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

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Abstract

Distribution Network Operators (DNO's) are identities that are responsible to operate the electric distribution network and provide customers with electricity supply. Besides the primary gold of supply all the consumers in the most effective and quality way, DNO´s are also responsible and should respond to challenges like climate change, affordability of energy and security of supply. These issues are deeply connected with the long-term well-being of society.

In the coming years, as load growth on UK's national electric system, DNO's will need to do network extensions and infrainstructure reinforcement. So, this study has as his major concern elaborate techniques which enables DNO's to obtain the best investment solution in a distribution network for a certain new development analyzed.

The model developed within the elaboration of this study will focus on the impact that demand side management programmes, energy efficiency measures and micro-generations technologies such solar electric photovoltaic, solar thermal hot water, micro-wind, ground source heating pumps, biomass, micro-combined heat and power systems have on reducing the electric demand from a certain new development.

As a study case, it will be analyzed the impact that the previous programmes, measures and technologies have on urban networks. It was made a research in order to understand the suitability of each micro-generation technology for implementation at urban developments.

A sensitive analyses of the developed model is made, for its appliance at urban developments, and several future scenarios were simulated in order to quantify and understand the impact that micro-generation technologies, energy efficiency measures and DSM programs have on reducing the electric development demand and then, determinate a cost effective investment solution for connecting the new development loads to the existing primaries substations.

Once that the analysed investment solutions can represent massive investments for DNO´s to make, the study here presented can provide an interesting toll for determinate the impact that the adoption, at new urban developments, of micro-generation technologies, DSM

programmes and energy efficiency measures could possibly have. This gives DNO's the possibility to know what measures or programmes they could support in order to favour the expansion of some kind of micro-generation technologies or energy efficiency measures and obtain a better investment solution for an expected development at an urban environment.

The consideration of the impact that the adoption at new developments of micro-generation technologies, DSM programmes and energy efficiency measures was made and analysed in this study because it is expected for these measures and technologies to have a great impact at a medium long term period due to the fact that U.K. government wants to encourage a greater uptake of distributed generation in a bid to turn the country into a low carbon economy. To this end, it is planned and expected a comprehensive review of the incentives and barriers affecting distributed electricity generation, to be carried out jointly with the electricity and gas Great Britain regulator, OFGEM. It is expected to be examined issues such as the economic and other incentives for suppliers to buy electricity from distributed generators as well as examined the potential barriers to installing distribution generation, such as licensing procedures and technical standards for connection.

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Table of Acronyms

CHP- Combined Heat and Power

DE- Distributed Energy

DNO- Distribution Network Operator

DSM- Demand Side Management

EPN- East Power Network

EQ- Equation

EU- European Union

GIS- Geographic Information Systems

GSHP- Ground Source Heating Pumps

LPG- Liquefied Petroleum Gas

LPN- London Power Network

OFGEM- Electricity and Gas Great Britain Regulator

PF- Power Factor

PV- Photovoltaic Panels

P.S. - Primary Substation

SPN- South East Power Network

SPRU- Science and Technology Policy Research University of Sussex

SWH- Solar Water Heating

UK- United Kingdom

Chapter 1

Introduction

In this chapter, the background of the elaborated study will be presented and a generic overview of the items described below will be made, in order to allow the reader a global idea of the proposed study. So, in this chapter, the addressed topics will be:

•Social overview;

•Motivations of preset study;

•Investment strategy for sustainable electricity distribution networks technical challenges;

•Investment strategy for sustainable electricity distribution networks eventual benefits.

A brief description of each chapter presented at this study will also be made within this chapter, highlighting the major objectives of each one.

1.1 - Social Overview

Distribution Network Operators (DNO's) are identities that are responsible to operate the electricity distribution network and provide customers with electricity supply. Besides the primary gold of supplying all the consumers in the most effective and quality way, DNO´s are also responsible and should respond to challenges like climate change, affordability of energy and security of supply. These issues are deeply connected with the long-term well-being of society. In simple terms it means living now in a way that gives all people, including future generations, the same or greater freedoms, resources and lifestyle choices that we enjoy today.

For DNO's these social issues could possible mean:

• Advance their commitment to corporate responsibility, ensuring the balance of their impacts on society and the environment is positive;

• Offer new products and services for the changing world in which social and environmental concerns are as important as financial ones;

• Think and act for the long term.

This study will mainly focus this last point that is: “Think and act for the long term.”, but having always in mind the actual energetic concerns. So, with the elaboration of this study, there will be developed a model to determinate possible investment strategies for sustainable electricity networks and then a study case for applying the developed model for urban environments networks.

1.2 - Motivations of preset Study

In the coming years, as load growth on UK’s national electric system, DNO’s will need to do network extensions and infrainstructure reinforcement. So, this study has as his major concern elaborate techniques that enables DNO’s to obtain the best investment solution for a distribution network in a certain area in a specific date (the forecast that is made is for investments that are needed in a medium-long time period). In order to plan electric power delivery systems, DNO’s must know how much power it will be expected to serve, and where and when that power must be delivered. Such information is provided by a spatial load forecast tool, in this work the software used was Geographic Information Systems (GIS). This software enables the user to have several information related with the future developments that are expected for a specific territory. Growth is expected in many areas where load already exists- facilities in those areas may need enhancement to higher capacity. Growth is also expected in many areas where no electric demand currently exists. There, DNO’s will need to install new equipment and facilities. Equally important, growth will not occur in many other areas- facilities built there would be wasted. And in minority areas, peak electric demand may actually decrease over time.

Effective planning of electrical energy systems requires such information to be taken into account, both to determine the least-cost plan to meet future needs and in order to assure that future demand can be met by the system as planned.

