Faculdade de Engenharia da Universidade do Porto

Model development and analysis for strategic investment in sustainable electricity networks in a rural environment

Ricardo Manuel Vilas Boas de Azevedo

Dissertação de Projecto realizada no âmbito do

Mestrado Integrado em Engenharia Electrotécnica e de Computadores

Major Energia

Orientador: Prof. Dr. Hélder Leite

Co-orientador: Dr. Cristiano Marantes

Julho de 2008

Abstract

Optimization in investment strategy is a fundamental way to achieve profitability of networks while improving reliability although the economical consequences are always dependent on the regulatory model. The changing in the operating environment is bringing new challenges and raise new questions to DNO's. Areas such as energy efficiency, micro-generation, demand side management, energy losses, renewable energy production and smart-meters are direct responsibility of DNO's and they all take part in the achievement of sustainable distribution networks. Regarding these matters, the study and development of tools that aid DNO's in strategic planning for the level and type of investment that should be made is essential, in order to justify the future demands near the regulatory system.

In this project, the impact of micro generation technologies in new developments was modelled and a calculation tool was developed using MS Excel and the Visual Basic. The tool evaluates the capability of existing primary substations to cope with expected demand from new developments, where sustainable technologies and measures are expected to be adopted.

A study case was carried out to examine the impact of two new developments in distribution network. The results showed that micro generation technologies for heating purposes have a higher impact in reducing demand from the perspective of a distribution network than technologies such as Photovoltaic and Micro Wind generators which showed only to have a marginal impact in the expected demand reduction seen by primaries substations.

The risk assessment for the technical solutions, demonstrated that investment should be made in order to stimulate the uptake of micro generation in new developments. A higher uptake in micro generation would lead to maximization of existing primary substations, rather by increasing available margins or by delaying the need of reinforcement.

Acknowledgements

I would like to start expressing a sincere acknowledgement to my advisor Dr Hélder Leite, for all the advices, encouragement and guidance throughout the last few months.

I also want to thank all the staff from EDF Energy Networks in Bury St Edmunds for all the help and support.

A great THANK YOU to Dr Cristiano Marantes, for all the patience, availability, help and advice throughout the project. For being more than an advisor, for being a friend.

To all my friends, wherever they were doing their projects and especially to João Couto my "brother in arms" in this enterprise abroad.

To Joana Moscoso for all the support, strength, love and dedication. For being always at my side, despite being away 18000kms.

I thank my family for providing me with numerous opportunities and unconditional support, trust and love throughout my life. Without their love and support none of this would have been possible.

To God for giving me the health, strength and motivation to finish this journey.

Table of Contents

List of Figures

List of Tables

Table of Acronyms

AC – Alternating Current
BRE – Building Research Establishment
CHP – Combined Heat Power
DC – Direct Current
DG – Distributed Generation
DNO – Distribution Network Operator
DSP – Demand side participation
EEE – Energy Export Equivalence
EPN – East Power Network
GIS – Geographical Information System
GSHP – Ground Source Heating Pumps
IDNO – Independent Distribution Network Operators
IDP – Infrastructure Development Plan
kWe – 1000 Watts of Electrical Output
kWp – Kilowatt Peak
kWth – 1000 Watts of Thermal Output
LCPD – Large Combustion Plant Directive
LPN – London Power Network
NAMP – Network Asset Management Plan
OFGEM – The Office of Gas and Electricity Markets
QoS – Quality of Supply
ROC – Renewable Obligation Certificates
SPN – South East Power Network
SWH – Solar Water Heating

Chapter 1

Introduction

1.1 - Introduction

Distribution network operators (DNO's) are facing new problems, the raising pressure caused by factors such as climatic changes, aging infrastructure and changes in the regulatory environment [1] are making network planning a difficult goal to achieve. Several regulatory elements such as power quality, operational costs, allowed income and efficiency benchmarking have to be taken into account when considering if a investment is a reasonable and profitable one [1].

The regulation of UK's DNO's has increased the incentives for cost effective, maintenance and efficient use of available assets [2]. However, reliability of power supply is the main concern of costumer and regulators, making the planning constrained by their requirements.

All investments in networks increase their value, either by replacing older equipments or by building new ones, but they may also have an impact in power quality and operational costs therefore affecting DNO's income [1]. Optimization of investment strategy is a fundamental way to achieve profitability of networks while improving reliability although the economical consequences are always dependent on the regulatory model [2]. Utilities need to implement new strategies for more effective planning techniques and asset management methods. Herein, the term asset management implies making the right decisions on:

- What assets to perform reinforcement on;
- What level of reinforcement to perform;
- What specific reinforcement steps to perform;
- When to perform the selected reinforcement

However, to make the right decisions the manager needs strategic tools, planning tools, data and different support systems.

Due to the increasingly dependency on imported energy by UK's energy system, combined with the rising fossil fuels price and the expected need of new generation (around 30GW in the next two decades) [3], the growing evidence of the impact of global warming and public concern about environmental issues made DNO's a vital part for the achievement of sustainable electricity systems and security of supply.

Areas such as energy efficiency, micro-generation, demand side management, energy losses, renewable energy production and smart-meters are direct responsibility of DNO's and they all take part in the achievement of sustainable distribution networks. Such measures and initiatives will soon be part of UK's national policy [2, 3] and then will become into regulatory measures which will bring implications and change the operating environment for DNO's. Regarding these questions, the study and development of tools that aid DNO's on strategic planning for the level and type of investment that should be made is essential in order to justify the future demands near the regulatory system.

The change in the operating environment will bring new challenges and raise new questions to DNO's. The new demand growth in specific parts of the network, how much impact will they have on the current capability of primary stations? The several futures scenarios, such as environmental awakening, where people start to realize the importance of green energy and change their energy consuming habits such as the acceptance of measures like energy efficiency, micro generation and the adoption of the concept of zero carbon-houses or even a scenario of economic concern where all the environmental issues don't play a primary role in peoples life, how will this scenarios affect load curves and primary stations capacity? How to optimize and pinpoint the investments in the network in order to balance the supply and demand? How to quantify and measure the implications of new technologies such microCHP, mediumCHP, biomass, photovoltaic, micro wind generators, biomass, ground source heating pumps (GSHP), solar water heating (SWH), zero carbon homes? How to integrate, if possible, geographical information system (GIS) based solutions in improving network investment efficiency? These are all technical issues which concern the modelling for optimization planning.

The current process that address the issue of connecting new loads to the feeders relay on the actual capacity of the primary substation where is intended to connect the new loads, if any new developments require more power than the primary is capable of supply then a new primary must be built. The connection and using costs of the electricity distribution networks depends on several factors such as the customers' location and the capacity a customer requires [5].

Ensuring customers are charged (or rewarded) for the impact they have on network costs is essential to encouraging the efficient development of these networks. Cost reflective charging methodologies could reduce the need for investment in the networks, benefiting business and domestic customers by lowering the distribution charges that make up around 17% [6] of a typical domestic consumer's bill.

With the model developed in this work, it is intended to do a long term forecast on primary substation capacity using the estimated load growth on the areas that DNO's have the information that new developments will be built, adding also the perspectives of future penetration of low carbon technologies and measures. This kind of methodology will help DNO's to plan their networks in terms of future needs of reinforcement or new investments, giving them the tools to aid the development of their charging methodologies in order to justify their investments in the network before the regulator.

1.2 - Project Aims

The main objectives for the proposed project are:

- analyse the capability of primary substations to cope with future load growth;
- study and describe the impact of different technologies and measures in the expected electricity demand;
- risk assessment of technical solutions.

It is expected that the model and framework developed can be useful for strategic planning and future network development, giving DNO's a robust tool to analyse several different network investments and their risks in order to optimize their efficiency in operation and maintenance costs in medium and long term scale.

1.3 – Dissertation's Outline

Chapter 2 provides a literature review on the related research, especially in areas such as asset management, micro generation technologies, UK transmission and distribution system and the current energy situation in UK. Chapter 3 provides a description in model development, methodology and considered assumptions. In Chapter 4, a case study, with two developments, was conducted in order to evaluate the impact of micro generation technologies and energy efficiency measures in the distribution network, specifically in the primary substations. It will also include a discussion and interpretation of the results obtained. The last chapter concludes the whole dissertation, reviewing the objectives and what this project has achieved. Further recommendation in this field as well as possible further work that can and should be carried out is also listed.

Chapter 2

Literature Review

In the first part of this chapter the political environment and the regulation system of DNO's will be briefly introduced. It is vital to understand how the current political environment and the regulatory regime will impact on a medium and long term the distribution companies and how they must face the upcoming challenges. On the subsequent sections, impact of technologies that will help DNO's face those new challenges will be discuss, mainly focusing on technologies that are more suitable for a rural environment. This chapter will provide the reader with the appropriate theoretical background to understand the approach in evaluating how the possible future drawn scenarios, political will, regulation systems, available technologies and network asset management affect future investment decisions.

Works on asset management and distribution network investment strategies are investigated with the intention of drawing conclusions on the advantages and disadvantages of the methods used and also to Figure out in which way they can be useful or not in the current modelling work.

2.1 - Political Environment

In this subchapter, it is discussed the main issues arisen from the review of current literature on several sources referring to UK's current energy situation and measures to tackle the current challenges brought by growing awareness on climate change.

2.1.1 - UK Energy Status

In the Energy White Paper from 2007 [3], it is described the serious challenge in which United Kingdom is actually facing; the continuous increase on energy demand is causing UK's economy to become more and more dependent on fossil fuels, as a result fuels reserves are rapidly decreasing making UK more dependent in imported fuels. It is expected that by 2020 around 80% of UK's energy needs will be supplied by overseas fuels [3]. As a result, UK's exposure to foreign volatility would drive his economy to become vulnerable and unstable. As referred in [3] strategy drawn by the British government to ensure the security of energy supply is to accelerate the transition to an energy efficient low carbon economy by boosting investment in infrastructure and the development and deployment of low carbon technologies.

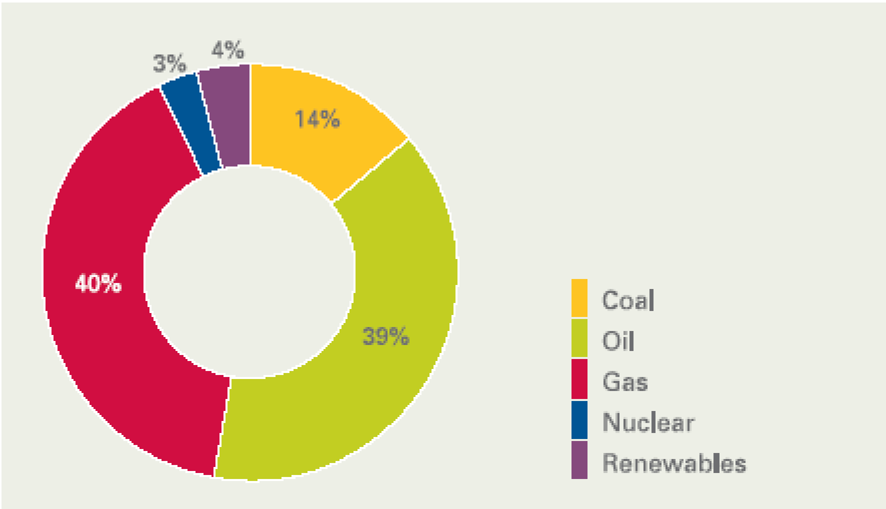

Figure 2-1 - UK Primary Energy Demand by Fuels [3]

UK is currently 'energy obese': far more is used than is actually required to deliver well-being. Years of cheap, abundant petrochemicals have led to highly wasteful practices and attitudes. The current UK's electricity generation capacity is around 76GW to meet an annual consumption of about 350TWh [3]. The composition of the generation system is a mixed of different sources, which enables the power system with a great flexibility to accommodate variations in demand.

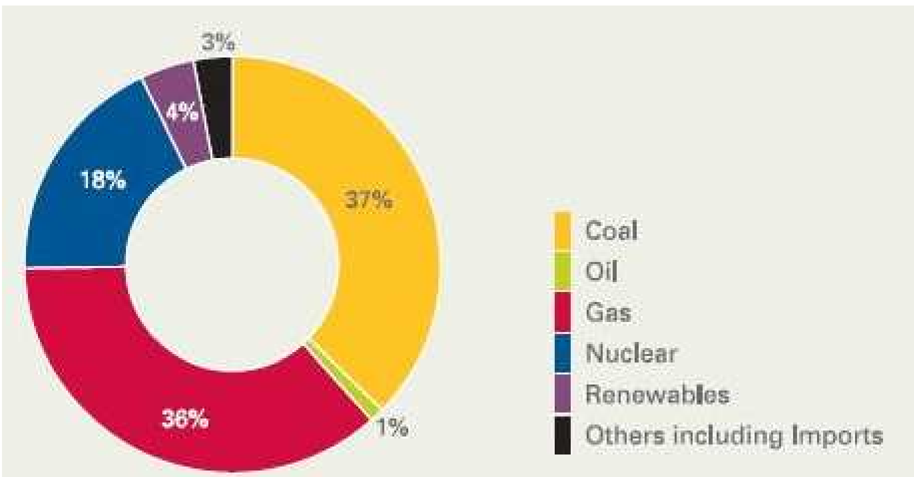

Figure 2-2 - UK Electricity Generation Mix [3]

The Large Combustion Plant Directive (2001) (LCPD) [7] imposes two separate constraints on coal and oil stations. One requires that about 11GW of "opted-out" coal and oil stations close by end 2015 and the second restricts the operation post-2016, of around 20GW of coal stations that "opted-in" to meet the requirements of the LCPD. To achieve this requirements; a report by Red Point Energy in [8] states that the de-carbonization of national grid will imply the close of power stations by a total of around 22.5GW by the end of 2020 [8]. This means that to maintain the quality of supply, new investments will need to be made in order to replace the closed power stations and to supply the future demand. The build of new power stations is dependent on how profitable are those investments but due to market and regulatory uncertainties, those investments are involved in great risks and adding the importance of timely investment to guarantee enough levels on generation the security of supply may get compromised.

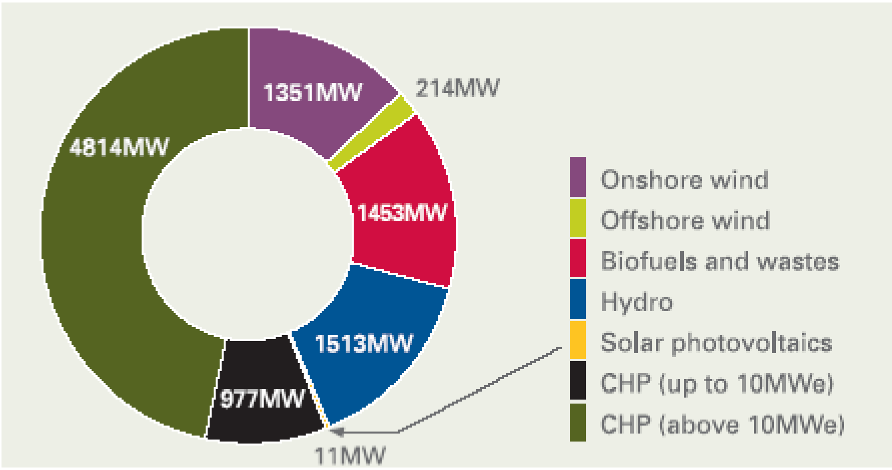

Figure 2-3 - UK Current Capacity of CHP and Renewable Generation [3]

With declining oil and gas, the electricity supply will be increased to compensate, requiring reinforcement of the National Grid. Compared to large-scale fossil fuelled generation, a grid with a high penetration of intermittent and variable renewables requires more sophisticated systems for integration and balancing of supply. Figure 2.3 shows the current capacity of CHP and renewable generation in UK [3].

2.1.2 - UK Government Measures

In Energy White Paper 2003 [9] a goal of 26-32% Carbon Dioxide (CO_2)reductions by the year 2020 in comparison with 1990 values is proposed [9], to deal with the current situation and to achieve the proposed goals, several measures have been carried away by UK Government in [3], such as, improvement on billing and the use of smart meters, real time display on the households of the current demand, changes on the building regulation such that by the year 2016 all new homes built in England will have to be zero carbon [10], practical implementation of building performance of buildings directive [11], more energy efficient products, power balancing is minimised by intelligent load management, wide geographical distribution of renewable generators, plus ‘firm’ renewables such as tidal and biomass fuelled CHP.

There will be also a package of incentives to encourage the spread of distributed generation and low carbon technologies; the confirmed intention by the government to strength the Renewables Obligation Certificate (ROC) by increasing them to up to 20% as and when renewables are deployed, the introduction of banding ROC to differentiated levels of support to different renewable technologies [3], more information and guidance on options in distributed generation, more flexible market and licensing arrangements, more clarity on the terms offered by energy suppliers to reward micro-generation [3], action to ensure a faster and efficient connections to distributed generators. According to Energy White Paper 2007, in result of this measures electricity consumption could be up to 15% lower in 2020 and gas consumption up to 13% lower than it would otherwise have been, thereby reducing gas imports. Overall, it is estimated that this measures will improve the energy efficiency of the UK economy by around 10% by 2020 [3].

2.2 - UK Transmission and Distribution System

The transmission network, on the whole, receives electricity from large power stations which in turn enters, via transformers, the distribution network. Most consumers receive their electricity from the distribution network. National Grid (NG) owns the England and Wales transmission system, with Scottish Power and Scottish and Southern Energy each owning a part of the transmission system in Scotland. As transmission owners, these companies are responsible for building and maintaining safe and efficient networks and are regulated by OFGEM (The Office of Gas and Electricity Markets) [3]. National Grid also has the responsibility of overseeing and managing the flow of electricity across the whole UK transmission network. In this role, National Grid is known as the transmission system operator.

Under the Utilities Act 2000 [12] distribution it is now a licensed activity and remains a monopoly business. Whilst this applies throughout the UK, the structure in England and Wales is different than it is in Scotland. In Scotland distribution is operated by two vertically integrated energy companies who in addition to operating their respective distribution businesses they are also responsible for generation and transmission throughout the Scotland.

Each distribution company holds a separate licence for each area they cover and they are strictly governed by the terms of that licence. They have a statutory duty to connect any customer requiring electricity within their area and to thereafter maintain the supply to them. Distribution companies are now known as DNO’s and as part of the legislation within the [12] they have an obligation to be non-discriminatory in all aspects of their business. Additionally, they must maintain an efficient cost effective and coordinated system to distribute electricity. In addition to DNO’s we now have the concept of Independent Distribution Network Operators (IDNO). IDNOs own and operate electricity distribution networks which will predominately be network extensions connected to the existing distribution network, e.g. to serve new housing developments. Licences are granted by OFGEM and as these are effectively monopolies they are regulated through a price control mechanism which is reset every four or five years. Whilst the number of Distribution Licences remains unchanged the whole UK Energy Market is going through a period of consolidation and the ultimate owner's of the individual DNO’s continues to change.

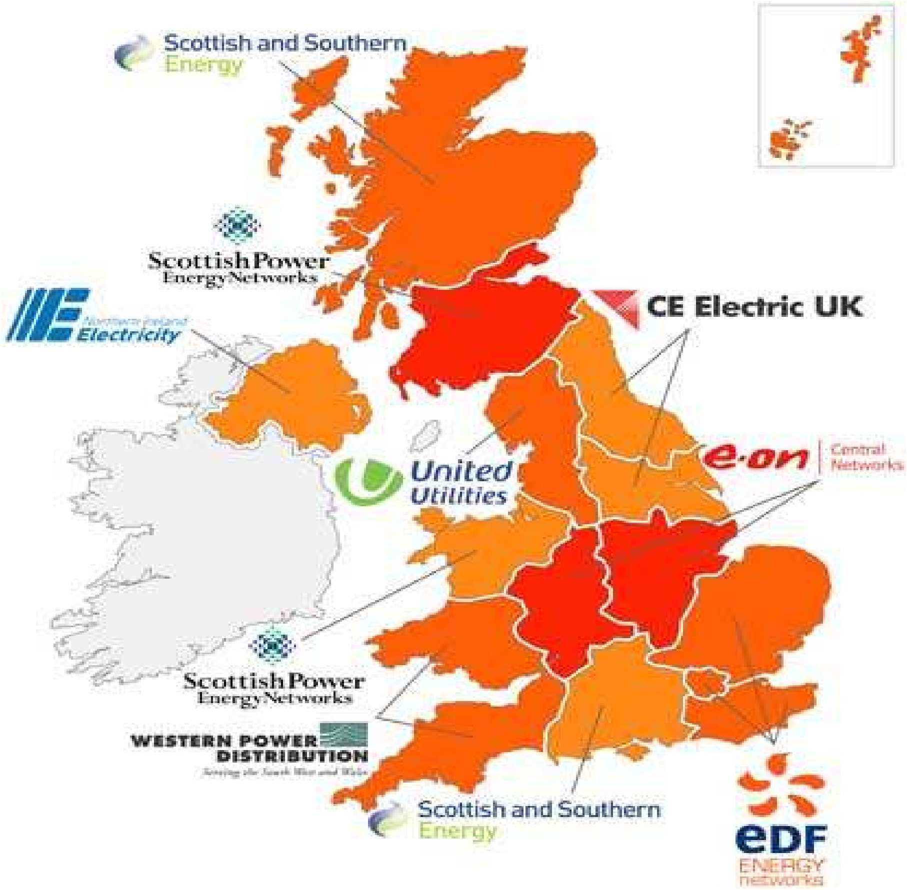

Figure 2-4 - UK Distribution Networks Operators [13]

2.3 - Regulatory System

The energy regulator, known as OFGEM holds key responsibilities which both directly and indirectly contribute to security of energy supply. These include: regulating the natural monopoly networks in gas distribution and electricity transmission by the issuing and modifying of licences; investigating and penalising licensees who breach their licence conditions; and setting price controls. OFGEM’s duties in relation to ensuring competition include protecting consumers’ interests, ensuring that markets are as free of distortions as possible and that price signals are accurate and reliable, hence helping new investment.

