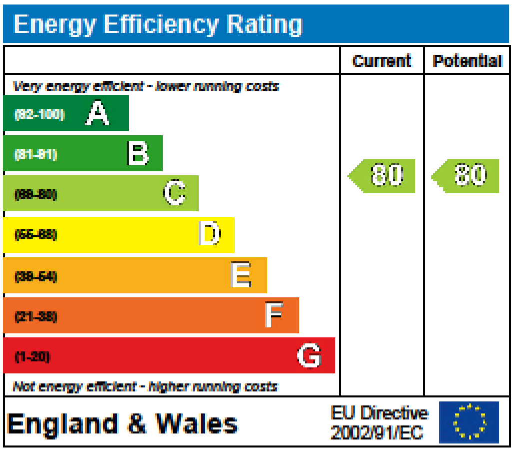
Appendix-3 Sample EPC Report

Energy Performance Certificate

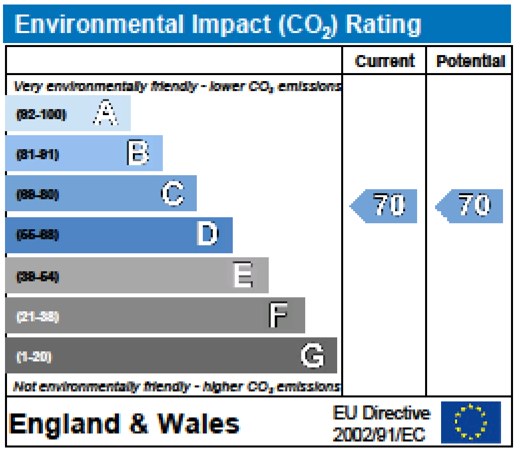
43, Blackburn Street
SALFORD
M3 6AS

Dwelling Type:	Mid-floor flat
Date of Assessment:	05/09/2008
Date of Certificate:	05/09/2008
Reference Number:	8618-6521-5550-6095-4006
Total Floor Area:	55 m²

This home's performance is rated in terms of energy use per square metre of floor area, energy efficiency based on fuel costs and environmental impact based on carbon dioxide (CO_2) emissions.



The energy efficiency rating is a measure of the overall efficiency of a home. The higher the rating the more energy efficient the home is and the lower the fuel bills will be.



The environmental impact rating is a measure of a home's impact on the environment in terms of carbon dioxide (CO_2) emissions. The higher the rating the less impact it has on the environment.

Estimated energy use, carbon dioxide (CO_2) emissions and fuel costs of this home

	Current	Potential
Energy Use	270 kWh/m² per year	270 kWh/m² per year
Carbon dioxide emissions	2.2 tonnes per year	2.2 tonnes per year
Lighting	£30 per year	£30 per year
Heating	£130 per year	£130 per year
Hot water	£117 per year	£117 per year

Based on standardised assumptions about occupancy, heating patterns and geographical location, the above table provides an indication of how much it will cost to provide lighting, heating and hot water to this home. The fuel costs only take into account the cost of fuel and not any associated service, maintenance or safety inspection. This certificate has been provided for comparitive purposes only and enables one home to be compared with another. Always check the date the certificate was issued, because fuel prices can increase over time and energy saving recommendations will evolve.

To see how this home can achieve its potential rating please see the recommended measures.

Remember to look for the energy saving recommended logo when buying energy-efficient products. It's a quick and easy way to identify the most energy-efficient products on the market.
For advice on how to take action and to find out about offers available to help make your home more energy efficient, call **0800 512 012** or visit **www.energysavingstrust.org.uk/myhome**

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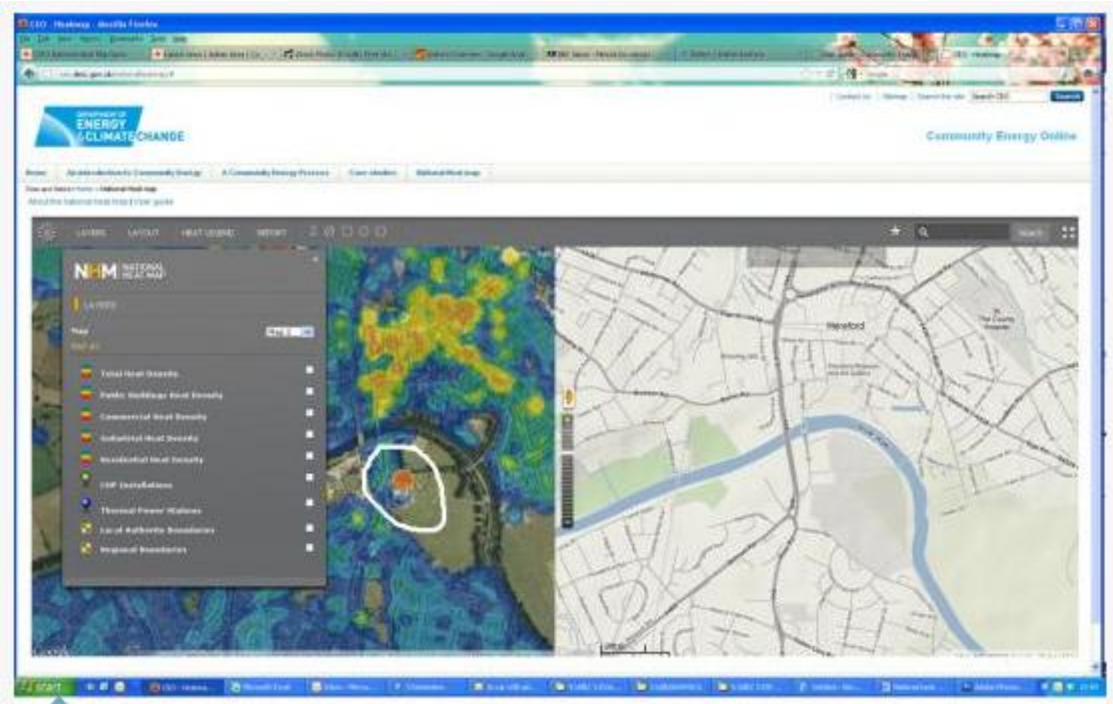
Appendix-4 HeatMap UK