Considering the load growth in specific parts of the network, it is expected, therefore, that efficient capital investment will become a great issue for UK’s DNO’s. So, in addition, there is an increasing recognition of the role that electricity networks have for achieving sustainable electricity systems and security of supply.

DNO’s are either directly or indirectly implicated in many elements of the current policy debate, including areas such as network energy losses, smart meters, micro-generation and energy efficiency.

The U.K. government release a document called “Meeting the Energy Challenge: A White Paper on Energy”. This document show the major UK’s environmental concerns related with the use and consumption of energies. By analysing this document it is possible to understand the major importance in the future years to use energy efficiency measures and micro-generation technologies. [1]

Quoting the same document:

“

Energy is essential in almost every aspect of our lives and for the success of our economy. We face two long-term energy challenges:

• tackling climate change by reducing carbon dioxide emissions both within the UK and abroad; and

• ensuring secure, clean and affordable energy as we become increasingly dependent on imported fuel.

As we set out in The Energy Challenge published in 2006, the context in which we are seeking to meet these challenges is evolving, in particular:

• the growing evidence of the impact of climate change and wider international recognition that there needs to be a concerted global effort to cut greenhouse gas emissions, especially carbon dioxide;

• rising fossil fuel prices and slower than expected liberalisation of EU energy markets at a time when the UK is increasingly relying on imported energy;

• heightened awareness of the risks arising from the concentration of the world’s remaining oil and gas reserves in fewer regions around the world, namely the Middle East and North Africa, and Russia and Central Asia;

• in the UK, companies will need to make substantial new investment in power stations, the electricity grid, and gas infrastructure.

”

Consulting this governmental release, White Paper [1], is easy to understand the reason why incentive regulation of capital investment needs to adopt mechanisms that encourage the DNO’s to:

(i) consider a wider an innovative range of options in their investment decisions;
(ii) balance the trade-offs between these;
(iii) pursue long-term socio-economically efficient investments.

As an example, the expected demand growth in specific parts of the network may be addressed by investment in new infrastructure capacity and the facilitation of distributed generation. The model developed will focus on the impact that demand side management programmes, energy efficiency and micro-generations technologies such solar electric photovoltaic, solar thermal hot water, micro-wind, ground source heating pumps, biomass, micro-combined heat and power systems have in the energy demand at the electrical network in a certain area. As a study case, the model will be applied in urban environments and the conclusion presented.

1.3 - Investment strategy for sustainable electricity distribution networks Technical Challenges

The main challenge for develop an investment strategy for sustainable electricity distribution networks is dealing with several circumstances that are not possible to take for shore. As this strategy is developed to work till the 2020 year, there are circumstances like the exact number of houses that are expected to be built in the considered area and if their are gone adopt energy efficiency measures and micro-generation or not. To deal with that different possibilities and uncertainties it will be considered four different scenarios.

Scenarios have proven themselves as a useful tool for considering long-term future developments in the face of uncertainty. In this particularly case, tit will be considered on the development of the model of Investment Strategy for Sustainable Electricity Distribution Networks four different scenarios:

- Continuing Prosperity;
- Environmental Awakening;
- Supportive Regulation;
- Economic Concern.

These scenarios were defined by Supergen Network Technologies Consortium and further detailed information can be found in their report released in July 2006 [2].

The common objective of these scenarios is their attempt to understand some aspects of an uncertain future through the use of differentiated approaches. So, in itch scenario formulation were considered different implementations of measures like energy efficiency and micro-generation technologies for the same development area at the same period of time.

The referred scenarios are used to paint a picture of possible futures that could occur, but these should not be viewed as forecasts. A good set of scenarios will, between them, present many of the possible developments in the future without prescribing any likelihood to any of the outcomes. Their value is in their combined view of the future and no one scenario should be viewed as the likely outcome or preferred outcome, i.e., each one of the scenarios present a plausible future on its own right.

Once specified the pretended Supergen scenario and the implementation of energy efficiency measures and micro-generation technologies, the model developed in this study will give the user the best investment solution in terms of connecting the new loads (referent to the chosen new development) to a primary substation that is available to supply the referred loads. If there is not a primary substation within a pretended distance from the new development area that is available to supply the pretended demand, the option of building a new one has to be considered.

1.4 - Investment strategy for sustainable electricity distribution networks : Eventual Benefits

The main propose of the model developed in this study is give the user the best option for connecting the new loads from a new development to a primary substation. So, the main benefits are that DNO's, by using this model, can have a prediction of the investment they possible have to make in the future, in order to supply the new developments that are expected to happen till 2020.

As a study case, the model application for urban developments was analysed and some forecasts for the availability and expected impact of the considered micro-generation technologies were made and several scenarios (considering different percentages of each micro-generation technology implemented and other distinct factors further detail on section 4.1) were simulated in the model, in order to give a wide perspective of the impact on the development electrical demand and consequently in the investment that will be need to be made by the DNO.

So, one possible benefit of the study here presented, is according to the investment predicted for the different scenarios simulated, the possibility for DNO´s supporting or not some kind of programs that favour the expansion of the adoption of energy efficiency measures and micro-generation technologies in order to reduce or optimise the investment predicted by the model.

1.5 - Brief Resume of Chapters presented at the study

1.5.1- Chapter Two: Literature Review

In this chapter, a research of the more relevant literature to the proposed study was made and the contribution of each one is presented. This chapter will provide the reader with the appropriate theoretical background, given by the analysed bibliographic references, to understand the approach made for the formulation of the model for Investment Strategies for Sustainable Electricity Networks and its application at an urban environment.

1.5.2- Chapter Three: Model for Investment Strategies for Sustainable Electricity Networks

In this chapter a detailed explanation about the conception, structure and results obtained with the developed model in this study will be made.