The regulator also has a key responsibility for ensuring that adequate, timely investment in the transmission network infrastructure occurs. Such investment is important not just to replace old network equipment but also to enable connections to the grid of new electricity generation such as that from renewable. Additionally, OFGEM regulates the operator of the national transmission system, National Grid, via a set of licence conditions that require National Grid to maintain a balanced system. Vincent de Rivaz (EDF Energy CEO) stated in Distribution Price Review 2005 conference [14] that the regulatory framework contribute to delivering electricity supplies via a network that OFGEM analysis showed to be 99.99% reliable in 2005.

According to [3] OFGEM also has a statutory duty to contribute to the achievement of sustainable development, consistent with its role as an independent economic regulator. The UK Government considers this duty an essential element of OFGEM's remit and attaches great importance to OFGEM making an effective contribution towards this objective [3].

2.4 - Supergen Scenarios Overview

To understand the wide range of factors which influence investment decisions it was analysed a number of scenarios of the dynamics of investment in electricity distribution

In the paper Generic Scenarios [15] it is said that scenarios are different visions of the future. They are used by organisations for many different purposes, such as to:

- Test current policies and plans against future challenges;
- Harness creativity and stimulate debate;
- Bring together disparate groups to work towards a common goal.

The most common use is probably to better understand an uncertain future such that action can be taken today to counter future challenges and/or exploit downstream opportunities.

Previous work by the authors Elders *et al*. (2006) has resulted in a set of six scenarios illustrating possible developments in the electricity industry in the period up to 2050. While such scenarios are valuable in gauging the long-term direction of the electricity industry and its economic and environmental consequences, shorter-range scenarios are useful in assessing the steps necessary to achieve these long-range destinations, and to determine their relationship to current trends, policies and targets [17].

The scenarios, in which this model is based, have been developed by Supergen Future Network Technologies [17], which brings together a consortium of researchers from a number academic institutions in order to study and develop the application and effects of new and emerging technologies for use in power systems in the forthcoming future. These scenarios are intended to allow the analysis of network performance under a variety of economic, technical and environmental variations and to illustrate the varied sets of background circumstances which may influence the industry over the coming years including political and regulatory factors, the strength of the economy and the level to which environmentally driven restrictions and opportunities influence policy and investment decisions.

2.4.1 - Scenarios Development and Key Parameters

In the Supergen Scenarios for 2020 [17] it is referred that one of the most important aims, was to achieve consistency both with the current situation and the Supergen Scenarios for 2050 [16]. In order to achieve this objective, consideration was given both to the likely trend in demand for electricity under each of the 2050 scenarios, and the technology mix which is anticipated. The effect of the underlying driving factors in each 2050 scenario is also taken into account in identifying a set of intermediate points (2020) in the development of each long-term scenario [17].

The process by which the four 2020 scenarios were developed is described, and the characteristics which are used to build possible "future worlds" are listed.

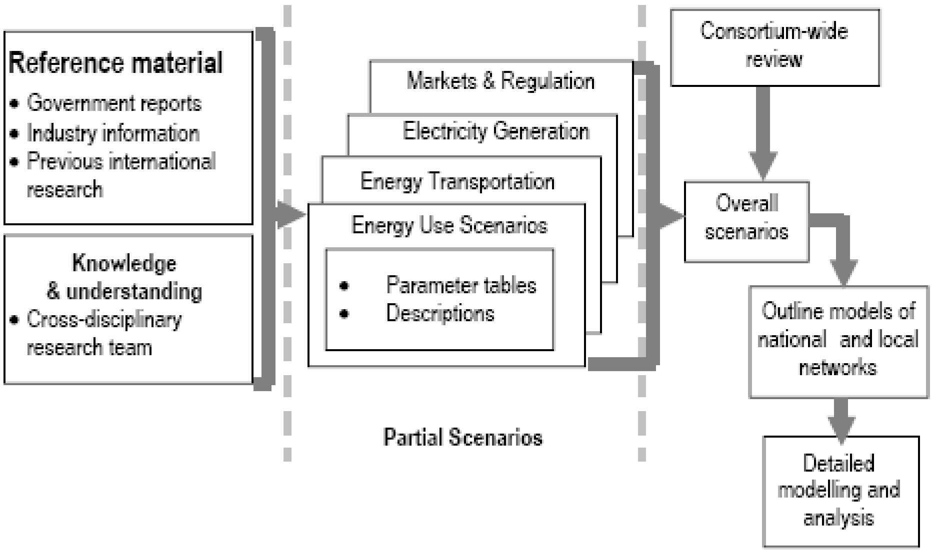

Figure 2-5 - Scenario Identification Process [16]

The process for scenario identifications starts by defining the key activities of electricity networks: energy use, energy transportation, energy generation, markets and regulation as showed in Figure 2.5. Then reports, forecast and analyses are studied by experts from each area in order to gather information of what are the key factors that are most likely to influence the development of electricity networks. As a result of the analysis the key parameters proposed were [17]:

Economic Growth: This parameter influences factors which include increases in energy demand and levels of investment finance. In these scenarios, the following range of values is considered:

- Low growth, whereby economic growth is significantly less than recent levels;

- High growth, in which economic growth is somewhat higher than current levels.

Technological Growth: The technological growth parameter governs the appearance and application of new technology to electric power networks. The following range of possibilities is considered:

- Revolutionary development, in which radical new technologies are developed and applied widely;
- Evolutionary development, in which technological advance is restricted to the application and gradual improvement of current and currently foreseen technologies.

Environmental attitudes: Strength or weakness of prevailing environmental attitude determines factors including emissions constraints and incentives and the acceptability of the power network. In these scenarios, the following range of possibilities is considered:

- Weak environmental attitudes whereby concern reduces in comparison to the current UK atmosphere to a situation similar to that current in the United States;
- Strong environmental attitudes whereby popular and governmental concern for the environment strengthen significantly with respect to the current situation.

Political and regulatory attitudes: This parameter concerns the attitudes of government and society in general to the management and development of energy industries in general, including energy use, transportation and electricity generation. Two possibilities are considered:

- Liberal attitudes, in which the current preference for relatively light regulation, together with a market-driven approach continues;
- An interventionist approach, in which a centrally directed model of management and development is adopted, with greater and more prescriptive government involvement.

Some other scenario-based work, such as that of the UK Government's Foresight Energy Futures Task Force [18] has presented scenarios graphically as quadrants within a "scenario space", despite the initial approach for such representation, further reflection and wider discussion among members of the Supergen research consortium suggested that in this case the approach tended to encourage the consideration of technically uninteresting and mutually similar scenarios, while failing to adequately represent the diversity of issues of interest [16]. Instead, a process of formal presentation, review and criticism of draft scenarios by the consortium has been adopted, in order to assure the relevance and diversity of the final scenarios presented.

2.4.2 - Scenarios Identification and Background

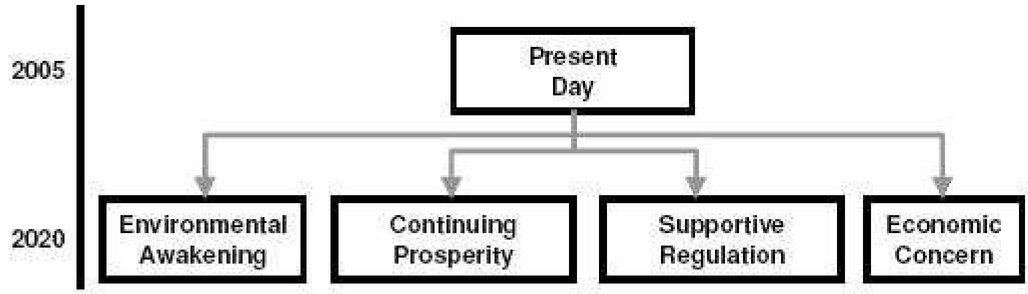

Figure 2-6 - Electricity Scenarios for 2020 [17]

As a result of the previous analysis, four scenarios were drawn (Figure 2.6): environmental awakening, continuing prosperity, supportive regulation and economic concern.

a) Continuous Prosperity Scenario Review

The Continuing Prosperity scenario developed by [17] envisions a future in which buoyant economic growth is supported by strong research and development investment in electricity network and generation technology. These factors result in an electricity industry of increasing technical sophistication, in which long-term growth in demand for energy services is addressed through a combination of continuing investment in network infrastructure and strong promotion of load management measures such as energy efficiency and demand-side participation. In this scenario several assumptions are made:

- Electricity demand continue to grow every year;
- Demand side management is applied in order to avoid network reinforcement;
- Smart metering wide adoption;
- Continuous investment in renewable energy with 18% of electricity generated at UK by 2020 with 10GW of installed capacity in onshore wind farm and 2GW in offshore, 7GW in biomass generation, 2GW in wave and tidal stream generation and 2GW in hydro-generation;
- Power electronic compensation and flow control devices are extensively deployed at transmission level;
- Interconnector circuits between Scotland and England have been upgraded to operate at higher voltages and a second interconnection with Europe is built;
- Small-scale generation connected to local distribution networks, including small-scale wind and biomass plants, together with gas-fuelled micro turbine-based CHP systems of which 3GW of capacity have been installed.

b) Economic Concern

The Economic Concern scenario [17] describes a future in which the economy enters a period of moderate decline, perhaps as a result of significant fuel price increases or because of unfavourable conditions in the wider global economy. As a result, the availability of finance for investment in the electricity network and for research into generation and network technologies is restricted. In this scenario some of the assumptions are:

- interest in reducing expenditure on energy through the deployment of low-cost energy efficiency measures;
- There is some industrial and commercial interest in demand side management schemes as a cost-saving measure to reduce the purchase of expensive peak energy;
- Renewable generation continues to develop in this scenario, but due to wind and marine intermittent production they become increasingly restricted by network contraints;
- No wave or tidal generation will be installed in this scenario although biomass develops quite strongly in this scenario with around 7 GW of capacity installed by 2020 representing 10% of UK's electricity consumption;
- Life-extension on large generation (coal and nuclear power plants) in order to avoid investment, representing 85% of UK's generation;
- At distribution level, networks remain passive, focusing on postponing or avoiding major investments;
- Small scale wind generation is discouraged due to his interment nature, which would lead to networks investments in order to keep quality of supply (QoS);
- MicroCHP does not develop to the point of being economically attractive to households.

c) Environmental Awakening Scenario Review

The Environmental Awakening [17] scenario considers a future in which the impact on the environment of the electricity industry, including generation, networks and end use, is a matter of increasingly important and popular concern, thus, for this scenario the considerations are:

- In this scenario the impact of electrical industry (generation, transmission and distribution) becomes increasingly important;
- By 2020, a peak of electrical demand is reached, starting then a slow but steady decrease in consumption due to energy efficiency measures and public consciousness;
- Strong investment in renewable generation capacity accounting with almost over 25% of electricity production in UK;
- By 2020 onshore wind with almost 12GW installed, 3GW of offshore wind capacity offshore, taken together, they both account around 8% UK's electrical production;

- Wave and tidal generation achieve commercial success, with about 2.5GW installed by 2020;
- Biomass has a strong development in this scenario with almost 10GW installed;
- The rise of carbon prices and the pressures from international prices, production from coal becomes unviable in economical terms leading to a decrease in coal generation;
- Due to renewable generation growth in remote areas, network reinforcement is undertaken, in order to permit the connection of that generation, but pressure to reduce environmental impact from electricity network has reduce the amount of reinforcement in general;
- Local distribution networks have seen a large increase in the volume of generation connected to them, smaller scale wind and biomass plants are an element of this growth, but another important influence is the rapid development of domestic microCHP plants using gas-fuelled micro turbine technology.

d) Supportive Regulation Scenario Review

The Supportive Regulation [17] scenario describes a future in which the government and regulatory authorities exert a gradually increasing influence over the development of the electricity industry. This development is brought about by increasing public concern over issues such as energy security, and strategic planning issues associated with power generation and network infrastructure. It is considered in this scenario that:

- Consumption demand continues to grow, although government measures such as energy efficiency and demand side participation restricts the growth to a demand peak of 63GW by 2020;
- The support of the government and regulation authorities increases in low and zero carbon technologies, with 10GW of wind generation (9GW onshore and 1GW offshore);
- Wave and tidal generation also benefits from institutional incentives, by 2020 2GW will be installed and small scale biomass generation grows till 8GW;
- Renewables have a share of over a little 20% on UK's electrical generation;
- Network development is focused in maintaining supply reliability and connecting renewable developments;
- Strong regulatory pressure on distribution networks in order to improve quality of supply and reliability of electric supply;
- DSP and microCHP have no official incentive, thus having small impact.
- Reliability of the local electricity supply is improved by increased under grounding of lower-voltage distribution networks.

These scenarios give a small picture, for what may happen if the assumed assumptions take place, giving a clear message that UK's electricity production decarbonisation is an achievable objective, nevertheless it will require an significant effort from a large variety of UK society.

2.5 - Distributed Generation and Technological Overview

Distributed Generation (DG) will play a key role in this paradigm change of the power industry. Many definitions have been proposed to describe power that comes elsewhere than from traditional large generating units feeding electricity into the networks.

To the International Energy Agency (IEA) [19] distributed generation is generating plant serving a customer on-site, or providing support to a distribution network, and connected to the grid at distribution level voltages. The technologies generally include engines, small (including micro) turbines, fuel cells and photovoltaic. It does not generally include wind power, since most wind power is produced in wind farms built specifically for that purpose rather than for meeting an on-site power requirement [19].

The US Department of Energy [20] refers to distribution generation as small, modular electricity generators sited close to the customer load - can enable utilities to defer or eliminate costly investments in transmission and distribution system upgrades, and provides customers with better quality, more reliable energy supplies and a cleaner environment [20].

Directive 96/92/EC [21] states that Distributed generation shall mean generation plants connected to the low-voltage distribution system and for ENIRDGnet [22] distributed generation is simply a source of electric power connected to the distribution network or to the customer site.

DG covers a wide range of technologies, including high efficiency combined heat and power plants, small gas turbine, reciprocating engines, fuel cells and many renewable technologies supplying small scale power like small-medium size biomass, hydro and geothermal plants, photovoltaic solar roofs, small wind machines. These technologies have improved during these last few years their performance and the cost of energy produced has dramatically decreased: “economy of large product volume” has replaced “economy of facility size”, and they offer new market opportunities and enhanced industrial competitiveness.

Renewable energy can be defined as the energy flows derived from natural sources that are continuously at work in our environment and are not depleted by being used [23] and according to the Energy Saving Trust [24] micro generation is defined as any technology, connected to the distribution network (if electric) and with a capacity below 50kW.

Solar radiation is responsible for the majority of renewable energy; however, there are other sources where the energy generated comes from. Many others micro generation and renewable energy technologies for domestic use are available on the market. The various renewable energy technology options are outlined in terms of their underlying basic principles and suitability for use in different size rural developments. The following technologies are capable of generating heat or electricity for use in dwellings:

- Solar thermal (SWH);
- Photovoltaic or ‘PV’;
- Biomass heating;
- Micro wind;
- Micro-Hydro.

Despite Micro-Hydro is able of generating electricity for domestic use, it is important to mention that due to specific terrain topology of the network where this model is going to be applied and the subsequent null implementation, Micro-Hydro is no taken into account.

In addition to the above sources of renewable energy, some of the other low carbon technological solutions are available and should be considered;

- Ground Source Heating Pumps (GSHP).
- Micro combined heat and power (microCHP).

Table 2-1- Number of units installed by 2020 [24]

Units installed	PV: 2.5kWe (Dom.)	PV: 40kWe (Comm.)	Wind: 1.5kWe (Dom.)	Micro-hydro: 0.7kWe (Dom.)	GSHP V Elec. Heating (Dom.)	Biomass V Elec. Heating (Dom.)	Active Solar	CHP 1.2kWe Stirling - Large House	Fuel Cell - 1kWe (small house)	CHP 33kWe Large Recip.	FC: 3kW (large house)
2010	2,402	250	1,025	334	2,260	2,792	51,071	614	210	1,760	54
2020	30,751	660	48,599	519	100,838	61,064	51,071	35,145	11,428	7,655	2,584

According to the report Potential for Microgeneration by the Energy Saving Trust [24], table 2-1 shows the expected number of units installed till 2020 for each technology, the difference between each is mostly explained by the different economic breaking points expected for each.

As shown in Figure 2.7, some technologies have different break even points, this happens because in the report [24] two scenarios are considered. In the earliest break even scenario it is assumed that domestic energy cost is high and the cost of energy produced by each technology is low, and in the median break even point it is considered that both domestic energy cost and technology energy cost is median. In these scenarios is also taken into account the Energy Export Equivalence (EEE), which is a support scheme where the excess electricity is sold to the grid at a value which is equivalent to electricity imported from the grid. With these scenarios, is easy to see that very few technologies will have early break even points if incentives to local production isn't adopted and production costs don't decrease in a near future.

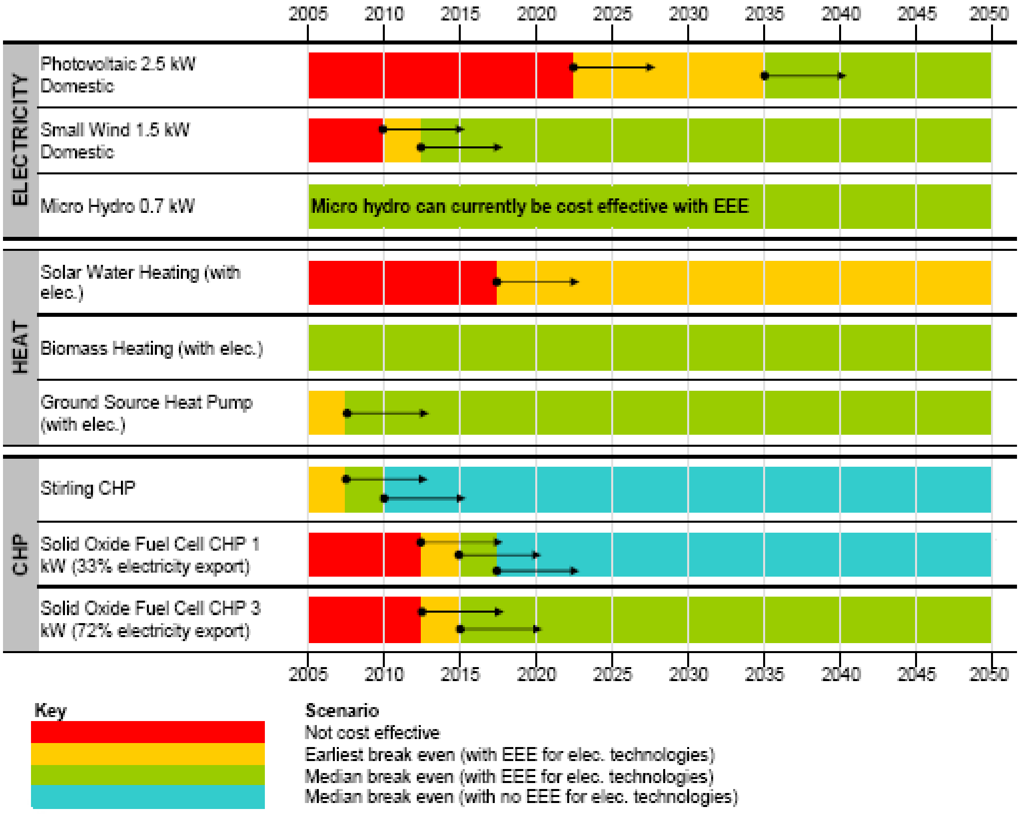

Figure 2-7 - Expected Break Even Points [24]

Before applying renewable energy technologies to new dwellings it is important to consider reducing the total energy requirement (for electricity, space heating and hot water). This can be achieved by using appropriate energy efficiency measures, passive solar and low energy design techniques. New dwellings also need to comply with the thermal performance standards set out in the relevant building regulations [25]; however this should be seen as only the minimum specification. Constructing dwellings to higher levels can make compliance easier. In addition, reducing the total energy requirements of an individual dwelling or a development as a whole means a smaller and therefore cheaper renewable system can be used. Building regulations across the UK are increasingly adopting a holistic approach to improve energy efficiency for new dwellings as part of ensuring compliance [25]. This is seeking to tackle all areas where dwellings consume energy. This approach will allow design flexibility within certain limits, however it is possible that the target could be met by using building integrated renewable (technologies that are built into the building fabric and that utilise renewable energy sources).