Basic functions for Residential Level

Map Layer	Data source	Details used
	Experian Consumer Dynamics at Postcode level	Predominant size, age, built form, tenure
Address level characteristics	Census 2001	Rurality
	Ordnance Survey BoundaryLine	Region and local authority
	English House Condition Survey 2008	Model predicted heat demand using size, age, built form, tenure, rurality, region
Heat demand weights:	CIBSE Guide F and TM46	Floorspace benchmarks by sector
Addressing	National Land and Property Gazetteer (NLPG) 2010	Address classification and coordinates. Multiple coincident addresses used to indicate flats
Dataset cross-references	National Energy Efficiency Data Framework (NEED)	Cross-reference tables
Small Area energy consumption values	DECC Subnational Statistics 2009	Mean gas and E7 electricity use at LLSOA, mean unmetered fuel use at Local Authority (intermediate data values supplied by AEA Technology)
Metering status	National Energy Efficiency Data Framework (NEED)	Presence/Absence of gas and E7 electricity meter (no access to actual consumption)

Screenshot of Heatmap



The heat map in split-screen mode, showing total heat demand in Hereford. The circled 'hotspot' in the left-hand map is a public swimming pool

Appendix-5 IRENA model

Specifications

The Atlas enables to overlay maps of resources, protected areas, grids (available in some places), slope, landcover...etc. It is possible to prospect sites of interest anywhere in the world using a large library of datasets called the 'data catalogue'. It is possible to create and save your own version of the Atlas, with the datasets you find most interesting, centered over your area of interest. Three tools are available for demonstration as of January 2013:

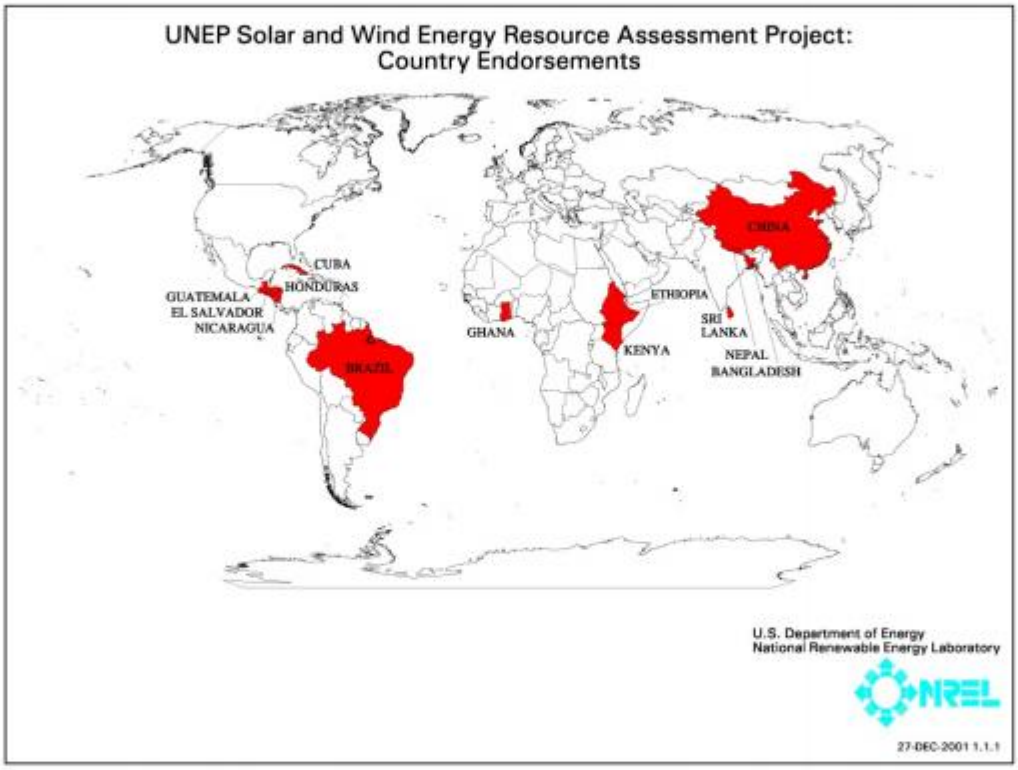
- A prospector, giving access to wind and solar statistics all over the world, using SWERA datasets.

- A solar prospector for Africa, which gives access at any point on the continent to 30 years of data measured every 15 mns, validated against ground measurements.

- A site-ranking tool for European solar projects, showing score of suitability every km in Europe, based on parameters chosen by the end-user.

Visit Model web address: http://www.irena.org/globalatlas for further details

Appendix-6 SWERA model



SWERA is a tool that provides easy access to credible renewable energy data to stimulate investment in, and development of, renewable energy technologies.

Please launch the tool for further details at: http://en.openei.org/apps/SWERA/