With the model presented, is proposed the achievement of the best investment solution that DNO's have to make in order to supply the new developments that are expected to happen in U.K. till the year 2020. Therefore, this chapter will provide the reader with the appropriate theoretical background critical to understanding the approach made by this model for Investment Strategies for Sustainable Electricity Networks.

1.5.3- Chapter Four: Investment Strategies for Sustainable Electricity Networks - Urban Environments

This chapter will address the main issues and results obtained by using the presented model at new developments that are expected to happen within urban environments.

Although the developed model could be both used for urban or rural developments, each one of these environments have specific constrains and the main ones for the application of this model at urban environments will be exposed within this chapter. Sensitivity analyses of the results achieved with the model as well as an investment and risk assessment for the investment solutions obtained will also be presented.

1.5.4- Chapter five: Conclusions and Future Work

This chapter presents the main concerns and conclusions obtained with the elaboration of the proposed study. The main limitations noted during the elaboration of this study as well as the future work that could possibly be done in order to improve this same study are also presented within this chapter.

Chapter 2

Literature Review

In this Chapter there will be briefly introduced the formulation of the model for Investment Strategies for Sustainable Electricity Networks and in the subsequent sections, it will be discussed several crucial topics for the proper understanding of the developed study. So, those sections will be:

• Actual Energetic Concerns;

•Electricity Network Scenarios;

•Micro-Generation Technologies, Energy Efficiency and Demand Side Management Programmes;

•Study Case: Appliance of the developed model to an urban environment.

In each section, a research for the most relevant literature for each theme was made and the evaluation of their contribution for this specific study is presented in several references.

This chapter will provide the reader with the appropriate theoretical background to understand the approach made for the formulation of the model for Investment Strategies for Sustainable Electricity Networks and its application at an urban environment.

2.1 – Investment Strategies for Sustainable Electricity Networks on an Urban Environment: Problem description

The model presented in this study was developed in order to try to find the best investment solutions to connect the loads from a new development to a primary substation. This model incorporates the expected impact that certain micro generation technologies, energy efficiency measures and DSM programs have in the demand of the new development.

This fact is considered to be innovative because, despite the fact of the existence of numerous publications and reports about the importance of these technologies and measures in a medium-long term (governmental [1] and European [3] releases), there is a gap between all the intentions and previsions for the adoption of these measures and technologies and the real expected impact of those in the networks. This model takes into account these measures and technologies and a prediction of the impact of those in a development demand is made. So, the usefulness of the developed model is that, as load growth on UK's national electric system, in the coming years, DNO's will need to do, for certain areas, network extensions and infrastructure reinforcements and the model developed in this study could be an important tool to predict possible investments in terms of connecting new loads to existing primaries substations.

In order to plan electric power delivery systems, DNO's must know how much power it will be expected to serve, and where and when that power must be delivered. That information, needed for the model databases, is provided by a spatial load forecast tool, in this work the software used to provides that kind of information was Geographic Information Systems (GIS). This software does a prediction of future development in a specific area throw the years [4]. In this study, the prediction of consumes in a new development area, is made till the year 2020. As is easily understandable, even having a forecast of the number of houses that are expected to be built in that certain area for that period of time (that information is given by GIS), the implementation of micro generation technologies and energy efficiency measures in each new development and even the house growing may vary according to different economical and social scenarios.

Indeed, in this study where considered four different socio-economic future scenarios:

Indeed, in this study where considered four different scenarios:

- Continuing Prosperity;
- Environmental Awakening;
- Supportive Regulation;
- Economic Concern.

Each scenario was formulated considering a different propagation of efficiency energy measures and appliances of micro-generation technologies. The energies measures and the micro-generations technologies adopted for the method that was developed, where selected among several. As energy efficient house, was considered a house in which energy efficient measures prove to save at most 17% of the total electrical energy consumed [5]. The micro-generation technologies considerer where:

- Solar Electric Photovoltaic Panels;
- Solar Thermal Hot Water Systems;
- Micro-Wind Turbines;
- Ground Source Heating Pumps;
- Biomass Boilers;
- Micro-Combined Heat and Power Systems.

All this technical information was gathered from several websites and bibliographic references, and a critical analyse of that information will be made later on this chapter (section 2.4).

The model developed in this study to find the best investment solution in a certain new development area, gives as an output some possible investments solutions. Those investment solutions are related with the options that exist in terms of connecting the new loads from a new development to the several existing primaries substations. The option of build a new primary substation has to be also considerer in the cases that the existing ones, within a certain area of the new development (this option is selected on the model), are not capable to supply the loads of the new development area.

2.2 – Actual Energetic Concerns: Energy Efficiency and Micro-generation technologies

In this section the overview of UK's and EU's major concerns in terms of energy efficiency and micro generation will be discussed. These issues have a major impact on the study here present in terms of understanding the pretended impact that these technologies and measures could have in a medium-long term on electric systems, in this particularly case, the impact on the demand reduction of new developments. Therefore, the approach of the UK government and EU commission visions will be presented.

"Over the next two decades, the UK will need substantial investment in new electricity generation capacity to replace a number of closing coal, oil and nuclear power stations and to meet expected increases in electricity demand. We want to ensure we have an investment framework which encourages investment to come forward at the right time and as much as possible in low carbon forms of generation."[6]

2.2.1 – Micro-generation Technologies

There are many uncertainties about the future and it is not possible to know today which mix of electricity generation technologies will be the most appropriate for delivering UK's energy policy goals over the medium to long-term. If in seventy's the green energy was considered a utopia and treated as a dream of scientists, the situation was changed over the years and the vision of "a future of renewal energy" has become a subject of debate.