2.5.1 - Energy Efficiency

In new and existing housing, the total energy requirement (for space heating, hot water and electricity) should always be reduced as much as possible by using appropriate energy efficiency measures, low energy design and passive solar design techniques. By achieving reduced electrical and heating demand of a dwelling, the energy requirement can be met by a smaller and cheaper renewable energy system.

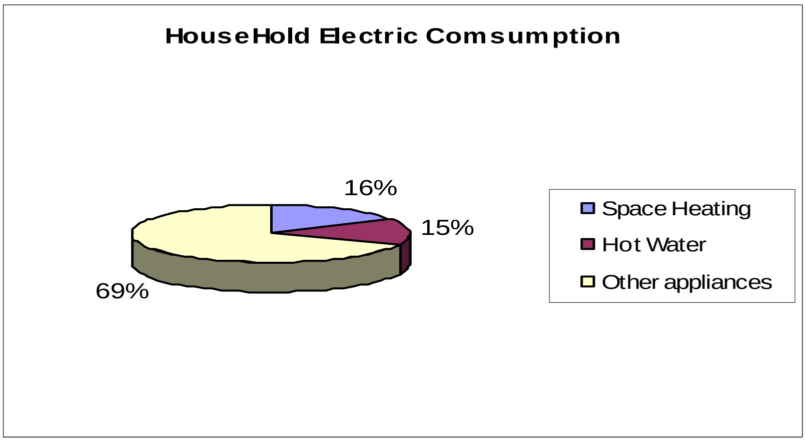

Figure 2-8- Household Electricity Consumption in UK [26]

New dwellings should, wherever possible, be positioned to take maximum advantage of solar gains, daylight and any existing protection from the wind. To maximise passive solar gain the dwellings should be planned internally so that main living areas are facing south [27]. In addition:

- Space dwellings at least twice their height apart (north to south);
- Orientate houses so that their main glazed elevation faces within 30° of south.;
- Arrange dwellings so that main living areas and bedrooms are within 45° of south;
- Avoid over-shading within 30° of south;
- Use garages to shelter north elevations;
- Increase the proportion of the total glazed area that is south facing;
- Avoid large ventilated entrances and stairs in block of flats – they introduce a cold area into the idle of the block;
- Specify heating systems and controls which respond to solar gain. Rooms subject to high solar gain should have their own zone temperature control.

2.5.2 - Photovoltaics

Photovoltaic cells convert energy from the sun into electricity through semi-conductor cells. The electricity is generated in the form of Direct Current (DC) which can either be used directly depending on the application, or converted into Alternating Current (AC) for household use or for exporting to the local electricity network/national grid. The brighter the sunlight, the more power is produced – although PV cells still produce a reduced level of power when the sun is hidden by clouds. Shading from other objects (such as nearby buildings and trees) is a key issue, as PV cells are more likely to show a drop in system output than solar thermal panels. Ideally panels should face as close to due south as possible, and be unshaded for most of the day. Because individual PV cells only provide a small amount of electricity, they are generally grouped together into a module for convenience. A full domestic system may well have several modules, together with other system components such as an AC/DC inverter, batteries (for storing the energy until it is needed), a central control unit, mounting structure or materials for fixing the array, wiring, fuses and isolator [28].

Different semiconductor materials are used to produce photovoltaic cells. A semiconducting material is one which only conducts electricity under certain conditions, e.g. when sunlight falls on it. The most widely used material is silicon. Silicon is one of the most abundant non-metallic elements on earth. It is used extensively in the manufacture of components for televisions, radios and computers, and is consequently much cheaper than other potential PV cell materials.

Table 2-2- Conversion Efficiencies of Silicon based PV Modules

Efficiency (per cent)	Module type	Durability (yrs)
12-15	Monocrystalline	25-30
10-13	Polycrystalline	20-25
3-6	Amorphous	15-20

Depending on UK location, between 900 and 1100 kWh of solar energy falls on each m^2 of unshaded surface annually. In most parts of the UK, PV installations will generate around 800 kWh annually per kWp of installed capacity. A 3 kWp installation should generate the equivalent of a small household's annual electrical consumption (2400 kWh) [29], but this does not allow such an installation to supply the house directly, because of the mismatch in supply and demand:

- Peak power demand in many houses exceeds PV generation;
- Maximum PV output is in summer, while maximum domestic electricity demand is in mid-winter.

In Figure 2.9 the profile of the output of a typical 2kWp system is shown, as reported in the System Integration of Additional Microgeneration [30]. It shows the 2 kW rated output is only attained on an ideal summer's day. Over the whole period of the summer season, the mean maximum output is around 1.2 kW. Outputs at other times of the year reflect reduced intensity and duration of sunlight. It is not expected that mains-connected installations will incorporate batteries to smooth the output, because of the significant extra cost which would be entailed. In general there will be no diversity between micro-PV installations in a single locality, e.g. as defined by the area served by a single Low Voltage feeder. For much of the time this will apply over much larger areas also.

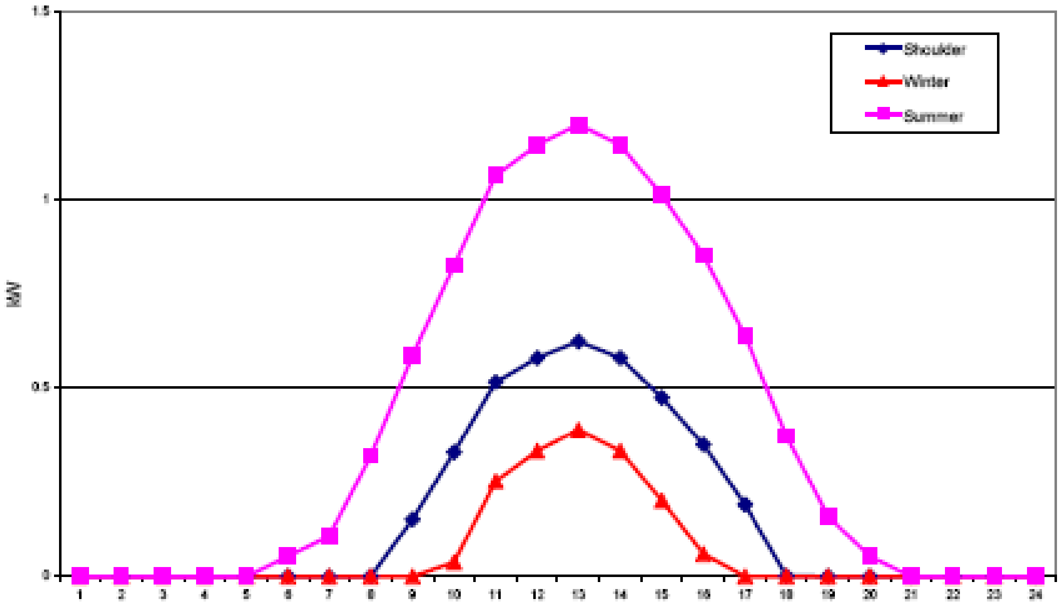

Figure 2-9 - Daily generation profile for 2kW PV installation [30]

The current status of PV technology in the UK is focused in [24] and it showed that in general PV is not generally cost effective at present and significant incentives are required to maintain the market for small grid connected systems, only in small markets such as remote power, PV is already cost effective. The cost effectiveness, as shown in Figure 2.7, is not predicted to occur until 2030. However, a technology breakthrough could reduce capital costs and bring this forward towards 2020. PV is the technology with the largest market potential due to lack of planning issues and if cost issues were overcome this technology could supply almost 4% of UK electricity demands, and reduce domestic sector CO_2 emissions by up to 3%.

Photovoltaic are ideal for use in rural environments because electricity is generated at the point of use, energy loss and costs associated with transmission and distribution are avoided. The capital cost of installing these systems however, can be prohibitive. In areas where the power supply is usually available but is not always reliable, the PV system can be connected to the local electricity network and a back-up battery. The battery is charged during normal operation, with excess electricity sold to the network. If the electricity supply becomes unavailable, power can be drawn from the battery. PV modules are commercially available in a range of different types for integration into rural dwellings and locations. They vary from traditional aluminium framed modules and roof mounted systems, to products like roof tiles and semitransparent conservatory/atrium roof systems. The flexibility of the technology enables products to be used which have the same structural and weather properties as traditional construction materials. Furthermore, their modular construction allows any size of system to be installed. PV systems can be considered for small scale, low voltage applications e.g. the operation of outside lights, pumps on solar water heating systems, and boats/caravans which may already have batteries. Although the cost of the equipment is still high, capital costs are reduced significantly when a main connection is not required.

2.5.2 - Solar Water Heating

Energy from the sun can also be harnessed to provide domestic hot water. These systems do not generally provide space heating, and are described as 'solar thermal' systems. They are among the most cost-effective renewable energy systems that can be installed on dwellings in rural or urban environments. In a typical system, a heat transfer medium (generally a water/antifreeze mixture) travels through a series of heat conducting tubes known as a heat collector. During its circulation through the tubes, the fluid picks up heat which is then transferred to the domestic hot water supply as it passes through a coil in an appropriate storage cylinder.

Solar hot water (SHW) systems can be either active or passive in terms of the circulation method. Active systems use an electric pump to circulate the heat transfer fluid (some installations use a small PV module to generate electricity for driving the pump). In a typical system a controller will compare the temperature of the solar collectors with the temperature of the water in the storage cylinder(s). If the collector temperature is hotter than in the storage cylinder, the controller will switch on the pump. The circulating fluid will then start to flow through the collectors and heat exchanger, thus heating the water in the cylinder. These systems are generally more efficient than passive systems but more expensive to buy and install. Unlike active systems, passive systems do not use an electric pump to circulate the heat transfer fluid. Instead these systems rely on natural convection or water pressure to circulate the fluid through the collector to the point of use [31].

There are two standard types of collector: flat plate and evacuated tube. Flat plate collectors are simple but effective devices, comprising a dark plate within an insulated box with a glass or durable plastic cover. The plate is usually coated with a 'selective' coating to ensure that it has high absorption but low emissivity (heat loss by re-radiation). Evacuated tube collectors are more sophisticated, with a series of metal strip collectors inside glass vacuum tubes. Their efficiencies are usually higher and they are more effective in cold weather because of their low heat losses, but they do tend to be more expensive than flat plate collectors, and succumb more easily to vandalism. Both collector types can capture heat whether the sky is overcast or clear. Depending on UK location, 900–1100 kWh of solar energy falls on each m^2 of unshaded UK roof surface annually. The annual energy captured by typical designs is:

- flat plates: 380–450 kWh per m^2 of collector;
- evacuated tubes: 500–550 kWh per m^2 of collector.

A typical solar domestic system features 4 m^2 of flat plate or 3 m^2 of evacuated tube, providing 50% to 65% of the energy required annually for water heating [29].

Like PV systems, solar collectors provide optimum performance when positioned in direct sunlight and located on sloped roofs with a southerly orientation. Unlike PV cells however, the degree of offset from due south is not so critical, enabling correctly sized systems within approximately 45° of due south to provide a significant contribution to hot water demand. During the summer months a typical SHW system can achieve between 80-100 per cent of hot water demand, although this will be considerably less in winter. High-efficiency boilers should be used where applicable to provide auxiliary 'top up' heating of the domestic hot water supply. This is particularly important since there is a risk of *Legionella* forming unless the household water supply is heated to 60°C at least once a day. This applies to ground source heat pumps as well as solar thermal systems.

Currently SWH, as shown in Table 2-1 is the most common micro generation technology in UK homes. Despite that number, it is referred in [24] that currently SWH is not cost effective and substantial grant support is needed in order to take SWH to a cost effectiveness level. In the other hand, the paper Boardman *et al* (2005) *[32]* firmly state that SWH is the micro generation technology closest to being commercially viable. This apparent contradiction may be explained by the actual cost effectiveness of SWH but only if replacing heating systems. In the current model, the approach by [24] will be taken into account, but due to the large numbers of actual installed SWH devices, the impact of this technology will also be studied.

2.5.3 - Wind Power

Harnessing wind as a renewable energy source involves converting the power within a moving air mass (wind) into rotating shaft power. Wind turbines extract energy from the wind using a rotor which usually comprises of two or three blades similar in profile to the wing of an aeroplane. If the diameter of the rotor is doubled, the power output from the turbine is quadrupled at a given wind speed. Small variations in wind speed can result in large changes in potential energy output. By doubling the wind speed available to a prospective wind turbine, the power available increases by a factor of eight. Serious consideration must therefore be given to the sitting of a turbine, regardless of size and application. Most modern turbines have a horizontal axis (as opposed to vertical axes), and range in size from less than 100W (suitable for battery charging) to several megawatts. The largest currently in development has a capacity of 5MW [33].

Generally, investment in a wind turbine should be recouped where there is a minimum average wind speed of 5 m/s; however, while a viable 2.5 kW wind turbine installation should generate at least 4000 kWh pa [33], which is equivalent to an average household's electricity consumption, it does not follow that a 2.5 kW installation can supply a house with all its electricity because:

- peak power demand in many houses exceeds wind generation;
- while maximum output is in winter and therefore coincides with maximum demand, there can be prolonged winter calms, especially when atmospheric pressure is high [29].

Watson *et al* (2006) [34] states that 1.5kW is expected to be the maximum size for domestic roof-mounted turbine and for a good micro wind site, a 1.5kW turbine with a load factor of 0.13 would have an annual output of 1680kWh [34], this value is based on measures from various sites along one year.

Micro wind break even point is supposed to happen earliest around to 2010 and for sites with average speeds of (>6m/s) the cost effectiveness is supposed to happen before 2010; nevertheless micro wind is unlikely to achieve cost effectiveness before 2050 [24].

Information related with the daily or annual electrical output of a wind generator turbine is referred in [30] as having no significance due the stochastic nature of wind energy resource; it is suggested that in order to evaluate the impact on the electricity distribution network, to assume that the maximum output coincides with the time of minimum load, but at the time of maximum demand the weather is calm with nil contribution from the wind turbine generator.

Ideal locations are those where the turbine can be positioned on top of a smooth hill, with an absence of obstructions in the prevailing wind direction. Wind increases in speed as it reaches the top of the hill. Excessive turbulence should be minimised by sitting away from obstructions. Commercially available small scale wind turbines are generally suited to rural applications. Not only are higher wind speeds more readily available, but there is also less potential for opposition to their installation[27] [32] [34]. For grid-connected systems in particular, assistance will be needed from the appropriate DNO in order to meet relevant electrical connection requirements. Other planning issues include the method of fixing turbines to buildings to eliminate vibration, the visual impact of the turbine and any associated noise whilst in operation. Rural locations where mains electricity may not be available, or is prohibitively expensive, are particularly suitable for small scale wind turbines. Small turbines, typically less than 100W, can be used to provide electricity in remote applications e.g. electric fencing, caravans, boats and telephone boxes. Wind speeds as low as 2-2.5m/s can produce enough power for mechanical applications such as pumping water. These turbines will usually be of a multi-bladed design to generate the high torque needed to operate a piston pump in a borehole or well.

2.5.4 - Ground Source Heat Pumps

A heat pump extracts solar heat from the ground by ‘moving’ heat from one place to another and from a lower temperature to a higher temperature, to heat dwellings. It is essentially the same technology (in reverse) as a conventional domestic refrigerator. Ground source heat pumps (GSHP) therefore utilise stored solar heat, and do not generally use deep geothermal heat generated by the earth’s core. There are three key elements to any GSHP system:

- Ground heat exchanger.
- Heat pump.
- Heat distribution system.

The ground heat exchanger is a loop or coil of pipe that is buried in the ground. A fluid consisting mainly of water mixed with antifreeze circulates through the loop and increases in temperature by absorbing heat from the surrounding soil. A heat pump works by driving a working fluid or refrigerant around a circuit which comprises of an evaporator, compressor, condenser and an expansion valve. As heat is absorbed by the heat source, the refrigerant changes its state by evaporation from a liquid to a gas. The refrigerant is now at a low temperature and pressure; it enters the compressor where both the temperature and pressure are increased as a result of work done on the refrigerant. The gas now enters the condenser where the heat absorbed by the collector coil is released, to be used in the dwelling via the heat distribution system. The refrigerant, still in the form of a gas, but reduced in pressure and temperature, is throttled back further in the expansion valve before recommencing the cycle by absorbing more heat from the collector. The compressor runs on electricity and consumes approximately one unit of electricity for every three units of heat energy produced. However, the total amount of heat energy delivered to the dwelling is equal to the energy required to run the heat pump plus the energy extracted from the soil. Therefore GSHP systems typically achieve overall efficiencies of between 200-400 per cent depending on the operating conditions. A distribution system is needed to transfer the heat extracted from the ground by the heat pump. The heat is often in the form of hot water, and is distributed around the dwelling by radiators or a low temperature under floor heating system [29] [35] [36].

For indirect GSHP systems supplying low temperature distribution systems, typical seasonal efficiencies (annual energy delivered by heat pump: total annual energy supplied [for the pumps] to the system) of between 300 and 400% are common, reducing the demand for purchased electricity [29]. Break even point for GSHP with electrical heating will be around 2005-2010, even then, support schemes still will be needed. It is not expected that GSHP will be cost effective with gas heating [24].

In rural environments GSHP systems are at their most cost-effective where high levels of insulation have been achieved and mains gas is unavailable. Where there is a low heating demand, underfloor heating and other low temperature heating distribution systems become possible options. The choice of vertical or horizontal system depends on the land area available, local ground conditions and excavation costs. Horizontal collectors require a relatively large area of land for the trench. It can be placed vertically in a narrow trench, or horizontally in a wider trench. Horizontal collectors are therefore more suitable to rural applications where properties are generally larger. In contrast, vertical collectors are inserted into boreholes and are ideally suited in locations where ground space is limited. However, they are more expensive to install and consequently less cost-effective than horizontal collectors in rural areas. Furthermore in rural environments it might be possible to use an alternative heat source such as a lake, flowing water or even an existing deep well to permit a smaller and therefore cheaper collector to be used.

2.5.5 - Biomass

Biomass or wood burning systems differ from other renewable energy sources because they emit CO_2 when they are burnt. The amount released is equal to the carbon absorbed when the tree was growing, so the process is essentially carbon neutral. In order for biomass to be a truly renewable energy source, the fuel must come from a sustainable source (i.e. it is replenished) and should be used in close proximity to where it has been grown. Even allowing for emissions of CO_2 in planting, harvesting, processing and transporting the fuel, replacing fossil fuel energy with wood will typically reduce net CO_2 emissions by over 90% [29] [37]. For domestic small scale applications, three different types of wood fuel are generally used: logs, pellets and woodchip.

Larger rural applications such as social housing and multi-dwelling developments can present the opportunity for automatic wood chip boilers with capacities ranging from 20kW to over 1,000kW. When burning fuel with high moisture content, the boiler plant can become more technically complex and expensive. These boilers are generally designed for use with woodchips with a moisture content of between 25-35 per cent. Large scale boilers will perform at their maximum efficiency when operated at, or close to, total capacity. They are therefore best suited to providing base-load heat demand, with fossil-fuelled boilers operating as an auxiliary back-up to fulfil peak load demand. As technology advances, models are becoming available with sophisticated controls allowing the boiler to 'modulate' and follow the heat load as it varies, without compromising efficiency and performance. [29] [37]

Biomass heating can currently be economic compared with electrical heating, but large cost reductions are necessary for break-even with gas heating. [24]

Although the UK's natural gas distribution network is extensive, there are some areas which are not supplied with mains gas. These areas are often close to supplies of biomass/wood fuel. New developments can strengthen local rural economies by providing employment in activities like wood fuel harvesting, transport and processing, and the construction, operation and servicing of plant machinery. Transforming derelict woodland into wood production also helps to conserve and promote biodiversity, as well as improving wildlife habitats. Short rotation coppice especially brings substantial biodiversity and habitat improvement benefits. Where appropriate, community heating fuelled by biomass can be a viable alternative to individual heating systems currently relying on fossil fuels that are imported into the area. Availability of specific forms of wood fuel is also a major concern when considering the suitability of biomass heating.

2.5.6 - Micro Combined Heat and Power

Micro combined heat and power (CHP) is an emerging energy technology, for use in dwellings, the system will generate electricity as well as heat for space heating and hot water. MicroCHP installations run on natural gas, but bio-gas systems are a future possibility. These systems are typically around 1kWe in size. They are claimed to have a low electrical efficiency at around 15% but a high overall efficiency around 90% when operating in condensing mode [29]. Aside from the fuel and electricity connections, the main elements of a CHP installation consist of a prime mover, an alternator, a heat recovery system and a control system. There are several types of prime mover used in microCHP systems but the two most common types serving the domestic sector in the UK are the Stirling engine and the internal combustion engine. Stirling engines are currently the most prominent microCHP technology for individual dwellings. These systems are typically around 1kWe in size giving approximately 5kW; they are claimed to have a low electrical efficiency at around 15% but a high overall efficiency around 90% when operating in condensing mode. Some Stirling engine system suppliers are also planning to provide the option of configuring the system to work in the event of a power cut, maintaining heating and providing some power. A small number of pioneering applications are currently taking place in the UK. Internal combustion engine systems tend to be too large and noisy for individual properties and are therefore usually used to supply small groups of dwellings through a network of heating pipes. They are typically around 5 kWe in capacity and tend to have higher electrical efficiencies at around 25%. They also tend to have higher maintenance requirements than Stirling engine systems.

In [24], two microCHP technologies were considered, Stirling Engine and Fuel Cells, and for both is expected early break even scenarios. In the case of Stirling Engine, EEE metering enables the break-even of Stirling CHP systems circa 2015 and the absence of EEE delays this by approximately 5 years. In the long term, fuel cell CHP is potentially the most cost-effective technology with break even circa 2015. The small 1kW electricity-led fuel cell CHP achieves cost-effectiveness with EEE circa 2010-2015 and 5 years later without EEE depending on technology cost assumptions.

Figure 2-10 shows the profiles of the output of a typical 1.1kW system, as analysed by the report System Integration of Additional Micro generation [30].

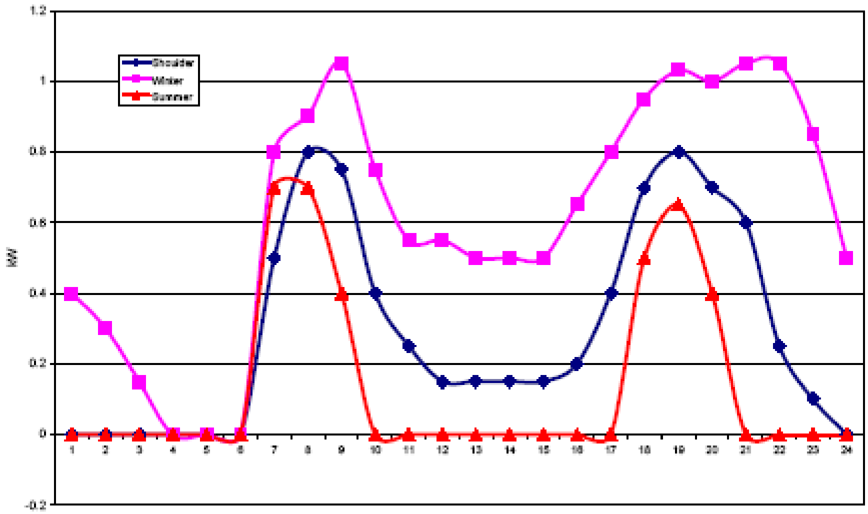

Figure 2-10 - Daily generation profile for microCHP [30]

The electrical output depends on the heating and hot-water load in the premises and various manufacturers may adopt different control strategies for maximising efficiency and minimising costs. MicroCHP units with modulating controls may exhibit smoother curves with a lower rate-of-rise in the early morning, but the area under the curves would be the same, as these are determined by seasonal heat demands. [30]

The carbon savings from microCHP are, as yet, unproven. BRE is developing a methodology that will make use of the laboratory test results to evaluate the energy benefits of microCHP heating systems in houses. MicroCHP suppliers have, however, made estimates of the savings achievable from their systems. For example, CO_2 savings of 1.5 tonnes per household per annum, equivalent to a 20% reduction in CO_2 emissions, are suggested. [29]

2.6 - DNO’s Asset Management Framework

According to EDF Energy Networks [38] the defined objective of the Network Asset Management Plan (NAMP) is to provide a systematic, risk-based, approach to the management of the networks and to ensure the optimum scale and timing of network investment to satisfy stakeholder requirements [38]. The NAMP’s demonstrate and support the Networks Branch commitment to network performance improvement by preserving and, where appropriate, enhancing the functionality of network assets in order to ensure that the long-term operating capability of the system meets the needs of its stakeholders and customers.

NAMP is often perceived as a set of engineering programmes but it is important to recognise that it is more than this; it is a long-term, business-driven strategy. A sound understanding of the sometimes complex linkages between business drivers and asset performance is essential, as this allows the performance of the network assets, or the risk of their functional failure, to be related to DNO’s business performance. By understanding the performance improvement potential and, conversely, the risk of failure, it is possible to optimise investment and expenditure. [38]

A minimum requirement of each NAMP is to ensure that the individual assets, and the network as a whole, continue to perform so as to ensure that DNO’s meet all licence conditions and statutory obligations, including health, safety, and environmental requirements, and that DNO’s are able to discharge fully its corporate responsibilities. At the same time, the networks must continue to provide, as a minimum, a satisfactory level of service to connected customers and an acceptable financial performance through efficient and effective investment decisions and delivery. [38]

The NAMP’s are, therefore, a crucial element in ensuring that DNO’s achieve its corporate objective of obtaining the right balance between the interests of customers, staff and shareholder. Projects and programmes of work, and the associated investment and expenditure levels within each category, are set to ensure that their purpose is achieved within an agreed level of business risk. Project and programme scoping and prioritisation are, therefore, an essential part of decision-making when formulating the work and expenditure volumes. [38]

2.6.1 - Basis of costs

The values of the projects and programmes described in the NAMP’s are a mixture of specific cost estimates, normally associated with specified projects, and values determined from the application of unit costs to generic programme volumes. Both approaches use prime costs and exclude attributable overheads, these being added retrospectively for Regulatory and Management Accounting purposes. For 2007 onwards, project costs include project management costs. For major projects costs are based on mid-range estimates and, wherever possible, the most recent tender prices for similar projects. [38]

2.6.2 - NAMP outputs

The NAMP's provide a set of justified, approved and risk-assessed investment programmes for each DNO's. They have been developed to address the performance of the physical assets that make up the network. Performance issues can be asset-specific, but can also relate to the performance of the network as a whole, managing the performance of the distribution system as a whole is a primary function of any DNO [38]. A set of very important secondary outputs derived from the NAMP process are the two year Production Plans, which are used by the delivery units for budgeting and to forecast and organise the resources required to deliver the work programmes included in the plan.

Included in the NAMP is Infrastructure Development Plan (IDP) for each network. These are stand-alone documents that describe in detail the major network infrastructure projects to be undertaken in each area. The cost and volume data contained in these plans are harmonised with the NAMP by interfacing the Development Plan databases with the NAMP database. However, this alignment represents a 'point in time' view and it should be noted that the IDP databases are continually being modified to reflect the continuing development in investment plans. The 'NAMP' view is budget aligned and represents the agreed programme. A formal change control mechanism can be applied during the life of the NAMP to modify the content, although all such changes need to be evaluated in terms of their impact on business performance.

In addition to the financial outputs, the NAMP's also include high-level resource estimates (in terms of field-based core skill requirements) to enable resource planning and provide indicative volumes to facilitate procurement planning. The initial two-year period is covered in sufficient detail to provide strategic guidance to those parts of the Networks Branch responsible for delivery, and through the Production Plans enables them to plan their short to medium-term resource requirements. The remainder of the period of the Plan is designed to support long-term financial and resource planning within all parts of the business.

2.6.3 - Asset Condition

Asset condition knowledge underpins an effective asset replacement strategy. The management of such knowledge is, therefore, a critical element in the development of the NAMP. It generates technical and economic information that is used to develop the asset strategies and ensure the optimisation of the whole life cost of ownership of each asset. [38]

These strategies integrate information gathered from a wide range of sources, both within and external to the business. Examples of inputs include feedback from asset condition reports, failure mode feedback reports and external research and development. Modelling and risk assessment techniques support the development of replacement strategies for each asset group. These techniques facilitate comparisons between the relative criticality (in terms of safety, reliability and cost impact) and the condition of the asset population. This model assesses the current residual life of that asset group and forecasts future trends, establishing the replacement requirements for each asset, which are then detailed in the asset strategic plans. Applying these knowledge acquisition techniques also informs the maintenance requirements for each asset group. Combining these requirements allows DNO's to develop a complete picture of asset related investment requirements, which then feeds into the strategic planning process.

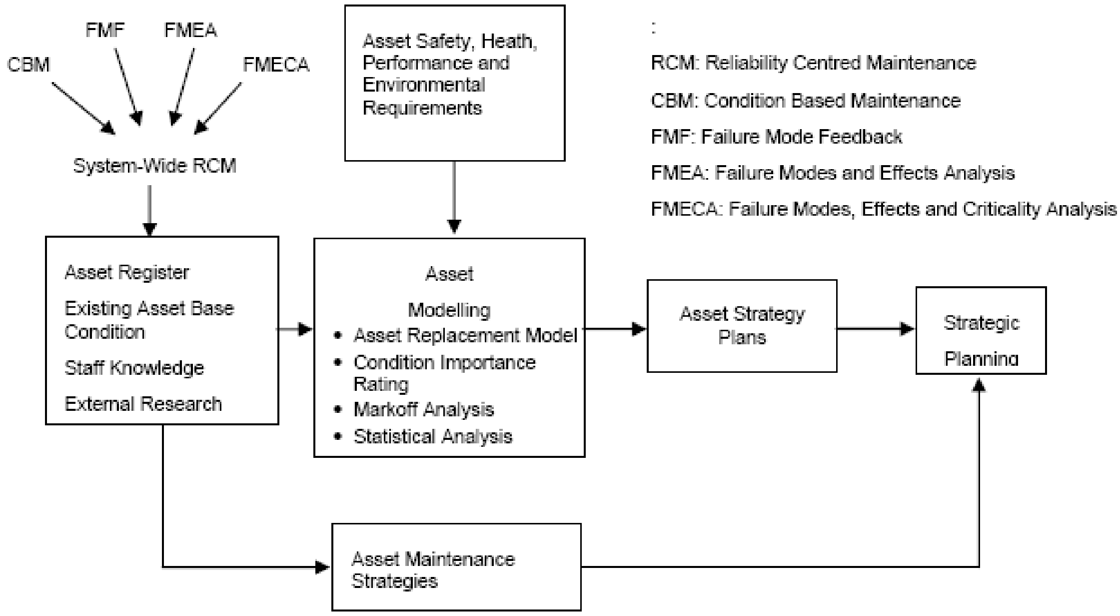

Figure 2-11 – Asset Knowledge Process [38]

2.6.4 - Decision Criteria

DNO's must consider the following important criteria when making asset replacement decisions:

- Cost of Operation;
- Asset performance;
- Risk of Failure;
- Environment and Safety;

Every asset replacement scheme is an opportunity to achieve the following benefits for the future network:

• Improvement in reliability where an understanding of the condition degradation process is such that imminent failure can be anticipated or performance has deteriorated to the extent that the number of recurring failures is unacceptable. Also, there may not have been any failures to date but its condition, when considered with the consequence of failure, is such that replacement is considered a justifiable policy;

• Reduction of inspection, maintenance and operating costs, especially where the cost of operation has increased (i.e. maintenance and spare parts);

• Improvement in performance where a replacement decision may be taken simply because the current asset is obsolete and the functionality available from new equipment is desirable;

• Improvement to environmental and safety issues where the modern replacement option removes or reduces the existing impacts.

2.6.5 - Asset knowledge and Asset Life Prediction

Effective asset management must achieve the fine balance between cost, performance and risk. This balance can be optimised only when the asset manager has an intimate understanding of the assets. In some cases, where knowledge of the asset is limited, this may lead to risk-averse decisions (i.e. early replacement) or, in the extreme, catastrophic failure.

Catastrophic plant failure is, of course, precisely what an effective condition-based asset management regime seeks to avoid. By replacing plant 'just in time', based on good asset knowledge, the plant provides its maximum useful life without incurring higher than average costs. Unfortunately, on occasions, either because of less than full asset condition data, a rapid deterioration in condition or perhaps a design fault on newer equipment, plant can still fail catastrophically. Such events are rare, but when they do occur there is potential for significant damage. Supply disruption is likely to occur, there can be safety issues for staff and the public, media attention will invariably follow and repairs can be disproportionately expensive. Strategic spare management is the main way of mitigating the effects of these events.

Some methodologies have being introduced into DNO's [38] which will allow them, a better understanding of the network assets and thus support replacement decisions based on objective criteria rather than subjective judgement. These methodologies addresses electrical and civil assets, including substations, overhead lines, and gas and fluid-filled cables, but will not encompass LV, HV and EHV solid cable systems. These methodologies have redesigned and rationalised across the DNO's the business processes of work initiation, planning and delivery with (i) the installation, removal and replacement of assets; (ii) the inspection and maintenance of assets; and (iii) the defect and follow up work.

They are also a vital part of meeting or exceeding OFGEM efficiency frontiers and mitigating legislative and regulatory non-compliance.

Chapter 3

Model Development

3.1 - Introduction

Due to the extreme importance of load forecast in network management, it is essential to develop robust methodologies/tools that can be capable to assist network managers in aiding and supporting them to make the right decisions on where and when investments need to be made in order to maximize their assets and maintain the high standards which DNO's are obliged to fulfil.

The following chapter will provide the reader with the necessary understanding in how the current model was built, what are the assumptions made, and what sort of outputs are expected. It will describe in detail the structure of the model and how it uses employment growth, housing growth, distributed generation penetration, energy efficiency, demand side management and how it converts them into load demand seen by primary stations perspective.

3.2 - Approach

In this model the load demand forecast was based on publicly available data in respect of projected housing and employment growth in the new developments which are supposed to happen till the year 2020 in the three operating areas of EDF Energy Networks: East Power Network (EPN), London Power Network (LPN) and South East Power Network (SPN). To convert the number of houses and the number of jobs, available data from EDF Energy Networks regarding average house consumption and average commercial consumption for each location within each network was used.

The approach in the model also includes the selection of three different scenarios based on those proposed by the Supergen Future Networks Technologies Consortium [referred to from now as the Supergen scenarios]. Three scenarios are modelled, these being Continuing Prosperity, Environmental Awakening and Economic Concern. A fourth scenario was also proposed by Supergen Consortium (Supportive Regulation), but due to is similarity with Continuing Prosperity, the scenario was discharged.

To keep the model complexity in a reasonable level, some assumptions must be taken into account:

- Connections are made just to one primary station unless that primary station gets full loaded and a new primary is needed;
- Exceptional loads aren't taken into account in this model;
- The number of houses considered for each year it is an average of the number of houses expected for the number of years that is supposed to last the development;
- Due to his “high level” nature, this model does not take into consideration the specific machinery schemes, lines and cables adopted and their limitations;
- Network reinforcement is not considered in case of negative load;
- Duration of developments are considered to take place since the beginning of the first year till the end of the last year;
- It is assumed a unitary power factor (PF=1). The assumption of a unitary power factor is due to consider only active power (reactive power is not considered) in the model maths operations, therefore demand will be in MW and not in MVA;
- It is not considered the impact of micro generation in underlying load growth in the developments not evaluated.

The model represented with the previous flowchart at Figure 3-1 was a combined effort from Ricardo Azevedo (University of Porto student) and João Couto (University of Porto student) at EDF Energy. The author of this dissertation was responsible for researching the expected contribution and output profiles of each technology and to model its contribution at peak times regarding the demand load profiles. He was also responsible for developing the excel background calculations for the expected demand output and for the methodology for evaluating the capability of the selected primary substations to cope with the expected underlying load growth and the development demand regarding the connection costs and the available margins throughout the period of time considered was developed by him.

3.3 - Model Overview

This model is built in MS Excel workbook with Visual Basic Macros.

A generic approach has been taken whereby the user can select the network area, districts within the network and the correspondents developments; it gives the user the possibility to define the maximum distance from the development to the primaries; it can also give the opportunity to select the modelled scenarios and the percentage of implementation of each technology considered for domestic and commercial load, it also make it possible for users to chose the percentage of expected energy efficiency reduction in electrical demand as for reducing factor for PV, micro wind and DSM.

The selections in Inputs worksheet will result in the appropriate factors and associated values to be loaded into the model. This facilitates the upgrading and further model development.

To evaluate the impact of micro generation technologies in the distribution network, some considerations had to be made in order to process the inputs information into results in the outputs worksheet.

Table 3-1 – Resume of Energy contributions researched for use in the model

Technology	Energy Contribution (kWh/yr)	Heat Contribution (kWh/yr)	Electricity Contribution (kWh/yr)
SWH(4m2)	1200	1200	0
PV (2kWp)	1600	0	1600
MicroWind (1.5kW)	1680	0	1680
GSHP	4500	4500	0
Biomass	6800	6800	0
MicroCHP	8000	6400	1600

As shown in table 3-1, each technology contributes in different ways to reduce domestic electrical demand. While technologies such as PV and Micro Wind contribute directly by producing electricity, other technologies such as SWH, GSHP and Biomass contribute indirectly, this happens because their energy contribution is related only to heat production. As shown in Figure 2-8, household heat demand includes space and water heating with a total amount of 31% with 15% for water heating and 16% for space heating.

For SHW technology, the energetic contribution considered is only in terms of hot water heating, so the electricity reduction obtained by the adoption of SHW systems has the maximum value of 15% of the average house consumption.

For GSHP and Biomass technologies, the energetic contribution considered is only in terms of heat (Water and Space), so the electricity reduction obtained by the adoption of GSHP systems has the maximum value of 31% of the average house consumption.

For microCHP systems, the energetic contribution is considered in terms of heat and electric production, in general heat output has a 4:1 ratio with electrical output, for typical systems of 1kWe (3300kWh), with heat outputs of 4kWth (13200kWh). Due to large variety of houses, with different heat demands, as shown in table 3-2, an average of 6400kWh of heat requirement per household was considered

Table 3-2 – Heat requirements for various types of Dwellings [39]

Dwelling type		Top floor flat	Mid-terraced	End-terraced	Semi-detached	Detached
Total floor area (m²)		60.9	78.8	78.8	88.8	104.0
Energy requirements (kWh/yr)	Space	2,270	2,232	2,893	3,423	4,451
	Water	2,813	3,228	3,228	3,412	3,762
	L&A	2,201	2,719	2,719	3,057	3,635
	Cooking	1,173	1,264	1,264	1,314	1,386
	Total	8,456	9,443	10,103	11,205	13,233

Because microCHP technology can provide most of the heat requirement of a house, and the electrical output is driven by the heat output with a ratio of 4:1, a value of 6440kWh for heat contribution and 1600 kWh of electrical contribution per household were considerate.

In Outputs worksheet, information, demands and margins will be shown in order to easily guide the user to find the best solution that suits the previous choices made in the inputs sheet.

The information regarding locations of developments and primaries substations is retrieved from the software ARCGIS and stored in Excel database.

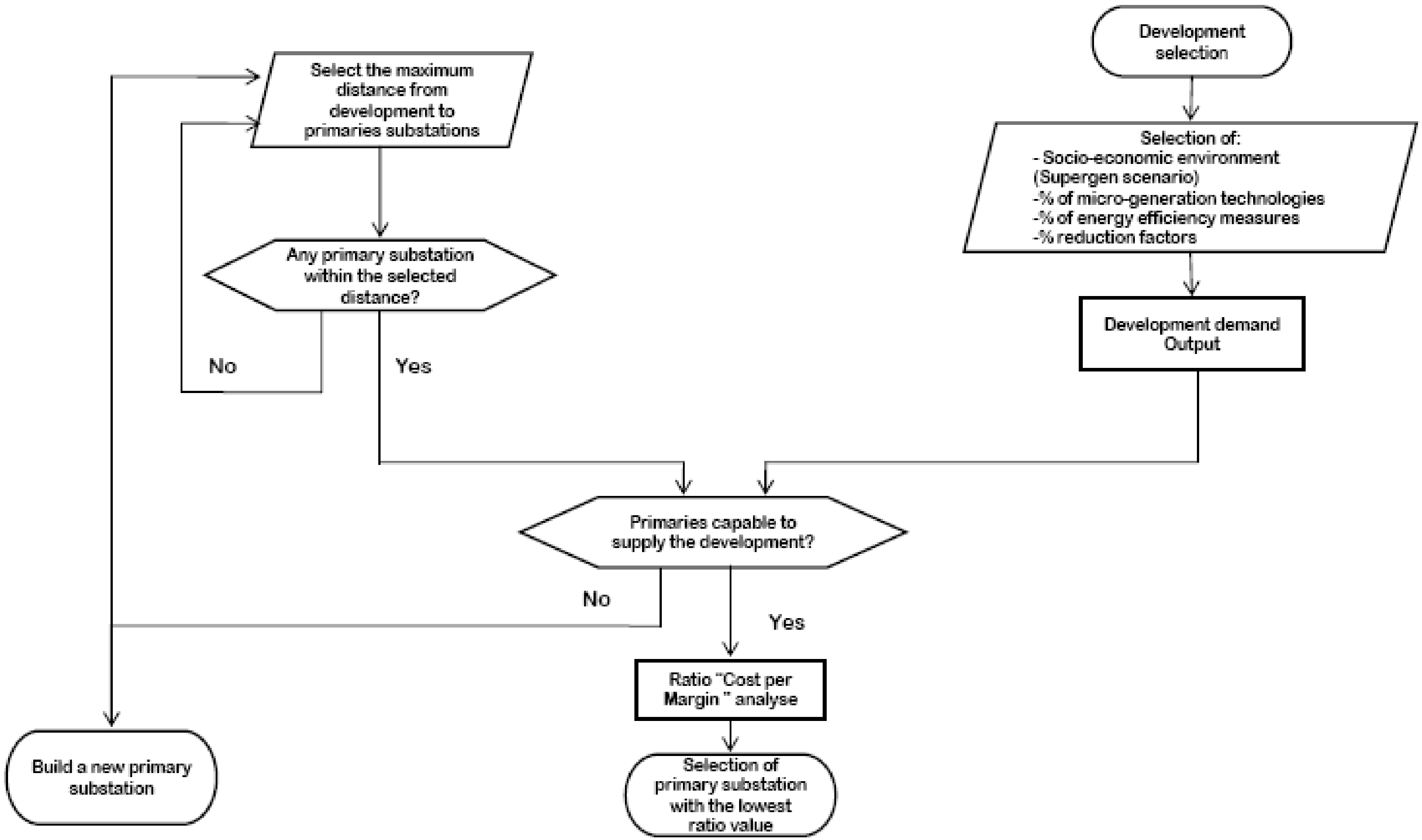

Figure 3-1 – Model Flowchart

3.3.1 - Inputs

This worksheet is separated in two coloured distinct sections; the Control and the Info. The Control with a yellow colour is composed by several drop down lists and text boxes, and gives the user the chance to change the inputs in the model. The info section, with a green colour, displays information referring the values and choices introduced in the control section. A Figure of inputs worksheet I shown in appendix A

In the Control section are the drop down lists allow the selection of:

- The licence area (SPN, LPN or EPN);
- The location;
- The development;
- The ‘Supergen’ scenario (Continuing Prosperity, Environmental awakening or Economic Concern).