While it may appear that Europe has been benefiting from a relative abundance of energy since the 1986 rebound from the oil crisis, thanks, in particular, to the nuclear power programme of some countries such as France, Belgium and Spain, or the penetration of natural gas into important markets like heating and electricity, the future might be less reassuring [7]. The internal energy resources which nowadays cater for half of the needs are drying up, whereas consumption is increasing. If no action is taken in the next 20 to 30 years, the environmental impact of energy will be untenable and the European Union external energy dependence will rise to a level of 70 % on average, going up to 90 % in the case of oil products [7]. This situation makes EU vulnerable, particularly on account of economic dependence on certain types of energy, such as oil and gas, and on particular exporting countries, such as Russia for natural gas and the Middle East for oil. What is more, energy production and consumption in fact account for almost all the man-made emissions of carbon dioxide into the atmosphere [7]. Minimizing emissions of CO2 is a major objective of EU and his entire Member States as United Kingdom. So, the development of renewable energy - particularly energy from wind, water, solar power and biomass - is a central aim of the European Commission's energy policy [3]. Increasing the share of renewable energy in the energy balance enhances sustainability. It also helps to improve the security of energy supply by reducing the Community's growing dependence on imported energy sources. Renewable energy sources are expected to be economically competitive with conventional energy sources in the medium to long term. The need for Community support for Renewable Energy is clear. Several of the technologies, especially wind energy, but also small-scale hydro power, energy from biomass, and solar thermal applications, are economically viable and competitive. The others, especially photovoltaic (silicon module panels directly generating electricity from the sun’s light rather than heat), depend only on (how rapidly) increasing demand and thus production volume to achieve the economy of scale necessary for competitiveness with central generation [3].

The European Commission's White Paper for a Community Strategy sets out a strategy to double the share of renewable energies in gross domestic energy consumption in the European Union by 2010 (from the present 6% to 12%) including a timetable of actions to achieve this objective in the form of an Action Plan [1]. The main features of the Action Plan include internal market measures in the regulatory and fiscal spheres; reinforcement of those Community policies which have a bearing on increased penetration by renewable energies; proposals for strengthening co-operation between Member States; and support measures to facilitate investment and enhance dissemination and information in the renewable field. The expected importance on UK´s energetic plan of micro generation technologies is high, and several reports and studies reinforce that idea:

“Given the urgency of delivering a major reduction in carbon dioxide emissions, a strategic approach to planning for energy in new and existing urban areas is essential. On the supply side, a low carbon, urban energy strategy should mandate greater use of renewables and Combined Heat and Power (CHP). On the demand side, reduction of energy use and greater conservation must be encouraged.” [8]

“We recommend that the new Planning Policy Statements on Climate Change require all new developments beyond a certain size to incorporate a strategic approach to energy planning and provision, that takes all opportunities to optimise the use of low carbon technologies, renewables, microgeneration and Combined Heat and Power, as appropriate, and in sympathy with air quality management objectives.” [9]

“Research shows that a 60% reduction in CO2 emissions from housing would be technically possible through a combination of major improvements to the building fabric (for example, cavity wall and roof insulation, draught proofing windows, and insulation of floors and solid walls throughout the housing stock), substantial increases in the energy efficiency of lights and appliances, and the installation of low and zero carbon technologies (LZCs)51 to provide renewable energy to buildings (figure 5-II). The combination of measures will be important – any one of these interventions on its own will not be sufficient.” [10]

"Household microgeneration installations which have little or no impact beyond the host property will be permitted development (ie removing the need for specific planning consent)" [11].

2.2.2 - Energy Efficiency

Other extremely important issue nowadays is energy efficiency. Improve energy efficiency whilst at the same time increasing the use of renewable energies can be a key issue to solve environmental, self-sufficiency, cost problems and adequately provide for increasing energy demand without major upheavals. This is especially true when seen in the light of the Kyoto Agreement to reduce CO2 emissions, where improved energy efficiency will play a key role in meeting the EU Kyoto target in an economic way. [12]

The Green Paper on Energy Efficiency points to the fact that the EU could save at least 20% of its present energy consumption in a cost-effective manner, equivalent to EUR 60 billion per year [13]. Otherwise White Paper states that in UK by adopting energy efficiency measures, the average household could avoid emissions of around 0.5 tonnes of carbon a year [14], [15]. In fact, UK's Government commitment with energetic issues seems to be real. Quoting a White Paper statement:

"The Government's intention is that, by the end of the next decade, all householders will have been offered help to introduce energy efficiency measures, with the aim that, where practically possible, all homes will have achieved their cost-effective energy efficiency potential."[16]

In order to achieve the target enumerated in the previous statement, is possible to enumerate some of energy efficiency measures/polices that UK's Government intent to adopt. (All this measures are described in more detail at White Paper [1]).

So, UK's Government:

- is working with retailers and manufacturers to phase out energy inefficient light bulbs by around 2011, and is publishing with White Paper proposals for higher standards in consumer electronics [14].

- will empower consumers to make more informed energy choices by requiring the provision of clearer information on bills and more advice about energy efficiency. It will be launched an on-line CO2 calculator which will enable households to know how their everyday activities contribute to emissions. The Government is also undertaking trials of smart meters and real time displays which enable people to track their energy use conveniently in their homes. Subject to the results of these trials the Government intends to work with energy companies to roll these out to households over the next 10 years. In the meantime, real time displays will be provided with any new meters fitted from 2008. Because it will take a number of years before a new meter and display can be rolled out to every household, Government have decided that between 2008-2010, real time displays, will be available free of charge to any household that requests one [17].