1. **Choose Network**

Displays a list of the DNO Network (due to usage of EDF Energy data, the Networks considered are EPN, SPN, LPN);

2. **Choose District**

Displays a list of the available locations within the chosen DNO Network;

3. **Choose Development**

Displays a list of the available developments located in the chosen location;

4. **Maximum Distance of Primary Substation to New Development (km)**

Blank field where users insert the maximum distance from the development, to existing primary substation

5. **Choose Supergen Scenario**

It provides three options:

- Continuing prosperity;
- Environmental awakening;
- Economic concern;

The choice of Supergen scenario determines preset factors and information displayed on the Info section in respect of:

- House and Job Scaling Factor;
- Trends referring to the deployment of several Micro generation technologies and energy efficiency in dwellings;
- Demand Side Management (DSM),

The default values used are summarised in the following tables.

House and Job scaling factor:

The house and job scaling factor gives the percentage of houses and jobs that are expected for each scenario. Although the information about the number of houses and jobs expected for each new development area is imported from another database, the values to consider in the model will be affected by these factors according to the chosen scenario. The percentage of houses and jobs considered for each scenario is presented in the table 3-3:

Table 3-3 - Job and Housing Scaling Factor

Scenario	House and Job scaling (%)
Continuing Prosperity	100%
Economic Concern	70%
Environmental Awakening	100%

Trends referring to the deployment of several Micro generation technologies and energy efficiency in dwellings

According to the scenario choice in control section, it will be displayed on the info section some information regarding the trend/usage of several micro generation technologies and energy measures such as energy efficiency, this information does not give any quantitative info, the only purpose is to help the user to have a general view on how those technologies are most likely to be adopted according to the scenario previously chosen.

Table 3-4 - Trends referring to the deployment of several Micro generation technologies and energy efficiency in dwellings

	Technologies/Measures						
Scenario	**Biomass**	**MicroCHP**	**GSHP**	**Photovoltaic Panels**	**SHW**	**Micro-Wind**	**Energy Efficiency**
Continuing Prosperity	Strong development	Small but growing proportion	Strong development	Reasonably strong development	Strong development	Reasonably strong development	Strongly promoted
Economic Concern	Reasonably strong development	Does not develop to the point of being economically attractive	Minimal application	Discouraged by economy	Minimal application	Discouraged by economy	Interest in adoption to reduce expenditure on energy
Environmental Awakening	Strong development due to concerned public	Strong development due to concerned public	Strong development due to concerned public	Strong development due to concerned public	Strong development due to concerned public	Strong development due to concerned public	High take-up by concerned public

<u>Demand Side Management (DSM)</u>

Demand side management is applied to the domestic demand and three profiles are shown based on the Supergen scenarios. Each assume an achieved level of DSM by around 2011/12 after which the uptake levels off, only economic concern scenario shows a small increase along the forthcoming years, despite being quite small.

Table 3-5- Expected demand side management evolution till 2020 according each scenario

Demand Side Management	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Continuing Prosperity	1.0%	4.0%	8.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
Economic Concern	0.5%	0.5%	0.8%	1.0%	1.0%	1.5%	2.0%	2.0%	2.5%	2.5%	3.0%	3.0%	3.0%
Environmental Awakening	2.0%	6.0%	8.0%	10.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%

6. Set % of electrical demand reduction due to Energy Efficiency measures

Blank field, where user inserts value for expected reduction on electrical demand caused by the implementation of energy efficiency measures, the chosen value must be within a range of [0% -17%].

7. Set % of Each Technology

Domestic Load:

Blank fields, where user inserts percentage value of number of houses that adopt each technology. The technologies considered for domestic load are:

- Micro-Wind;
- Solar Electric Photovoltaic;
- Micro-Combined Heat and Power Systems (microCHP);
- Solar Thermal Hot Water (SHW);
- Biomass;
- Ground Source Heating Pumps (GSHP).

Commercial Load:

Blank field, where user inserts value for expected reduction in electrical consumption. Due to the uncertainty nature of previous considered technologies and the need of more reliable electrical sources for the specific demands of commercial load, only microCHP is considered in the model.

8. **Set % of DMS reduction factor:**

Allow the user the possibility to select a reduction percentage of the expected implementation of DSM measures shown in Table 3-5. The percentages described on Table 3-5 are considered to be extremely optimistic [40], so the user has in this cell the possibility to choose a reduction factor (percentage) to reduce the impact that DSM programmes have in domestic electrical demand savings.

9. **Set % of Micro-Wind reduction factor:**

Allow the user the possibility to select a reduction factor within a range of [0% to 50%] for the expected annual contribution of micro-wind technology.

10. **Set % of PV reduction factor:**

Allow the user the possibility to select a reduction factor within a range of [0% to 50%] for the expected annual contribution of micro-wind technology.

In the info section of the Inputs worksheet, exist several boxes displaying information regarding the choices made in the control section, they are:

- Investment time: shows the years in which the new development is supposed to begin and to finish. The first year displayed is the year in which the development is expected to star (stars at the beginning of that year) and the second year displayed is year which the development is expected to finish (finishes at the end of that year).

- Total Number of Houses: represents the number of houses that are expected to be built in the selected new development for the investment time period.

- Total Number of Jobs: represent the number of new jobs that are expected to be created by the selected new development for the investment time period.

This value is affected by a scaling factor that is dependent on the chosen scenario.

- Average House Consumption: displays the average house electrical consumption in a year for the selected local authority district.

- Average Commercial Consumption/Job: displays the average commercial electrical consumption in a year per job for the selected local authority district.

- Demand Side Management on the first year: displays the percentage of DSM to be considered in the first year of the new development according to the selected scenario.

- Some information concerning Energy Efficiency Measures and Micro-Generation Technologies for domestic loads are made in this section. This information changes according to the scenario.

- In this section, is also displayed the information of the energy savings that can be made in commercial loads by the implementation of microCHP systems. This information is “static” and does not vary like the precedent information according to the chosen scenarios.

- The information relating to the % of DSM reduction factor reveals the user a possible estimate for this same value. The default values displayed in this informative consideration were obtained from [40]. In this report the impact of DSM on the electrical reduction, in a domestic level, was also considered to be optimistic and the default values of 30% for Continuing Prosperity scenario, 15% for Economic Concern scenario and 50% for Environmental Awakening scenario were assumed for DSM reduction factor. DSM is not modelled for commercial loads, this happen in accordance to the [40] that states that it is felt that the best opportunity for reducing system peak as far as a distribution company is concerned [as distinct from a generator] is to control domestic demand at system peak.

- The information relating to the % of Micro-wind factor shows the user information regarding the range of values [0% to 50%]. The lowest value is considered to be a year with very weak wind. The highest value considered to be a year with stronger wind.

- The information relating to the % of PV factor shows the user information regarding the range of values [0% to 50%]. The lowest value is considered to be a year with very weak solar radiation. The highest value considered to be a year with stronger solar radiation.

3.3.2 - Outputs

This worksheet is separated in five coloured distinct sections; the Primary Substations Info, the Demand Output, Primary Substation Margin Evolution, Primary Substation Ratio Evolution and Results. It will display information from available primaries substations where new developments can be connected and it will also aids users to select the best one in terms of cost/margin.

I) Primary Substation Info

The primary substation info section, displays general info of primaries substations existing in a range defined in point 4 in subchapter 3.3.1. This section is divided in six parts:

1. **Primary Substation Reference**

Display the names of available primaries.

2. **Distance to Development**

Display the distance of each primary to the selected development.

3. **Primary Capacity**

Display information of firm capacity of each primary in MW.

4. **Margin**

Display information of available margin of each primary in MW.

5. **Underlying load growth**

Display information on load growth for each primary in MW. Underlying load growth is a constant value of expected demand increase for each primary.

6. **Connection Cost**

Displays the current connection cost per mile to connect any new development to each primary. The connections costs are connected to the specific network chosen in the inputs worksheet, according to [40] the costs for each shown in table 3-6

Table 3-6 - Connection costs per network [40]

Network	Connection Cost (M£/mile)
EPN	0,069
LPN	0,097
SPN	0,069

II) Demand Output

In the Demand Output section, it is shown the load demand forecast for the chosen development. The development demand is a result of housing and commercial demand and housing, commercial and DSM offset.

1. Housing Demand

At this column it will be displayed the expected housing demand for the expected number of houses for each year.

The expected housing demand for each year is achieve by the following formula;

$$\text{Housing Demand}_n = \text{Housing Demand}_{n-1} + \frac{\text{Total Number of Houses} \times \text{Average House Consumption}}{\text{Total Number of Years}} \quad , (3.1)$$

- *n* → Start of new development
- *Housing Demand* $_{n-1}$ → Expected housing demand in year n-1 (MWh)
- *Number of Houses* → Total number of Houses expected to be built in the development
- *Average House Consumption* → Average Consumption per household in the selected district (kWh)
- *Total Number of Years* → Total number of years the development is expected to last

2. Housing Offset

At this column will be displayed the housing offset for the expected number of houses for each year. This value represents the electricity produced by each micro-generation technologies and energy efficiency measures for each year.

The expected housing offset for each year is achieved by the following formula:

$$\text{Housing Offset}_n = \text{Housing Offset}_{n-1} + \text{Micro generation Offset}_n + \text{Energy Efficiency Offset}_n \quad ,(3.2)$$

- *n* → Start of new development
- *Housing Offset* $_{n-1}$ → Expected housing offset in year n-1 (MWh)
- *Micro generation Offset* $_n$ → Sum of all electricity generated by all micro generation technologies adopted in the development in year n (MWh)

- *Energy Efficiency Offset* → Electricity saved by the adoption of energy efficiency in the new development (MWh)

The expected Micro generation Offset in year n is calculated by:

$$\text{Micro generation Offset}_{n} = \text{Micro generation Offset}_{n-1} + \frac{\text{Number of Houses} \times \sum \text{Energy Contribution}}{\text{Total Number of Years}} \quad , (3.3)$$

- *n* → Start of new development
- *Micro generation Offset* $_{n-1}$ → Expected offset due to micro generation in year n-1 (MWh)
- *Number of Houses* → Number of houses expected to adopt selected technology
- *Energy Contribution*→ Energy generated by all technologies in the new development (MWh)
- *Total Number of Years* → Total number of years the development is expected to last

The expected Energy Efficiency Offset (EE Offset) for housing demand in year n is calculated by:

$$\text{EE Offset}_{n} = (\text{Housing Demand}_{n} - \text{DSM Offset}_{n}) \times \%\,\text{Energy Efficiency} \quad , \quad (3.4)$$

- *n* → Start of new development
- *EE Offset* $_{n}$ → Expected reduction in housing demand due to Energy Efficiency in year n (MWh)
- *DSM Offset* $_{n}$ → Expected reduction in housing demand due to DSM in year n (MWh)
- % *Energy Efficiency*→ Percentage of expected reduction in demand due to energy efficiency

3. Commercial Demand

At this column it will be displayed the expected commercial demand in the new development due to new jobs.

The expected commercial demand for each year is achieve by the following formula:

$$\text{Commercial Demand}_{n} = \text{Commercial Demand}_{n-1} + \frac{\text{Number of Jobs} \times \text{Average Job Consumption}}{\text{Total Number of Years}} \quad , (3.5)$$

- *n* → Start of new development
- Commercial Demand $_{n-1}$ → Expected commercial demand in year n-1 (MWh)
- *Number of Jobs* → Number of Jobs expected to be created in the new development
- *Average Job Consumption* → Average Consumption per Job in the selected district (kWh)
- *Total Number of Years* → Total number of years the development is expected to last

4. Commercial Offset

At this column it will be displayed the commercial offset for the jobs created in the new development area. This value represents the reduction in demand due to adoption of CHP technologies and energy efficiency measures for each year. The user at Inputs worksheet is able to choose the percentage up to 25%, for the commercial electrical consume reduction.

The expected commercial offset for each year is achieved by the following formula:

$$\text{Commercial Offset}_{n} = \text{Commercial Offset}_{n-1} + \text{CHP Offset}_{n} + \text{Energy Efficiency Offset}_{n}\ , \quad (3.6)$$

- *n* → Start of new development
- Commercial Offset $_{n-1}$ → Expected commercial offset in year n-1 (MWh)
- *CHP Offset* $_{n}$ → Average commercial consumption affected by reduction factor due the use of CHP technologies in year n (MWh)
- *Energy Efficiency Offset* $_{n}$→ Electricity saved by the adoption of energy efficiency in the new development in year n (MWh)

The expected Energy Efficiency Offset (EE Offset) for commercial demand in year n is calculated by:

$$\text{EE Offset}_{n} = (\text{Commercial Demand}_{n} - \text{DSM Offset}_{n}) \times \%\text{Energy Efficiency}\ , \quad (3.7)$$

- *n* → Start of new development
- *EE Offset* $_{n}$ *t*→ Expected reduction in commercial demand due to Energy Efficiency in year n-1 (MWh)
- *DSM Offset* $_{n}$ → Expected reduction in commercial demand due to DSM in year n (MWh)
- *Commercial Demand* $_{n}$ → Expected commercial demand in year n (MWh)
- *%Energy Efficiency*→ Percentage of expected reduction in demand due to energy efficiency

5. Demand Side Management Offset

At this column will be displayed the offset of Demand Side Management measures. This value represents the domestic electrical savings that are expected to be achieved due to the adoption of DSM measures.

The expected impact of DSM measures will differ according the chosen Supergen scenario. The DMS percentage considered in the model is expected to vary according to years and also according to the Supergen scenario chosen.

So, for the years that the development is expected to last, the formula to determinate the DSM offset is:

$$\text{DSM offset n} = \frac{\text{Number of Houses} \times \text{Average Consumption}}{\text{Total Number of Years}} \times \%\text{DSM n}, \quad (3.8)$$

- *n* → Start of new development
- *DSM Offset* $_{n}$ → Expected reduction in commercial demand due to DSM in year n (MWh)
- *Number of Houses* → Number of Houses expected to be created in the new development

- *Average Consumption* → Average Consumption per Household in the selected district (kWh)
- *Total Number of Years* → Total number of years the development is expected to last
- *% DSM $_n$* → Expected reduction in percentage due to DSM in year n

6. Development Demand

At this column it will be displayed the expected electrical demand from the new development. To determinate the development demand the formula is:

$$\text{Development Demand}_n = \text{Development Demand}_{n-1} + \text{Housing Demand}_n + \text{Commercial Demand}_n - \text{Housing Offset}_n - \text{Commercial Offset}_n - \text{DSM Offset}_n \quad (3.9)$$

- *n* → Start of new development
- *Development Demand $_{n-1}$* → Expected development demand in year n-1 (MW)
- *Housing Demand $_n$* → Expected housing demand in year n (MWh)
- Commercial Demand $_n$ → Expected commercial demand in year n (MWh)
- *Housing Offset $_n$* → Expected housing offset in year n (MWh)
- Commercial Offset $_n$ → Expected commercial offset in year n (MWh)
- *DSM Offset $_n$* → Expected reduction in commercial demand due to DSM in year n (MWh)

In order to convert the unit MWh to MW, the conversion used was;

1 MW → 3300 MWh

III) Primary Substation Margin Evolution

The primary substation margin evolution section, displays the margin and the demand affected by the specific underlying load growth of each primary substations within the range defined in *point 5 in subchapter 3.3.1*, from the first year of development time to the year 2020.

The demand for each primary is calculated using the following formula:

$$\text{Primary Demand}_n = \text{Primary Demand}_{n-1} + \text{Load Growth} + \text{Development Demand}_n \quad (3.10)$$

- *n* → Start of new development
- *Primary Demand n-1* → Expected demand at the primary in year n-1 (MW)
- *Load Growth* → Underlying Load Growth in the Primary Substation (MW)
- *Development Demand $_n$* → Expected development demand in year n (MW)

The margin for each year and for each primary is calculated using the following formula:

$$\text{Margin}_n = \text{Primary Capacity} - \text{Primary Demand}_n \quad (3.11)$$

- *n* → Start of new development

- Primary Capacity → Primary firm capacity (MW)
- Primary Demand $_n$ → Expected demand at the primary in year n (MW)

III) Primary Substation Ratio Evolution

The primary substation ratio evolution section, displays the ratio between the connection cost to link the new development to the selected primary, and the margin of each primary substations within the range defined in point 4 in subchapter 3.3.1, from the first year of development time to the year 2020.

The ratio for each primary is calculated using the following formula:

$$\text{Ratio}_n = \frac{\text{Connection Cost} \times \text{Distance}}{\text{Margin}_n} \quad (£/\text{MW}) \qquad (3.12)$$

- *n* → Start of new development
- Connection cost → Cost of connecting new development to the selected primary (£/mile)
- *Distance* → Distance from the primary to the new development (km)
- Margin $_n$ → Margin in the year n (MW)

3.4 - Summary

The data gathered from the model can be used to form a high-level view of future asset requirements and allows DNO's to develop strategic plans in order to deal with the expected load growth.

The model is linked to the software ARCGIS where it obtains information relative to the selected networks regarding DNO's assets and expected developments; this is an important contribution to the model because allows it, to gather accurate information, thus making it more reliable. The model consists in two parts, the inputs and outputs. In the inputs, information regarding the selected developments and their specific characteristics is loaded; the information is then exported to the output section, where available primaries and expected demands are shown. The following step is to evaluate for the selected primaries, the evolution of demand and margin in the period of time considered, this information then leads to the final step where the ratio between connections cost and margin available is calculated.

Chapter 4

Cambridge District – Rural Developments

4.1 - Introduction

This chapter will briefly introduce the available technologies suitable for rural developments. It explains the developed scenarios in order to test all the different inputs within the model and how they impact the demand from a primary substation point of view.

4.2 - Data and Assumptions

In this case study no major technical issues were found in adopting PV, Micro Wind, Solar Water Heating, Ground Source Heating Pumps, Biomass, and microCHP in rural developments, so in order to restring the numerous scenarios that would appear from the combination of all technologies, two types of rural developments were considered: On Gas Grid and Off Gas Grid.

In the On Gas Grid, it is assumed that developments are connected to National Gas Grid, so due to lower cost of gas heating, technologies such as Biomass, GSHP and Solar Water Heating won't be cost effective making their expected penetration unlikely to happen in the near future. The same line of thought happens with Off Gas Grid, in these developments, connection to the National Gas Grid is not available, thus, gas fired microCHP technologies are not considered to be implemented. Another consideration was to choose technologies that could supply electricity and heat, so that in each zone, every house could have the possibility to produce their energy requirements.

Table 4-1 - Types of Technologies for each type of rural development

TYPE OF RURAL DEVELOPMENT	TECHNOLOGIES
On Gas Grid	Micro Wind
	Photovoltaic
	MicroCHP
Off Gas Grid	Micro Wind
	Photovoltaic
	Biomass
	GSHP
	SWH

It is also assumed that, for each development, every house will be equipped with the same type of technology. This happens because it is not expected that for the same development different technologies would be adopted, neither for economic reasons nor for traditional house visual homogeneity reasons.

It is assumed that each new house will have only one PV system with a peak capacity of 2kW with an output for this system assumed to be 1600kWh per annum. As shown in *Figure 2-9* the daily profile output of a PV system does not match the peak demand of a typical UK household shown in *Figure 4-1*.