- propose future changes to Building Regulations such as by 2016, all new homes built in England will have to be zero carbon [18]. This means that, over a year, the net carbon emissions from all energy use in the home would be zero (heating, lighting, hot water, and all appliances), achieved by improving the energy performance of the home and increasing the use of renewable and low carbon sources of energy, either installed in the individual home or supplied to an entire development. By 2016, if the housing supply ambitions were met, there will be an additional 200,000 homes every year, the majority of which will be newly-built, zero carbon homes [19].

- has also taken a number of steps to promote some of the specific DE technologies. The proposed changes to the Renewals Obligation will boost support for renewable Combined Heat and Power (CHP), including the recovery of energy from waste and some types of micro-generation technologies. Defra's Waste Strategy, published in May 2007, sets out our broader policy on improving the recovery of energy from waste, which will also boost DE."[20]

The appliance of energy efficiency measures have several benefits like the ones previously described and according to European Commission [3], the appliance of these measures will contribute to:

Security of supply:

By 2030, on the basis of present trends, the EU will be 90% dependent on imports for its requirements of oil and 80% dependent regarding gas. Making a real effort to at first cap EU energy demand at present levels and subsequently reduce it, would represent an important contribution in developing a coherent and balanced policy to promote the security of energy supplies for the European Union [3].

Competitiveness and the Lisbon agenda:

Applying measures on energy efficiency also means the creation of many new high-quality jobs in Europe. Furthermore, a successful energy efficiency scheme means that some of the €60 billion not spent on energy translates as a net saving, resulting in increased competitiveness and better living conditions for EU citizens. In this way an average EU household could save between €200 and €1,000 per year in a cost-effective manner, depending on its energy consumption [3].

Environmental protection and the EU's Kyoto obligations:

Energy saving is without doubt the quickest, most effective and most cost-effective manner for reducing greenhouse gas emissions, as well as improving air quality, in particular in densely populated areas. It will therefore help Member States in meeting their Kyoto commitments [12].

2.3 – Electricity Network Scenarios

In the model developed in this study were considered four distinct socio-economical scenarios. The reason for the assumptions of the four different scenarios is that these scenarios are an attempt to understand some aspects of an uncertain future through the use for differentiated approaches [21]. So, itch scenario will consider different implementations of measures like energy efficiency and micro-generation technologies for the same development area at the same period of time. Each one of the scenarios is an attempt to figure a realistic picture of possible future that may occur and each one of them present a plausible future in its own right and provides a valuable reference point for the development of the investment strategy made in this study.

The scenarios considered for this model were the Supergen Electricity Network Scenarios. The Supergen 2020 scenarios described here were developed as a collaborative effort between the Supergen project team and the ITI-Energy Networks Project team both based at the University of Strathclyde [2].

Supergen reports a set of scenarios for the development of the electricity supply industry in Great Britain till the year 2020. These scenarios 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.

For identification and development of 2020 scenarios, the technologies which were identified as being important to each scenario were categorised into three groups according to their likelihood of being available for commercial deployment in 2020:

- Mature technologies which are currently seeing large-scale deployment, but which might see incremental improvements in scale or efficiency by 2020 [22].

- Developing technologies which are currently seeing pilot or prototype use, but which might be expected to be available for deployment on a commercial scale by 2020 [22].

- New technologies which are at an earlier stage of development, and may not have demonstrated their capability to achieve commercial viability and make a significant impact by 2020. Some of these technologies may achieve deployment in a commercial environment by 2020 in the form of pilot plants [22].

Figure 1 below show the four different 2020 electricity scenarios according to Supergen report [23]:

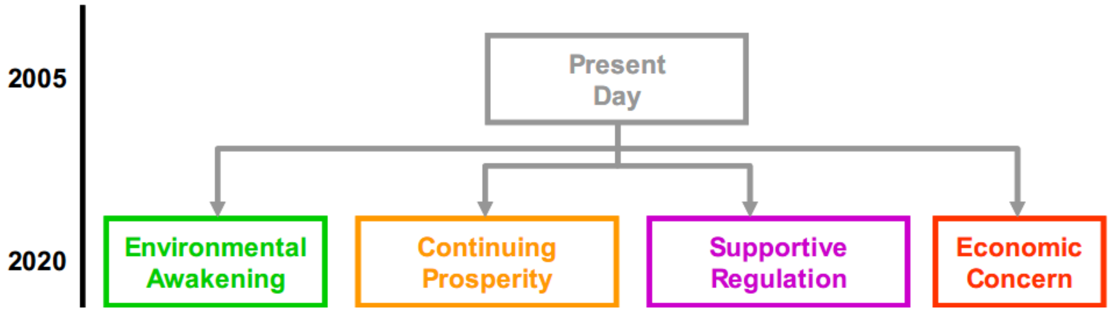

Figure 1: Supergen Electricity Network Scenarios [23].

According to each scenario specifications is possible to have an overall idea of the importance of energy efficiency measures and each distributed energy technology. So a brief description of each scenario will be now presented:

<u>Continuing Prosperity</u>:

This scenario 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 [24].

<u>Economic Concern</u>:

This scenario envisages 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. Concern over the economy tends to replace environmental issues in the public consciousness; therefore pressure to achieve targets on emissions and thus deployment of renewables tends to reduce in this scenario [24].

<u>Environmental Awakening</u>:

This 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. This awareness has its foundation in the heightened public awareness of climate change and the environment issues [24].

<u>Supportive Regulation</u>:

The Supportive Regulation 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 [24].

In the description of each one of these four scenarios in the “Supergen Future Network Technologies Consortium” report [2], were enumerated some considerations about the development of the micro-generations technologies used in the model presented in this study, as well as energy efficiency measures. That information was gathered and resumed and can be viewed in the follow table:

Table 1: Micro-generation technologies and energy efficiency measures implementation according to Supergen scenarios [2].

Supergen Scenario	Technologies/Measures						
	Biomass	**Micro-CHP**	**Heating Pumps**	**Photovoltaic Panels**	**Solar Heating Water**	**Micro-Wind**	**Energy Efficiency**
Continuing Prosperity	strong development	Small but growing proportion	strong development	reasonably strong development	strong development	reasonably strong development	Strongly promoted / maximum of 17%
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 / maximum of 17%
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 / maximum of 17%
Supportive Regulation	Government sponsored	minimal deployment(not encouraged by central policy)	Government sponsored	Not favoured by government policy: very little development	Government sponsored	Not encouraged (main incentives are for wind farms)	Government sponsored

Supergen scenarios were formulated considering several more information that the one expressed in the Table 1. More generic information about the considerations on the formulation of 2020 Supergen scenarios can be found on the Table 2 presented below (the information presented at this table was the possible to obtain by the understanding of the “Supergen Future Network Technologies Consortium” report [2]):

Table 2: Summary of Key elements used at the elaboration of Supergen scenarios [2].

Element	Continuing prosperity	Economic concern	Environmental awakening	Supportive regulation
Economic growth	Buoyant	Moderate decline	Growth to a peak in 2020	Relatively strong
Energy efficiency	Strongly promoted	Overshadowed by economy	High take-up by concerned public	Government sponsored
R & D	Strong	Very weak	Reacts to new paradigm	Supported by Government
Technical sophistication	Increasing	Restricted investment	Increasing	Increasing
DSP	Promoted	Low cost energy saving only	Driven by public concern	Seen as offering increased security
Demand for electricity	Moderate growth year-on-year	Depressed – modest increase	Growth then decline	Relatively strong growth
Peak vs. overall demand	Both grow	System peak unchanged in 2020	Peaks removed by DSM etc.	Peaks offset by DSP
DSM	Avoids significant reinforcement	Only as cost-saving measure	High commercial/industrial uptake	Non-domestic DSP programmes
Smart metering	Increasingly widely adopted	Doesn't feature	Adopted by all customer classes	Domestic DSP not encouraged
Other impacts	Supports DSM and micro-gen		Supports DSM and micro-gen	
Renewable energy	Continued investment	Continues to develop	Strong investment	Strong investment
Onshore	10GW	7GW	12GW	9GW
Offshore	2GW by 2020	A few hundred MW	3GW (with more in planning)	1GW
Biomass	7GW by 2020 (20MW typical)	7GW by 2020 (20MW typical)	10GW (20MW typical)	8GW
Marine	None	None	2.5GW (Tens of MW typical)	2GW
Non renewable energy	Dominated by gas-fired	Large generation dominates	Dominated by gas-fired (CCGT)	Resumed construction of nuclear
CHP	Growing proportion of micro-CHP	None	Rapid development	Local waste-generation schemes
Grid impact	Increasing demand	Networks largely unchanged	Power-electronic management	Power-electronic management
Distribution impact	Power flows much more variable	Largely passive	Some power-electronic controls	Control at transmission interface
Micro-CHP	3GW	Minimal	6GW	Not encouraged - minimal
Demand	Average & peak loads higher	Customer growth impact only	Large increase in generation	Large increase in generation
Intermittent generation	Significant concentrations	Restricted by network constraints	Strong investment	Significant support
Offshore	2%	1%	4%	1%
Onshore	12%	9%	15%	12%
Biomass	9%	9%	11%	10%
Marine	None	None	3%	3%
Micro-gen	4%	Minimal	7%	0.25%

The adoption of Supergen and not for other electrical network set of scenarios was made because these scenarios are the most know and adopted by DNO's on UK.

There are several electricity scenarios, including as an example the set of scenarios developed by SPRU to examine environmental futures over the next 20 to 50 years. These scenarios were originally commissioned by the Office of Science and Technology for the Foresight Programme, and also includes in their formulation the technical, economic and regulatory analysis of distribution networks, as Supergen scenarios does. Their complete formulation can be consulted at" Integrating Renewables and CHP into the UK Electricity System" Tyndall Centre report [25]. The main difference between these two sets of scenarios is their contextual approach, i.e. while Supergen scenarios where structured in Environmental Awakening, Continuing Prosperity, Supportive Regulation and Economic Concern [23], SPRU scenarios where structured in World Markets, Provincial Enterprise, Local Stewardship and Global Sustainability [25].

Besides the fact that technical, economical and regulatory considerations were adopted in these two electrical network scenarios, as was already stated, these two sets of scenarios presents two different and distinct approach of the future. In some cases is easy to relate a Supergen and a SPRU scenario, in some cases that parallelism cannot be easily made because their different structure and approach to future reality.

So, in this study, could be considered other sets of scenarios besides Supergen scenarios, but the choice for these was related to the fact that Supergen scenarios are to most known and adopt scenarios by DNO's in their electricity forecasts studies.

Although in this study an analyse of characteristics and properties of all 2020 Supergen scenarios is made (presented previously), when the appliance of these scenarios in the model developed was verified that the assumptions made for the scenario "Continuing Prosperity" and "Supportive Regulation" were basically the same. The expectance of the micro-generation technologies and energy efficiency measures implementation in these two scenarios were very similar as well as the prevision of the impact of DMS programmes had along the years in these two scenarios.

So, as has no interest presenting two different scenarios with the same assumptions for application in this model, the model will considered only three scenarios that are: "Continuing Prosperity", "Economic Concern" and "Environmental Awakening". The scenario "Supportive Regulation" was not considered because the values obtained by choosing this scenario would be the same values that the "Continuing Prosperity" scenario would present.