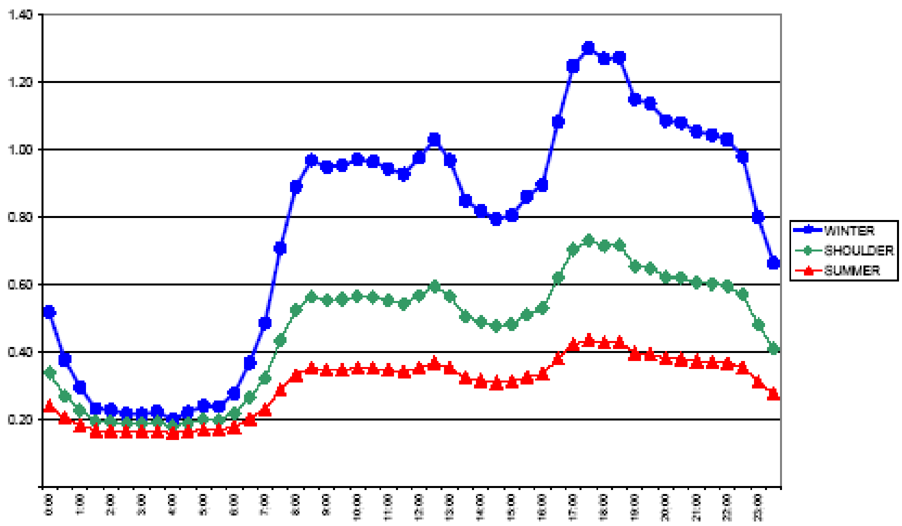

Figure 4-1 - Seasonal Demand Profiles [30]

Consumption in peak demand occurs between 17 pm and 18 pm and to evaluate the impact of PV array in the distribution network, comparison between peak demand and production has been made. From this comparison, it can be concluded that when peak demand occurs, PV electrical output can reduce it by 0% in winter up to 50% in the summer.

It is assumed as for PV, that each house would install no more than one micro-wind generator of 1.5 kW. The expected annual output for micro-wind being considered is a value of 1680 kWh. As for the impact of micro wind output in the distribution network, it is considered that in the period of maximum demand the generator would have minimum production, so in this case it will just be assumed that the minimum value for electrical production by micro wind generator will be similar as the value of minimal demand. A value of around 15% of annual contribution should then be expected, but due to random nature of wind and considering that in rural areas wind is a plentiful resource this value may be considered too pessimistic, thus a wider range of contributions of micro wind during peak demands may be considered.

Since heat demand is the driver for the power output of microCHP and because house heat demand has the same profile as house electrical demand, the impact of microCHP technology in the peak demand will be considered as 100% of his annual electrical output. It is assumed that every house will have only one microCHP device of electrical rating of around 1kWe.

Other heat power technologies such as Biomass and GSHP use the same output pattern of microCHP, for that reason their contribution will be assumed as 100% of their annual electrical output. In the case of SWH, despite having a profile similar to PV, their contribution will be also consider to be 100%, this happens because, heated water can be stored, and used in the peak demand period of time, thus saving the demand for electrical heat.

It will also be assumed that in every development all buildings will adopt the same energy efficiency measures, being these measures responsible for a maximum reduction of 17% of electrical demand.

For commercial load, the only technology considered is gas fired CHP, although in some developments connection with the gas grid may not be available for domestic loads, it is assumed that for commercial and industrial loads, gas supply exists, either by connection with gas network either by local gas reservoirs. The value for electric demand reduction by adopting CHP technologies can be up to 25%, despite that, a more modest value of 10% will be assumed as a base case.

4.3 - Base Scenarios

In this chapter, proposed developments will be simulated according to the zone where they are supposed to appear. Primaries substations around developments will be evaluated in order to assess their capability to cope with expected demand from new developments. Two distinct scenarios named as Optimistic and Pessimist will be simulated. These two scenarios are intended to evaluate the behaviour of existing primaries to two different approaches, the Optimistic scenario is driven by information related to the Supergen scenario Environmental Awakening, in this scenario, micro generation technologies, and energy efficiency measures are considered to be fully adopted in the development. The Pessimist scenario is related to the Supergen scenario, Economic concern; this scenario will show a cautious approach in the adoption of micro generation technologies and energy efficiency. It is also intended to evaluate how these variations may imply and justify future investments vs. incentives in DNO’s network

Scenarios will be run in specific developments; the general information will be displayed in Table 4-2;

Table 4-2 - Developments Info

Network	EPN	**EPN**
District	Cambridge	**Cambridge**
Development Code Name	SA/00053/06	**SOA/00013/05**
Location	Cambourne	**Northstowe**
Gas Connection	No	**Yes**
Start	2013	**2015**
End	2014	**2017**
Number Total of Houses	1400	**2826**
Number Total of Jobs	200	**100**
Average Domestic Consumption (kWh/year)	4360	**4360**
Average Commercial Consumption (kWh/year)	**5600**	**5600**

4.3.1 - Off Gas Grid

In this sub chapter, a development without connection to the gas grid will be simulated, it is intented to evaluate and measure how the non gas fired technologies may impact the expected demand.

4.3.1.1 - Development Demand

Development in this zone, as shown in table 4-1, will adopt PV panels and Micro Wind generators for electricity purposes and Biomass, SWH panels and GSHP for heating. Thus for this development three cases will be considered regarding the usage of different technologies and factors. The percentages for each input represent the Optimistic scenario; as shown below, technologies are considered to have a high penetration into the new developments, and likewise, factors such as electrical reduction due to energy efficiency and commercial CHP are expected to reach a considerable value.

Case 1:

Domestic

- 17% Energy Efficiency

Technologies

- 100% Micro Wind
- 100% PV
- 100% Biomass

Commercial

- 10% CHP

Factors

- Environmental Awakening
- 50%DSM
- 15% PV Factor
- 15% Micro wind Factor

Case 2:

Domestic

- 17% Energy Efficiency

Technologies

- 100% Micro Wind
- 100% PV
- 100% SWH

Commercial

- 10% CHP

Factors

- Environmental Awakening
- 50%DSM
- 15% PV Factor
- 15% Micro wind Factor

Case 3

Domestic

- 17% Energy Efficiency

Technologies

- 100% Micro Wind
- 100% PV
- 100% GSHP

Commercial

- 10% CHP

Factors

- Environmental Awakening
- 50%DSM
- 15% PV Factor
- 15% Micro wind Factor

Table 4-3 - Demands and offsets for each case

	Year	Housing Demand (MWh)	Housing Offset (MWh)	Commercial Demand (MWh)	Commercial Offset (MWh)	DSM Offset (MWh)	Development Demand (MW)
Case 1	2013	3052.0	1778.2	560.0	151.2	183.1	0.45
	2014	6104.0	3556.5	1120.0	302.4	366.2	0.91
Case 2	2013	3052.0	1289.9	560.0	151.2	183.1	0.60
	2014	6104.0	2579.8	1120.0	302.4	366.2	1.20
Case 3	2013	3052.0	1778.2	560.0	151.2	183.1	0.45
	2014	6104.0	3556.5	1120.0	302.4	366.2	0.91

In case 1 and 3 the contribution of offset supplied by Biomass and GSHP is equal, this is due to the restriction of a maximum of 31% demand reduction in electrical consumption regarding heating space and water.

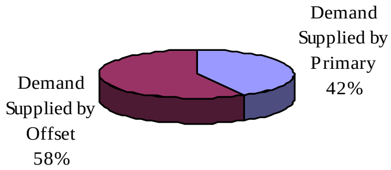

Figure 4--2 - Development Demand Supplied by Primary and Offset for case 1 and 3

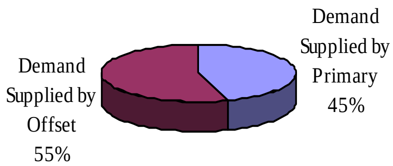

Figure 4-3 - Development Demand Supplied by Primary and Offset for case 2

In Figure 4-2, is shown the percentage of expected demand that will be supplied by the primary substation and by onsite generation. For case 1 and 3, 42% (0,9MW) from a total demand of 2,2MW is provided by the primary substation, the same goes for Figure 4-3 where the use o SWH in case 2 represents an increase on supply by primary substation of 13% in comparison with Biomass and GSHP technologies.

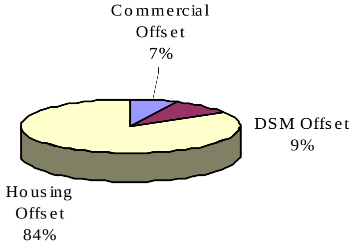

Figure 4-4 – Impact of each offset in overall offset for case 1 and 3

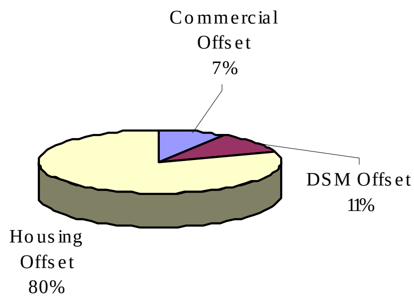

Figure 4-5 – Impact of each offset in overall offset for case 2

Figures 4-4 and 4-5 show the impact of each specific offset in the overall offset for this development, the low percentage of commercial offset in comparison with the housing offset is caused by the big difference between the number of houses and number of jobs expected to be created in the new development.

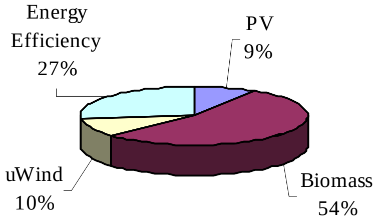

Figure 4-6 – Impact of each technology and energy efficiency in housing demand offset for case 1 and 3

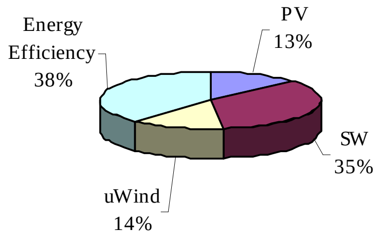

Figure 4-7 – Impact of each technology and energy efficiency in housing demand offset for case 2

Figures 4-6 and 4-7 show the contribution in percentage of each technology and energy efficiency in housing offset. For case 3 the impact of GSHP is the same as Figure 4-6 for biomass.

4.3.1.2 - Primaries Substations Demand

The new developments need to be connected to the distribution network; this is done by connecting them to a primary substation. In this subchapter, primaries in the surrounding areas of the new development will be evaluated in order to determine their capability to cope with the new demand, and the expected underlying load growth for a period of time till the year 2020.

The primaries substations considered has being able to have the demand from the new development connected to them are first pre-selected according to the distance to the new development. In rural areas, primary substations density is lower than in urban areas so, to find suitable primaries longer distances to the new developments are to be considered. The next step is to choose from the primaries within the range, the ones which are not overloaded.

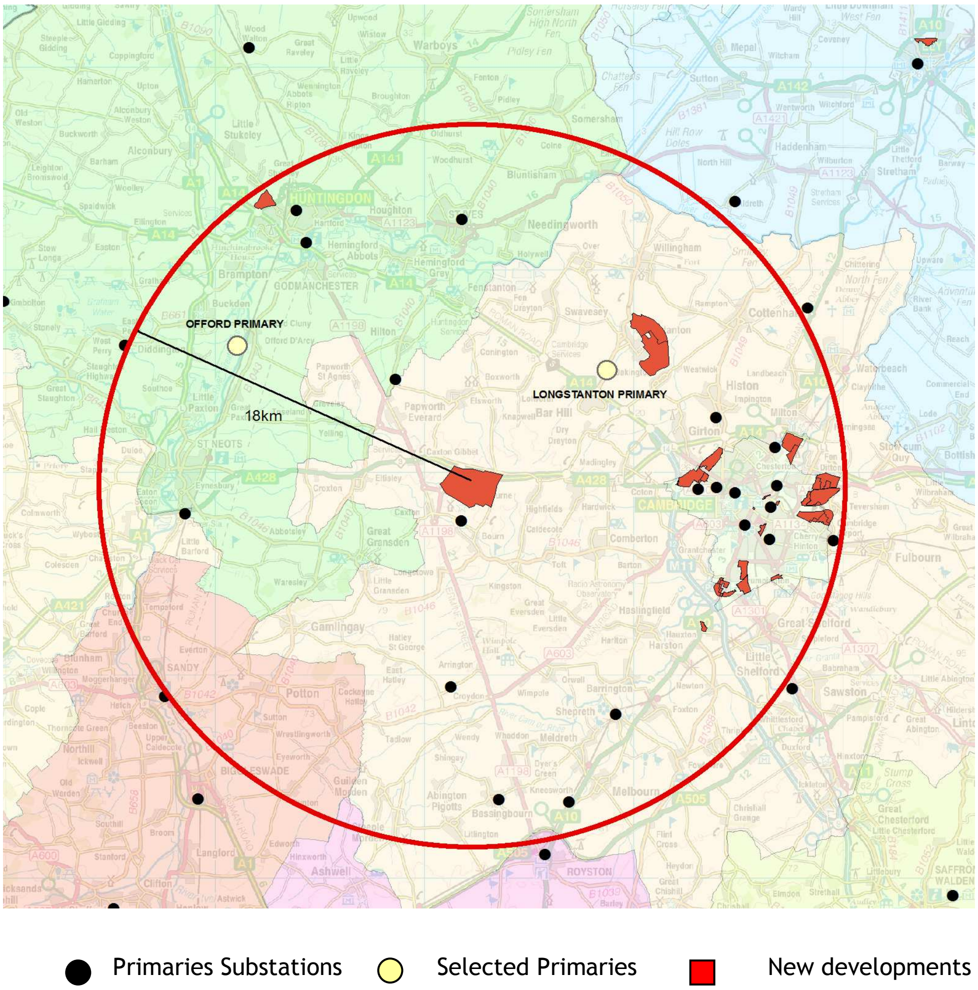

Figure 4-8 – Location of selected primaries and development

To this new development primaries within a range of 18km was considered, and 22 primaries were found, however only 2 primaries were found to be able to be connected to it. In table 4-4 general information regarding the primaries to be evaluated is shown.

Table 4-4 - Information regarding considered primary substations

P.S. Reference	Distance to development (km)	P.S. Capacity (MW)	Margin (MW)	Demand (MW)	Underlying Load Growth (MW)	Connection cost (M£/km)
E04 LONGSTANTON PRIMARY	8,6	23,1	8,9	14,2	0,42	0,069
B49 OFFORD PRIMARY	13,6	23,1	11,0	12,1	0,44	0,069

After the selection of suitable primaries, their margin evolution is to be evaluated, each primary has different underlying load growths, so, primaries with larger margins at the present time, are not automatically considered to be the most suitable solutions to cope with the demand from the new development for the 2020 time period. In Table 4-5 and Table 4-6 it is displayed the demand and the margin evolution for previous considered primaries, taking already into account the development demand for case 1 and 3 and 2 respectively.

Table 4-5 - Demand and Margin evolution for primaries substations for case 1 and 3

Primaries	2013		2014		2015		2016		2017		2018		2019		2020	
	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin
E04 LONGSTANTON PRIMARY	16.7	6.4	17.6	5.5	18.0	5.1	18.4	4.6	18.8	4.2	19.3	3.8	19.7	3.4	20.1	3.0
B49 OFFORD PRIMARY	14.7	8.3	15.6	7.4	16.1	7.0	16.5	6.5	17.0	6.1	17.4	5.6	17.9	5.2	18.3	4.7

Table 4-6 - Demand and Margin evolution for primaries substations for case 2

Primaries	2013		2014		2015		2016		2017		2018		2019		2020	
	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin
E04 LONGSTANTON PRIMARY	16.9	6.2	17.9	5.2	18.3	4.8	18.7	4.3	19.1	3.9	19.6	3.5	20.0	3.1	20.4	2.7
B49 OFFORD PRIMARY	14.9	8.2	15.9	7.1	16.4	6.7	16.8	6.2	17.3	5.8	17.7	5.3	18.2	4.9	18.6	4.5

Just by assessing the evolution from the considered primaries, the expected choice would be the primary with a higher margin by 2020 for the three cases, although, that's not the case. In order to maximize the existing assets, the decision criteria for the chosen primary will be a ratio between the connection cost and the margin left. In Figures 7 and 8 it is displayed the evolution of the specified ratio in the two primaries till 2020.

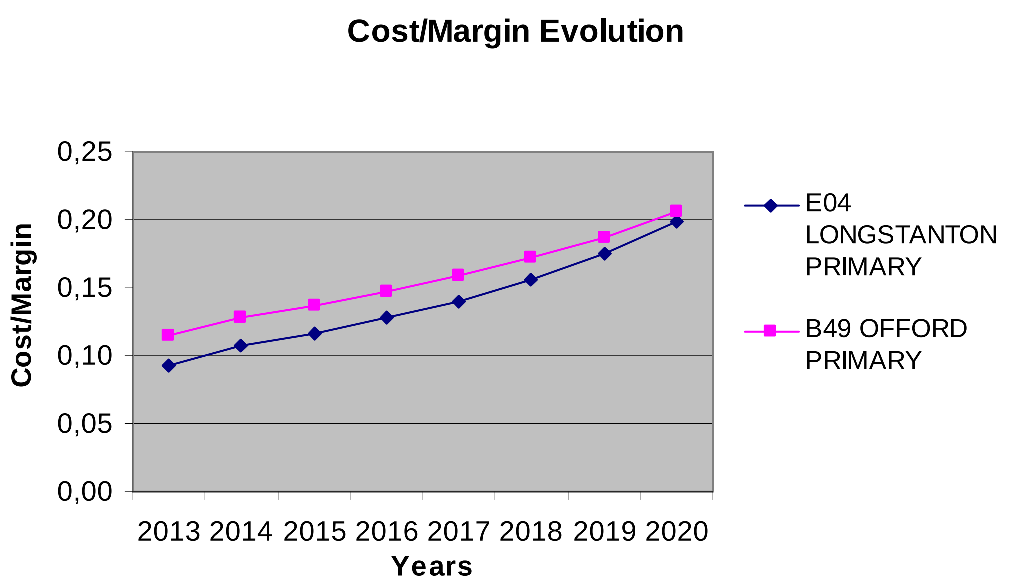

Figure 4-9 - Ratio Evolution for case 1 and 3

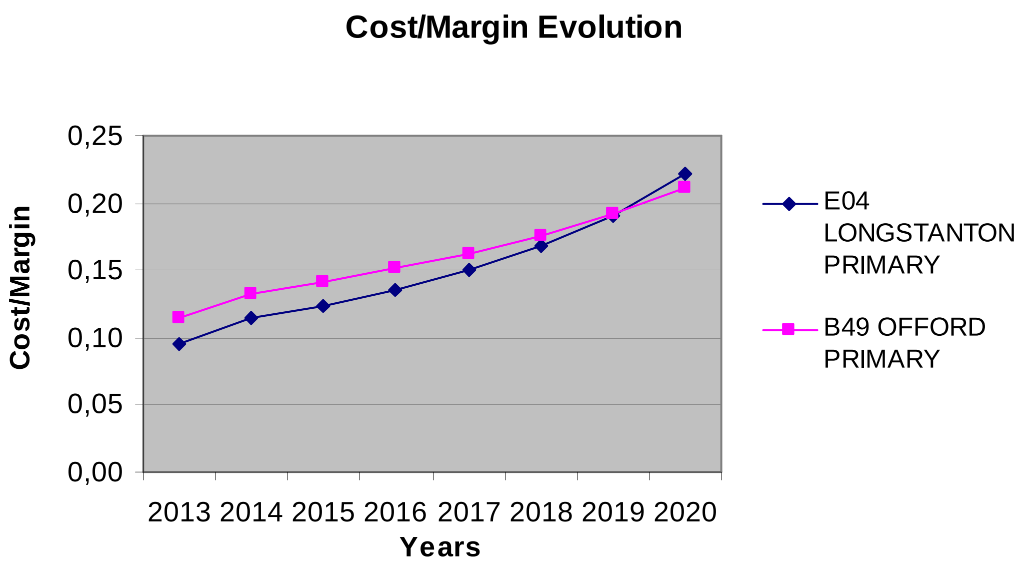

Figure 4-10 - Ratio Evolution for case 2

In Figure 4-9, for case 1 and 3, by evaluating the ratio evolution of E04 LONGSTANTON PRIMARY it is possible to see that it tends to get closer to the B49 OFFORD PRIMARY, but despite that, it never gets higher. By 2020 E04 LONGSTANTON PRIMARY ratio has the value of 0.199£/MW and B49 OFFORD PRIMARY the value of 0.206£/MW, so for case 1 and 3, the best solution would be to connect the new development to the E04 LONGSTANTON PRIMARY.

In Figure 4-10, for case 2, the ratios for both primaries show a different result from the previous cases; by 2020 the ratio for E04 LONGSTANTON PRIMARY is no longer lower than the one from B49 OFFORD PRIMARY, so in this case two solutions may be adopted: a short term and a long term solution. The short term solution would be to connect the development to E04 LONGSTANTON PRIMARY because, for the period of time from 2013-2019 this primary has a better ratio. The long term solution for this case is to connect the new development to the B49 OFFORD PRIMARY, due to the lower ratio after 2019. In this case the E04 LONGSTANTON PRIMARY has a ratio of 0.221£/MW and B49 OFFORD PRIMARY a ratio of 0.211£/MW both by the year 2020.

4.3.2 - On Gas Grid

In this sub chapter, a development with connection to the gas grid will be simulated, it is intended to evaluate and measure how the gas fired technologies may impact the expected demand.

4.3.2.1 - Development Demand

Development in this zone, as shown in Table 4-1, will adopt PV panels and Micro Wind generators for electricity purposes and microCHP technologies for heating. Thus for this development one case will be considered regarding the usage of different technologies and factors. The percentages for each input represent the Optimistic scenario; as shown below, technologies are considered to have a high penetration into the new developments, and likewise, factors such as electrical reduction due to energy efficiency and commercial CHP are expected to reach a considerable value.

Case 1:

Domestic

- 17% Energy Efficiency

Technologies

- 100% Micro Wind
- 100% PV
- 100% MicroCHP

Commercial

- 10% CHP

Factors

- Environmental Awakening
- 50%DSM
- 15% PV Factor
- 15% Micro wind Factor

Table 4-7 - Demands and offsets for On Gas Grid Case

	Year	Housing Demand (MWh)	Housing Offset (MWh)	Commercial Demand (MWh)	Commercial Offset (MWh)	DSM Offset (MWh)	Development Demand (MW)
Case 1	2010	4107,1	3914,2	186,7	50,4	164,3	0,05
	2011	8214,2	7814,3	373,3	100,8	410,7	0,08
	2012	12321,4	11700,6	560,0	151,2	739,3	0,09

In Figure 4-11, is shown the percentage of expected demand that will be supplied by the primary substation and by onsite generation. For this case, 2% (0,09MW) from of total demand of 4,5MW is provided by the primary substation.

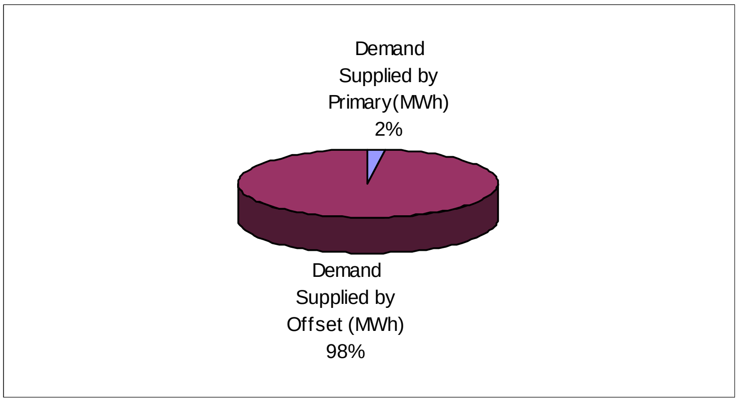

Figure 4-11 - Development Demand Supplied by Primary and Offset in on gas grid

Figures 4-12 show the impact of each specific offset in the overall offset for the this development, the low percentage of commercial offset in comparison with the housing offset is caused by the big difference between the number of houses and number of jobs expected to be created in the new development.

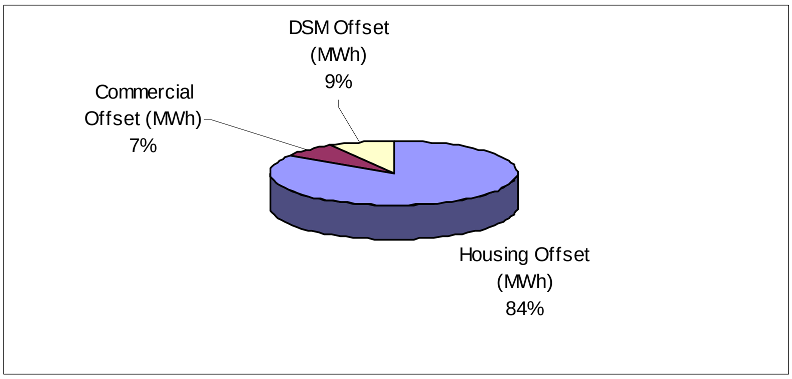

Figure 4-12 - Impact of each offset in development offset for on gas grid

4.3.2.2 - Primaries Substations Demand

As in sub-chapter 4.3.1.2, primaries in the surrounding areas of the new development will be evaluated in order to determine their capability to cope with the new demand, and the expected underlying load growth for a period of time till the year 2020.

The process, illustrated in Figure 4-8, in which primaries were chosen for evaluation, was the same for the off gas grid development. For this development a distance of 15 km to the development was considered and 17 primaries were found, however only 3 primaries were found to have the enough margin to be able to be connected to it. In table 4-8 general information regarding the primaries to be evaluated is shown.

Table 4-8 – Information regarding considered primary substations for on gas grid

P.S. Reference	Distance to development (km)	P.S. Capacity (MW)	Margin (MW)	Demand (MW)	Underlying Load Growth (MW)	Connection cost (M£/km)
E12 ST ANTHONY ST PRIMARY	12,7	22,1	5,7	16,4	0,35	0,069
E08 MILTON RD PRIMARY	14,3	22,1	2,6	19,5	0,10	0,069
E05 HISTON PRIMARY	11,9	22,1	3,6	18,5	0,30	0,069

After the selection of suitable primaries, their margin evolution is to be evaluated, each primary has different underlying load growths, so, primaries with larger margins at the present time, are not automatically considered to be the most suitable solutions to cope with the demand from the new development for the 2020 time period. In Table 4-9 it is displayed the demand and the margin evolution for previous considered primaries, taking already into account the development demand for case considered

Table 4-9 – Demand and Margin evolution for primaries substations

Primaries	2015		2016		2017		2018		2019		2020	
	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin
E12 ST ANTHONY ST PRIMARY	18,9	3,2	19,3	2,8	19,7	2,4	20,0	2,1	20,4	1,7	20,7	1,4
E08 MILTON RD PRIMARY	20,2	1,9	20,4	1,8	20,5	1,6	20,6	1,5	20,7	1,4	20,8	1,3
E05 HISTON PRIMARY	20,7	1,4	21,0	1,1	21,3	0,8	21,6	0,5	21,9	0,2	22,2	-0,1

Just by assessing Figure 4-13, only two primaries substations appeared to be valid solutions, depending on the criteria of choice. E05 HISTON PRIMARY for the period of time considered, never showed to be a better solution than the other two, despite the “competitive” ratio in the first years, by 2019 the ratio evolves to a higher value and becomes negative by 2020 due to lack of available margin. As a short term and long term solution E12 ANTHONY ST PRIMARY and E08 MILTON RD PRIMARY stay very close in the period of time considered. Even then, ANTHONY ST PRIMARY shows a slightly better ratio till 2018, and then is overtaken by MILTON RD PRIMARY for the remaining years.

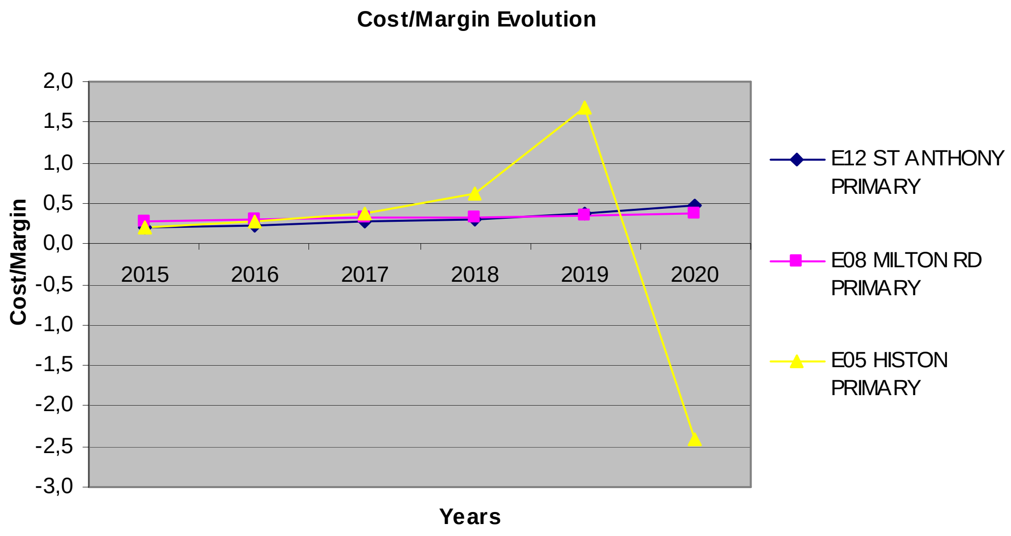

Figure 4-13 - Ratio Evolution for primaries on gas grid case

In this case the E12 ANTHONY ST PRIMARY has a ratio of 0.47£/MW and E08 MILTON RD PRIMARY a ratio of 0.39£/MW both by the year 2020.

4.4 - Risk Analysis

In every decision making, there is always a risk involved. The process of choosing a primary substation to connect a specific development is influenced by a wide range of assumptions that may not represent real life situation due to several reasons; the expected penetration of micro generation technologies may be influenced by it is economical feasibility due to lack of sponsoring and funding to turn these technologies more appealing to the general public, a general concern about possible economic crisis may lead the expected developments to be postponed, or to decrease the expected number of houses and jobs, thus reducing the expected demand. Therefore it is important to assess these decisions to a wider variation in the inputs in order to see the impact in the decision taken.

As specified in sub chapter 4.3 the developments will be submitted to two scenarios, the optimistic and the pessimistic scenario, in the chapters above, the simulation was a result from a set of inputs considered to be an optimistic scenario. In this sub chapter, another set of inputs considered to be a more constrained and pessimistic approach will be simulated and results will be compared.

4.4.1 - Off Gas Grid

For this scenario, other 3 case will be simulated:

Case 1:

Domestic

- 5% Energy Efficiency

Technologies

- 25% Micro Wind
- 25% PV
- 50% Biomass

Commercial

- 5% CHP

Factors

- Economic Concern
- 15%DSM
- 15% PV Factor
- 15% Micro wind Factor

Case 2:

Domestic

- 5% Energy Efficiency

Technologies

- 25% Micro Wind
- 25% PV
- 25% SWH

Commercial

- 5% CHP

Factors

- Economic Concern
- 15%DSM
- 15% PV Factor
- 15% Micro wind Factor

Case 3

Domestic

- 5% Energy Efficiency

Technologies

- 25% Micro Wind
- 25% PV
- 25% GSHP

Commercial

- 5% CHP

Factors

- Economic Concern
- 15%DSM
- 15% PV Factor
- 15% Micro wind Factor

In this 3 cases, lower values for demand reduction trough energy efficiency were considered in order to take into account the possibility of a slower uptake in adopting energy efficiency measures; supergen scenario of economic concern is considered, thus, according to the information specified in the model, penetration of micro generation technologies is considered to be reduced with exception made to biomass, which is considered to have a reasonably strong development. In commercial demand, a low value of reduction trough CHP is assumed, due to adoption is considered to only occur in establishments were heat is usually used for processes that have a stable demand for heat.

In tables 4-10, 4-11 and 4-12 the demand and margins for cases 1 2 and 3 respectively, will be displayed for the pessimistic scenario

Table 4-10 – Demand and Margin evolution for primaries substations for case 1

Primaries	2013		2014		2015		2016		2017		2018		2019		2020	
	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin
E04 LONGSTANTON PRIMARY	16,9	6,2	17,9	5,2	18,3	4,8	18,7	4,3	19,1	3,9	19,6	3,5	20,0	3,1	20,4	2,7
B49 OFFORD PRIMARY	14,9	8,2	15,9	7,1	16,4	6,7	16,8	6,2	17,3	5,8	17,7	5,3	18,2	4,9	18,6	4,5

Table 4-11 – Demand and Margin evolution for primaries substations for case 2

Primaries	2013		2014		2015		2016		2017		2018		2019		2020	
	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin
E04 LONGSTANTON PRIMARY	16,9	6,1	18,0	5,0	18,4	4,6	18,9	4,2	19,3	3,8	19,7	3,4	20,1	2,9	20,5	2,5
B49 OFFORD PRIMARY	15,0	8,1	16,1	7,0	16,5	6,5	17,0	6,1	17,4	5,6	17,9	5,2	18,3	4,7	18,8	4,3

Table 4-12 – Demand and Margin evolution for primaries substations for case 3

Primaries	2013		2014		2015		2016		2017		2018		2019		2020	
	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin
E04 LONGSTANTON PRIMARY	16,9	6,2	18,0	5,1	18,4	4,7	18,8	4,2	19,2	3,8	19,7	3,4	20,1	3,0	20,5	2,6
B49 OFFORD PRIMARY	14,9	8,1	16,0	7,0	16,5	6,6	16,9	6,1	17,4	5,7	17,8	5,2	18,3	4,8	18,7	4,4

From the data showed in previous tables, and comparing with the data for the optimistic scenario, it is possible to see that from SWH to GSHP and from GSHP to Biomass, the margin shows an increment of 0.1 MW by the year 2020. For both primaries, it is shown in Figure 4-14 the available margin by 2020 for each case in both scenarios. Case 1 showed to have the highest margin both in optimistic and pessimistic scenarios.

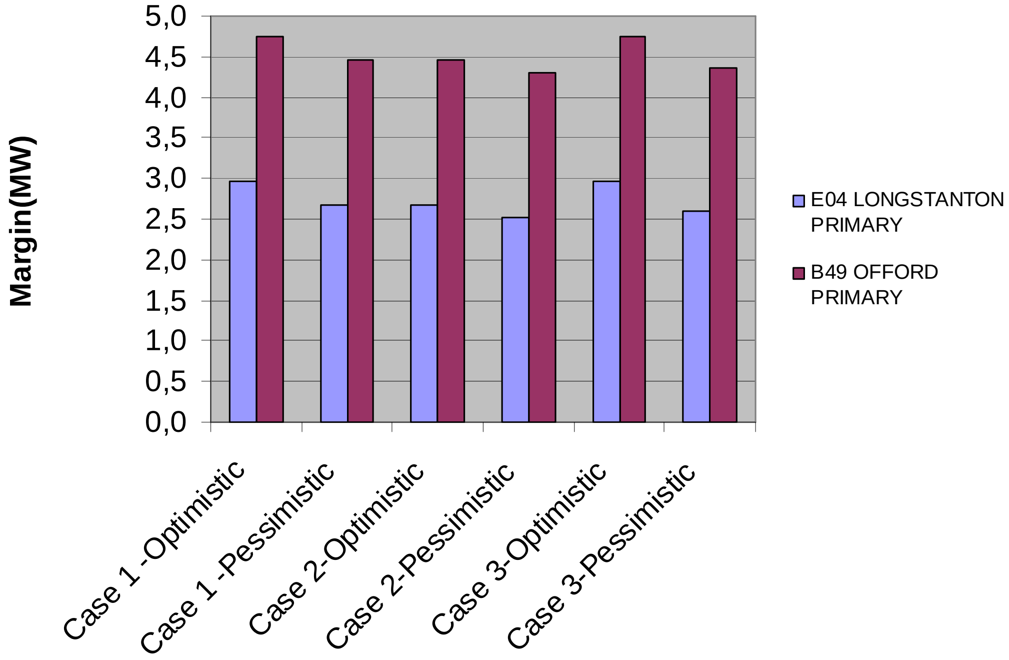

Figure 4-14 - Available margins for each case and scenario in selected primaries

For the selected primaries, the three cases from the pessimistic scenario were simulated in order to study how the ratios develop. By comparing these results with the ones from the optimistic scenario, it will be possible to evaluate how these changes in scenarios will impact the selected investment solutions in short and long term.

In Figures 4-16, 4-17 and 4-18 it is shown the ratio evolution for each case for the selected primaries.

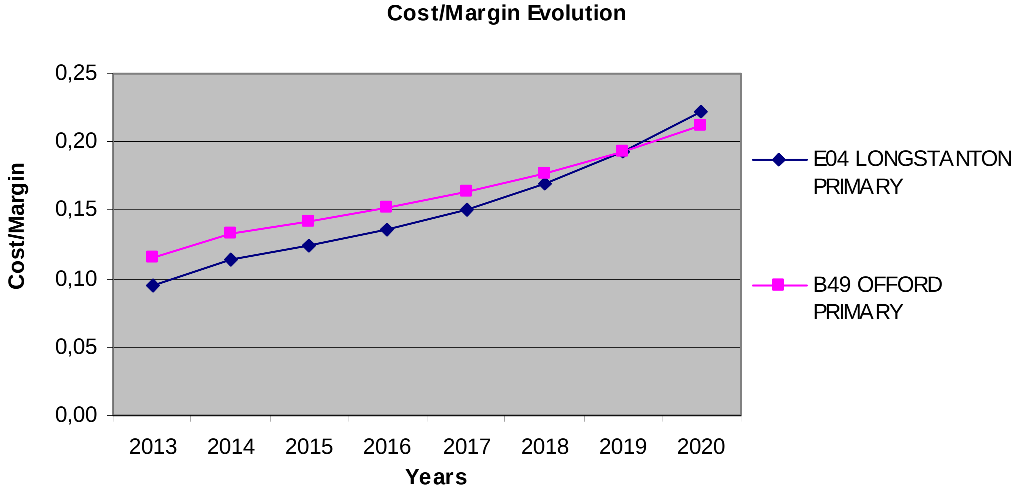

Figure 4-15 - Ratio evolution for pessimist scenario in case 1 for off gas grid

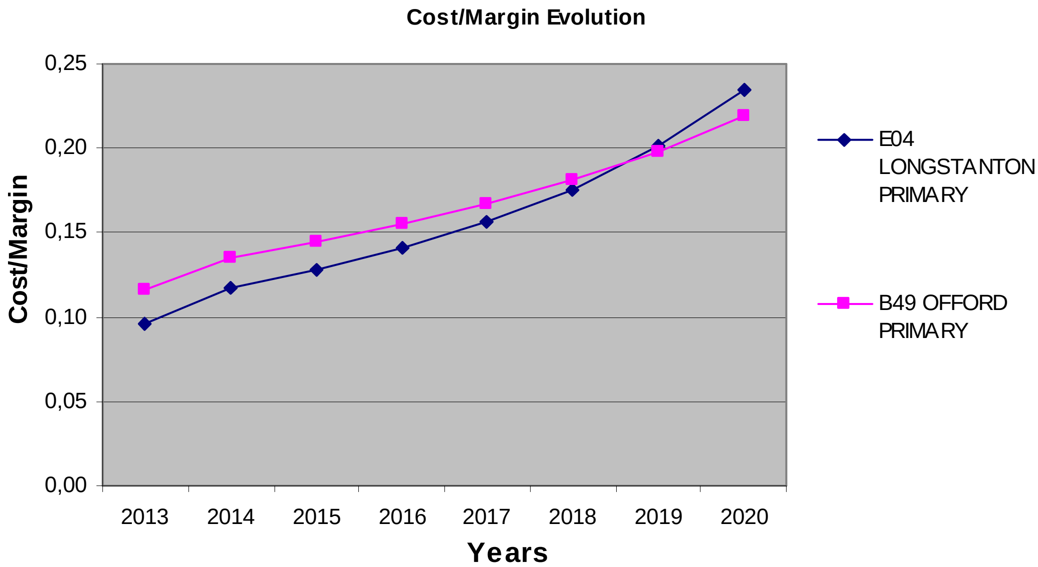

Figure 4-16 - Ratio evolution for pessimist scenario in case 2 for off gas grid

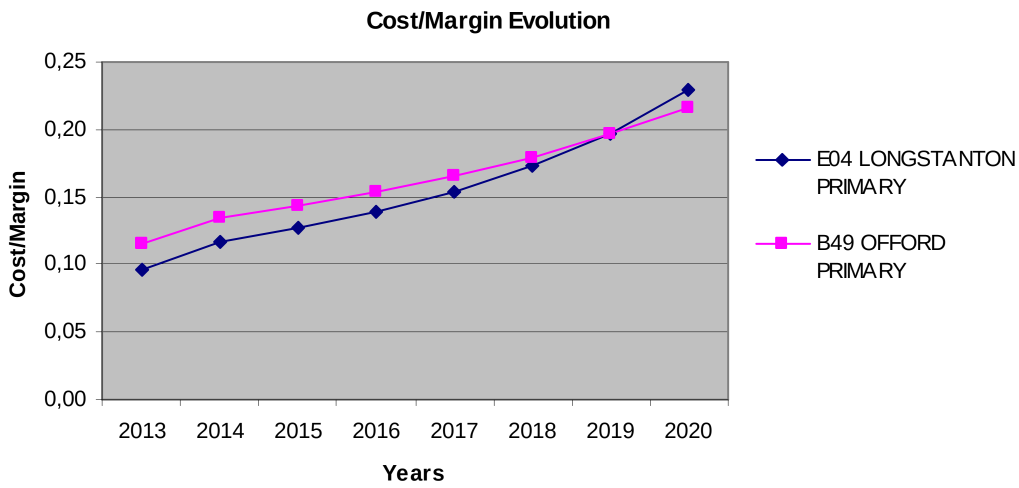

Figure 4-17 - Ratio evolution for pessimist scenario in case 3 for off gas grid

By comparing the graphics for pessimist scenario with the ones from the optimistic scenario, it can be noticed that for case 1, the change in scenario, caused a change from a one term solution to a two term solution. For the short term solution, E04 LONGSTANTON PRIMARY, showed to be the best one, with lower ratios from year 2009 to 2019 and B49 OFFORD PRIMARY appeared to be the best solution for the period 2019-2020. For case 2, the main change in the solution, in comparison with the optimistic scenario, was the decrease by one year of the short term solution, which means that instead of having a lower ratio till 2019; E04 LONGSTANTON's short term solution will be from 2009 till 2018. In case 3, a similar situation with case 1 occurs, the difference between them is that, for the year 2019, the ratios of both primaries are the same, resulting in E04 LONGSTANTON PRIMARY being the best solution till 2018. In 2019 both primaries are equally best solutions, and after 2019, B49 OFFORD PRIMARY, starts to be the best solution.