2.4- Micro-Generation Technologies, Energy Efficiency and Demand Side Management Programmes

The model developed in this study has in consideration the impact on the development demand reduction of the adoption of micro-generation technologies and energy efficiency measures. The importance of the adoption of these and the expected impact on economy and society are described in more detail at section 2.2. Briefly, the importance of adopting this technologies and measures is that they can help the environment by reducing our reliance on fossil fuels, adding to the diversity and security of future energy supply, cutting energy imports and contributing to national and international targets on emissions reduction [1, 3, 15].

So, in the model are considered several micro-generation technologies and the user is able to choose the pretended implementation of each one, between the given options. The micro-generation technologies considered in this model are:

- Solar Electric Photovoltaic Panels;
- Solar Thermal Hot Water Systems;
- Micro-Wind Turbines;
- Ground Source Heating Pumps;
- Biomass Boilers;
- Micro-Combined Heat and Power Systems.

The consideration of these technologies is based on the fact that the application of these will be in a new development area that could be either in an urban or a rural environment. So, the technologies to be considered in the model need to be suitable for the application in houses or commerce that will possible develop in this new development area. The consideration of large local electricity generation will not be considered because is out of propose of this study. In this study will only be considered the technologies or measures that can be adopted for each individual household or commerce to reduce their electrical consume and to even produce their own electricity.

The consideration of these technologies was based on the fact that for Renewables Advisory Board (independent, non-departmental public body sponsored by the UK Department for Business, Enterprise and Regulatory Reform), these are expected to be the main micro-technologies suitable for housing applications in UK till 2020 [26]. This fact can be comprised in the Figure 2 below. This figure shows the uptake of the top 10 technologies chosen by developers over the timescale of the model developed by Renewables Advisory Board in the: "The Role of Onsite Energy Generation in Delivering Zero Carbon Homes " report [27]. In this figure, the units are number of homes per year which have the technologies installed.

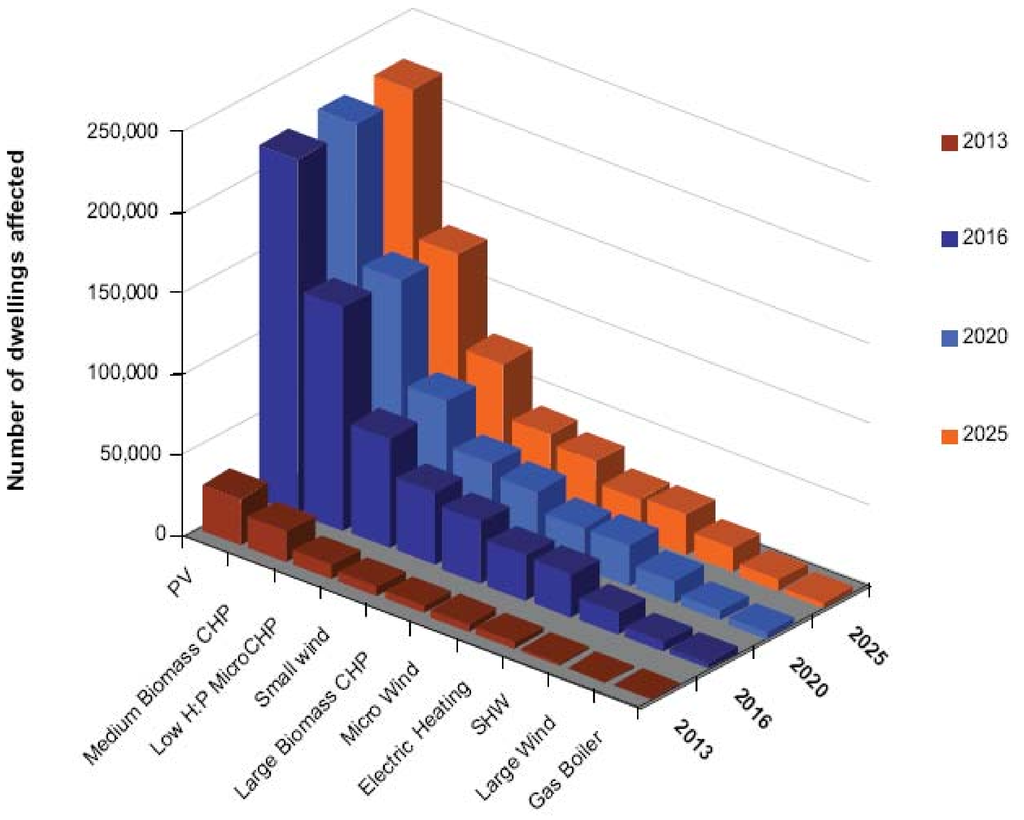

Figure 2: Change in uptake over period 2013-2025 [27]

In the model developed in this study, for commerce establishments was assumed that only CHP systems are considered to have a significant impact on the electrical demand of these. The other micro-generation technologies considered for application in houses are not expected to have must relevance and impact on commerce establishments' demand.

At this study, is gone be formulated a study case for the implantation of the developed model to urban environment areas. Therefore, in the follow sections, some considerations about the sustainability of these technologies in an urban environment are gone be made.

2.4.1- Micro-generation in the UK: Current Status

According to a study promoted by UK´s Department for Business, Enterprise and Regulatory Reform named “Potential for Microgeneration Study and Analysis” [28], in UK, there are currently less than 100,000 microgeneration installations (of which most are solar water heaters installed pre-2000). The sectors seeing the most yearly installations are PV and solar water heating, in response to generous grant schemes. The yearly installations in ground source heat pumps and small wind turbines is also increasing rapidly stimulated by the Clear Skies SCHRI program and rapid cost reductions. Micro-CHP is only just beginning to enter the market, but there is a very large technical effort on both Stirling engine and fuel cell technologies.