Another assessment was to quantify how much the difference of margin by the year 2020, between the two different scenarios, represent in terms of capital, this conversion is done by multiplying this difference with the ratio in 2020 in the pessimistic scenario; the usefulness of this consist in providing DNO's with information in how much capital could be drifted in order to sponsor and fund the uptake of technologies in new developments. This would represent a direct intervention from DNO's in trying to change what could be a pessimistic scenario into an optimistic scenario.

It is shown in table 4-13, for each primary, the conversion of margin to capital.

Table 4-13- Conversion of margin into capital

	Case 1	Case 2	Case 3
	Margin in Pounds (k£)	Margin in Pounds (k£)	Margin in Pounds (k£)
E04 LONGSTANTON PRIMARY	6,5	3,5	8,4
B49 OFFORD PRIMARY	6,2	3,2	8,5

4.4.2 - On Gas Grid

Case 1:

Domestic

- 5% Energy Efficiency

Technologies

- 25% Micro Wind
- 25% PV
- 25% MicroCHP

Commercial

- 5% CHP

Factors

- Economic Concern
- 15%DSM
- 15% PV Factor
- 15% Micro wind Factor

As in sub chapter 4.5.1, in this case the same considerations to all the inputs are used. Likewise in table 4-14 the demand and margins for cases 1 will be displayed for the pessimistic scenario.

Table 4-14 - Demand and Margin evolution for primaries substations for pessimist scenario in on gas grid zone

Primaries	2015		2016		2017		2018		2019		2020	
	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin
E12 ST ANTHONY ST PRIMARY	19,5	2,6	20,6	1,5	21,6	0,5	22,0	0,1	22,3	-0,2	22,7	-0,6
E08 MILTON RD PRIMARY	20,9	1,2	21,7	0,4	22,5	-0,4	22,6	-0,4	22,7	-0,5	22,8	-0,6
E05 HISTON PRIMARY	21,3	0,8	22,3	-0,2	23,3	-1,2	23,6	-1,5	23,9	-1,8	24,2	-2,1

From the data showed in previous table, and comparing with the results for the optimistic scenario, it is possible to see that the changes in both scenarios represent substantial increases in demand. For all primaries, it is shown in Figure 4-18 the available margin by 2020 for each case in both scenarios.

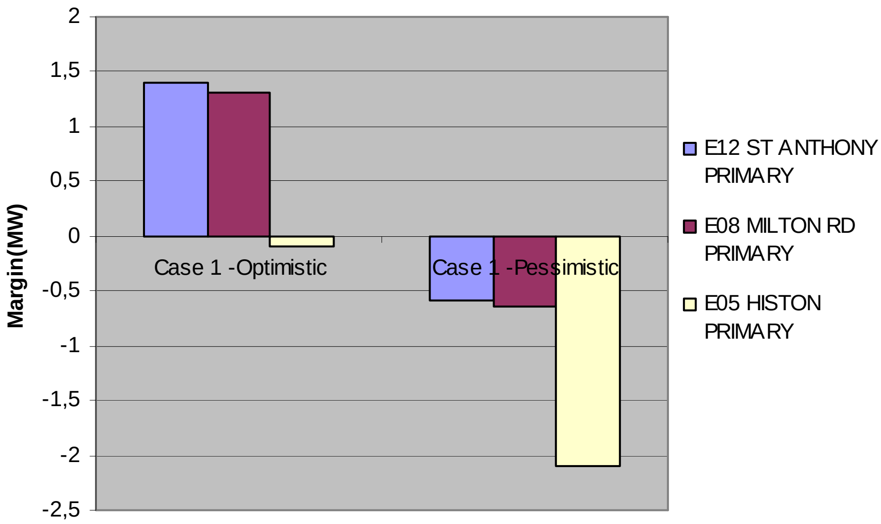

Figure 4-18 - Available margins for each case and scenario in selected primaries

In Figures 4-20 it is shown the ratio evolution for each case for the selected primaries

By comparing both graphics for ratio evolution it is clear to see a drastic change in available solutions. In the pessimist scenario only ST ANTHONY PRIMARY is capable of being connected to the development in the first years since the beginning of the development, however, in a long term view, none of the evaluated primaries show enough margin. In this situation two available options emerge, or a new primary substation is built in order to cope with the new demand or a wider distance range is considerate in order to search for further available primaries; both solutions require higher cost.

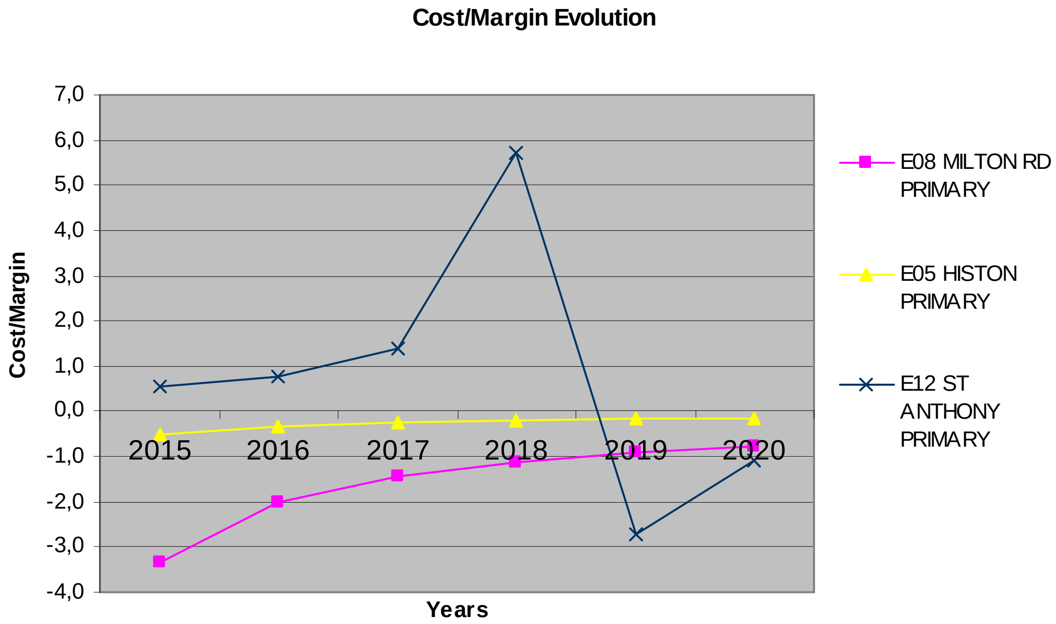

Figure 4-19 - Ratio evolution for pessimist scenario in case 1 for on gas grid

In this cases where studied primaries can't cope with the expected demand for the period of time considered, the conversion of margin into capital takes a different approach, this happens because the available capital for supporting the change of a pessimistic scenario into a optimistic scenario does not come from the difference of margin for each scenario but comes from the cost of investment for connecting the development to longer primaries, or by the cost of investment of building a new primary.

4.5 - Summary

The case study simulated has shown the differences between expected impacts for the selected micro generation technologies. Due to the high level view of the model developed, the two scenarios (pessimistic and optimistic) were created in order to reach as wide as possible the consequences of two distinguish and opposite views of what could be happening in new developments in the near future. In the study case it has been shown that indeed, the uptake of micro generation technologies and more efficient attitudes can make a difference in asset maximization in a distribution level not just by postponing the expected year of maximum capacity by primaries substations but also by giving the information of which one gives DNO's the best ratio between margin and connection cost.

Chapter 5

Conclusions and Future Work

This final chapter provides a summary and conclusion of the work done in modelling and analysis for strategic investment on sustainable electricity networks on a rural environment and provides a list of suggested further work that can be carried out, building on the foundation that this work has laid down.

5.1 - Introduction

The aim of this research was to analyse and evaluate the impact of micro generation technologies on rural areas and how they will affect the network on a distribution level and risk assessment of the technical solutions.

In this project, the impact of micro generation technologies in new developments was modelled and a calculation tool was developed using MS Excel and the Visual Basic Editor. The tool was used to evaluate the capability of existing primary substations to be connected to new developments, taking also into account the possibility of a high penetration of sustainable technologies and measures to be adopted in these new developments. The model is explained in detail in Chapter 3.

5.2 - Technical Conclusions

After modelling the impact of micro generation technologies, the developed tool was used in a real study case. Due to the specificities of several considered technologies, two developments were chosen according to the availability of gas connection. In a Rural Zone with gas connection it was concluded that the most likely technologies to have a strong development were the micro wind generators, photovoltaic panel for electricity purposes and microCHP technologies for heating purposes, having this technology the plus of also contribute to the electricity output. For rural zones without gas connection, al major technologies for electricity (PV and micro wind) and heating purposes, (biomass, solar water heating and ground source heating pumps) were considered to be suitable, this happens because the lack of gas supply wouldn't enable microCHP to be a economically interesting technology.

The results for this zones, showed that heating technologies would have a higher impact in reducing demand from the perspective of a distribution network, this happens because this technologies show a less intermittent profile in comparison with technologies such as Photovoltaic and Micro Wind generators which showed only to have a marginal impact in the expected reduction of demand seen by primaries substations.

The risk assessment for the technical solutions, demonstrated that investment should be made in order to stimulate the uptake of micro generation in new developments. A higher uptake in micro generation would lead to maximization of the existing assets, in particularly primary substations, or by delaying the need of reinforcement or just by increasing available margins. In cases where new primaries are inevitable, the use of a micro generation can imply the delay of major investments for several years which in a regulated business such as distribution is of great importance.

5.3 - Limitations and Suggestions for Further Work

The current model requires running ARCGIS as a standing alone program first in order to gather information, this information then needs to be processed so it can be loaded into the Excel model. It may be more efficient to combine both programs into one in order to program can run smoothly in a larger scale area.

Due to its complexity, developments are considered to connect to only one primary. The simulation also assumes that in case of negative load, and by negative load we mean loads flowing in the opposite direction, no reinforcement in the network is considered. Due to constraints of time, the evaluation of loss reduction by onsite generation was not realised. Due to his "high level" nature, this model does not take into consideration the specific machinery schemes, lines and cables adopted and their limitations

The following further work is suggested:

- The use of targeted investments to balance the supply and demand for network services. For example network reinforcement investments versus energy efficiency, loss reduction;
- Understanding the sources and nature of demand growth to help identify practicable and cost-effective demand-related measures that could defer larger capital investments. For example, examination of load duration curves for the areas where

network capacity is approaching its limits in relation to the likely demand offsets that would be realised by the introduction of demand side measures;

- The implications and opportunities associated with specific policy measures such as building of large number of zero-emission homes;
- Use of GIS based solutions to display information on wind speeds and sun radiation and therefore optimize the selection of technologies in selected areas;
- Improving information related to the expected contribution of intermittent micro generation technologies in demand peaks;
- Model development for network management, taking into account decentralization polices and bidirectional production in distribution network.

References

[1] J Lassila, S. Honkapuro, J. Partanen," Distribution network investment strategies in the new business environment," in *Power Engineering Society General Meeting,* 2006

[2] OFGEM, "Regulation of Independent Electricity Distribution Network Operators," 2004 [Online] http://www.OFGEM.gov.uk [Mar 27, 2008]

[3] HM Government, "Energy White Paper 2007, " [Online] http://www.berr.gov.uk/files/file39387.pdf [Mar 27, 2008]

[4] HM Government, "Climate Change the UK Programme 2006," [Online] http://www.defra.gov.uk [Mar 27, 2008]

[5] EDF Energy Networks, "Statement of Basis and Methodology of Charges for Connection to the Electricity Distribution System," 2007

[6] OFGEM, "Electricity Distribution Cost Review 2005-2006," 2007 [Online] http://www.OFGEM.gov.uk/ [April 11, 2008]

[7] Directive 2002/91/EC of the Parliament and the Council, "The limitation of emissions of certain pollutants into the air from large combustion plants", 2001

[8] Redpoint Energy, "Dynamics of GB Electricity Generation Investment: Prices, Security of Supply, CO2 Emissions and Policy Options," 2007 [Online] http://www.berr.gov.uk/files/file38972.pdf [Apr 23, 2008]

[9] HM Government, "Energy White Paper 2003: Our Energy Future, Creating a Low Carbon Economy," 2003 [Online] http://www.berr.gov.uk/files/file10719.pdf [Mar 27, 2008]

[10] Renewables Advisory Board, "The Role of Onsite Energy Generation in Delivering Zero Carbon Homes," 2007, [Online] http://www.renewables-advisory-board.org.uk/ [April 1, 2008]

[11] Directive 2002/91/EC of the Parliament and the Council,"The energy performance of buildings," 2002

[12] HM Government, "Utilities Act 2000", 2000, [Online] http://www.opsi.gov.uk/ [April 30, 2008]

[13] National Grid, [Online] www.nationalgrid.com [May 11, 2008]

[14] Vincent de Rivaz EDF Energy CEO, *Distribution Price Review 2005 conference*, 2005, [Online] http://www.amicustheunion.org/ [April 1, 2008]

[15] R Cousens, T Steinberg, B White and S Walton, "Generic Scenarios – A Strategic Futures Paper," December 2002, [Online] http://interactive.cabinetoffice.gov.uk [May 11, 2008]

[16] I Elders, G Ault, S Galloway, J McDonald, M Leach, E Lampaditou and J. Köhler (2006). Electricity network scenarios for the United Kingdom in 2050, in T. Jamasb, W.J. Nuttall and M.G. Pollitt (eds), Future Electricity Technologies and Systems, Cambridge: Cambridge University Press.

[17] G Ault, I Elders, J Macdonald, G Burt, R Tumilty, "Supergen: Electricity Network Scenarios for 2020," 2006, [Online] http://www.supergen-networks.org.uk/ [April 1, 2008]

[18] Foresight, "Energy for Tomorrow - Powering the 21st Century," September 2001, [Online] http://www.foresight.gov.uk/Drumbeat/Energy/Energy_For_Tomorrow_Sep_2001.pdf [May,11 2008]

[19] International Energy Agency, "Distributed generation in liberalised electricity market," IEA Publications, 2002

[20] http://www.eere.energy.gov/de/about.html [May, 20 2008]

[21] Directive 96/92/EC of the European Parliament and the Council, "Concerning common rules for the internal market in electricity," 19 December 1996~

[22] European Network for the Integration of Renewables and Distributed Generation, "Addressing barriers to sustainable electricity supply," 2004

[23] Ellesmere and Port Neston Borough Council, "Designing for Energy Efficiency – Renewable Energy," 2008, [Online] http://consult.epnbc.gov.uk/ [May 1, 2008]

[24] Energy Saving Trust, "Potential for Microgeneration - Study and Analysis," 14 November 2005

[25] Communities and Local Government, "Code for Sustainable Homes: Technical Guide," 2008[Online]http://www.planningportal.gov.uk/ [May 1, 2008]

[26] The Impee Project, "Domestic Energy Use and Sustainability," University of Cambridge, 7 July 2006

[27] The Carbon Trust, "Information on energy efficiency in non-domestic buildings," [Online] www.thecarbontrust.co.uk

[28] Photovoltaic – British Photovoltaic Association, [Online] www.pv-uk.org.uk [May 2, 2008]

[29] NHBC Foundation, "A Review of Microgeneration and Renewable Energy Technologies," 2008

[30] DTI, "System Integration of Additional Microgeneration," 2004

[31] Solar thermal – Solar Trade Association, [Online] www.solartradeassociation.org.uk [May 2, 2008]

[32] B Boardman, S Darby, G Killip, M Hinnells, C Jardine, J Palmer, G Sinden , *40%House*, ISBN 1 874370 39 7, Environmental Change Institute, February 2005

[33] Wind turbines (small scale) – British Wind Energy Association, [Online] www.bwea.com [May 5, 2008]

[34] J Watson, R Sauter, B Bakr, P James, Myers Luke, R Wing, "Unlocking the Power House: Policy and System Change for domestic micro-generation in the UK," Imperial College, University of Sussex, University of Southampton, October 2006

[35] Heat Pump Association, [Online] www.feta.co.uk [May 5, 2008]

[36] Ground source heat pumps – The UK Heat Pump Network, [Online] www.heatpumpnet.org.uk [May 11, 2008]

[37] Biomass – NEF Renewables – logpile [Online] www.greenenergy.org.uk/logpile [May 11, 2008]

[38] EDF Energy, "Network Asset Management Plan," 2007

[39] Energy Saving Trust," Meeting the 10 per cent target for renewable energy in housing – a guide for developers and planners," March 2006

[40] B Basset, "High-level Model for forecasting demand growth and associated load-related expenditure," EDF Energy, 17 March 2008

Appendix A

Inputs Sheet

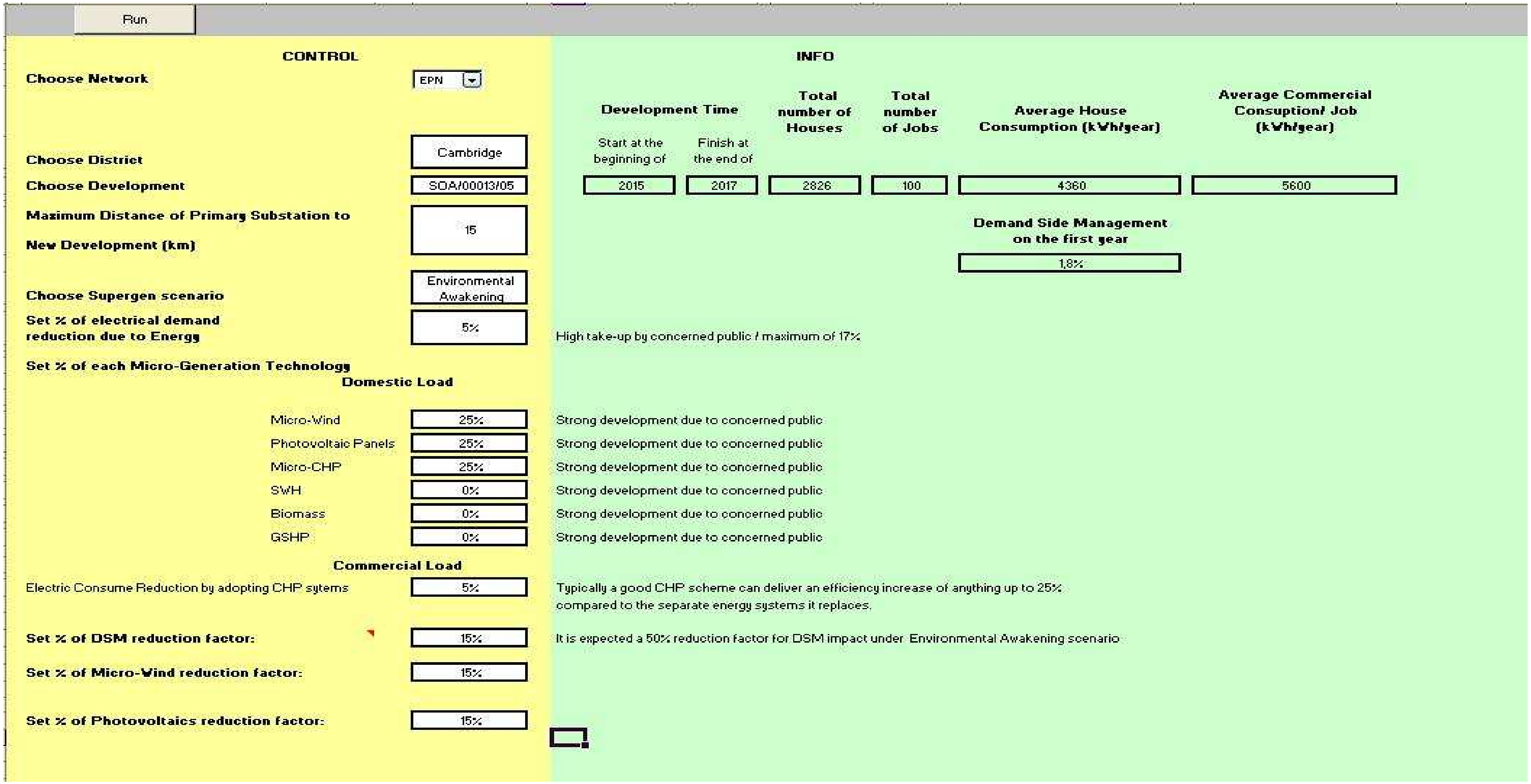

FIGURE A-1 – INPUTS SHEET