Now, and according to “Potential for Microgeneration Study and Analysis” report, the current status of each micro-generation technology will be presented [29]:

-<u>Micro-CHP (stirling engine)</u>

•This technology is likely to be successful in larger dwellings with higher than average heat loads.

•Currently, this technology is not far from being cost effective and this is strongly dependent on achieving lifetime and maintenance costs close to those of the incumbent (gas boilers).

•Following likely commercial introduction circa 2010, this sector grows quickly as costs reduce further.

-<u>Micro-CHP (fuel cell)</u>

•This technology is more suited to smaller dwellings with lower than average heating loads.

•Cost effective introduction is likely circa 2015. Thereafter costs continue to reduce significantly.

•Commercialization is strongly dependent on achieving lifetime and maintenance costs close to those of the incumbent (gas boilers).

-<u>Small Wind</u>

•Small wind systems are generally not cost effective at present.

•However, a number of new products have recently come to market with potential for significant volume related cost reductions. As a result, mass-commercialisation could occur circa 2015.

•The potential for small wind is significant –there are a number of UK developers, a suitable UK market of significant size and near term potential for significant cost reductions.

-<u>Photovoltaics</u>

•Photovoltaics are not generally cost effective at present. In many countries (including the UK) significant incentives are required to maintain the market for small grid connected systems.

•There are small markets where PV is already cost effective, including for remote power and in prestige facades.

•Cost effectiveness is not predicted to occur until 2030. However, a technology breakthrough could reduce capital costs and bring this forward towards 2020.

-<u>Biomass heating and heat pumps</u>

•Both biomass heating and GSHP technologies can be commercial when compared against electric or LPG heating. In general the technologies are not competitive with natural gas or oil fired heating.

•Although only a small proportion of the housing market uses electric heating, and only a fraction of these will be suited to biomass or GSHP, the CO2savings are disproportionately large (due to the high CO2emissions of electric/LPG heating).

-<u>Solar water heating</u>

•Currently the largest microgeneration industry, installing 2000 units annually.

•Generally, solar water heating is not cost effective at present.

•The technology is most effective if replacing electric heating systems.

•However, while capital costs are projected to reduce, the learning rate appears low and it is not likely that solar water heating will provide cost effective water heating over the timescales of the study without substantial grant support.

In the “Potential for Microgeneration Study and Analysis” report a study of the possible uptake levels of each micro generation technology was made and with the study results [30], Figure 3 and 4 were prepared (these predictions are consider to be without intervention or support).

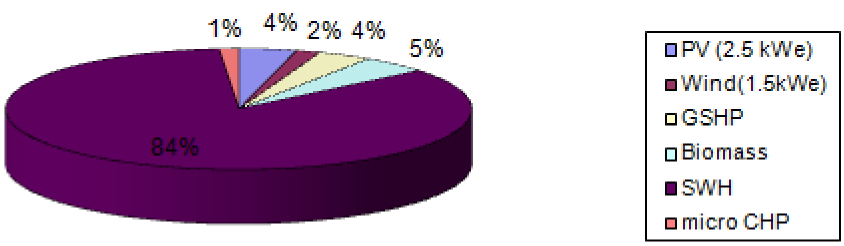

Figure 3: Uptake of each micro generation technology by 2010 [30].

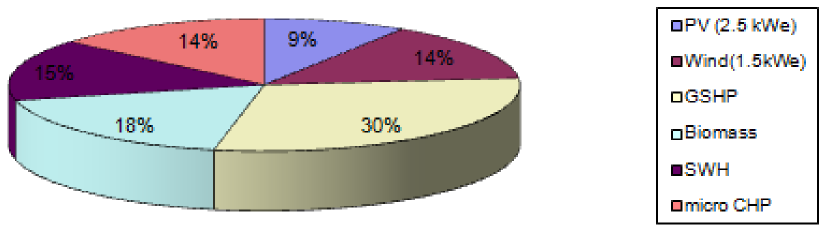

Figure 4: Uptake of each micro generation technology by 2020 [30].

In the model developed in this study, DSM programs and energy efficiency measures were also considered. In the follow sections some considerations about those measures are gone be made.

2.4.2- Demand Side Management

Demand Side Management, or "DSM" is the process of managing the consumption of energy, generally to optimize available and planned generation resources. According to the US Department of Energy [31], Demand Side Management refers to:

"Actions taken on the customer's side of the meter to change the amount or timing of energy consumption. Utility DSM programs offer a variety of measures that can reduce energy consumption and consumer energy expenses. Electricity DSM strategies have the goal of maximizing end-use efficiency to avoid or postpone the construction of new generating plants."

Demand-side programs focus on reducing the peak-to-average demand profiles through automation in the customer premises. According to Energy Information Administration webpage (official energy statistics from US government) [31], these programs consist at the planning, implementing, and monitoring activities of electric utilities that are designed to encourage consumers to modify their level and pattern of electricity usage. According to the same source [32], Demand Side Management refers only to energy and load-shape modifying activities undertaken in response to utility-administered programs. It does not refer to energy and load-shape changes arising from the normal operation of the marketplace or from government-mandated energy-efficiency standards.

According to The Demand Side Management website [33], a DSM program will include measures that promote the following:

- Reduced customer peak and overall energy demand;
- Improves the electric grid's reliability;
- Balances the electric grid through increased efficiency;
- Energy efficiency;
- Manages electricity costs;
- Conservation through both behavioural and operational changes;

•Load management;
•Fuel switching;
•Distributed energy;
•Provide systems that encourage load shifting or load shedding during times when the electric grid is near its capacity or electric power prices are high.

Also according to The Demand Side Management website [33], by the adoption of DSM programmes, there will be several benefits to consumers, enterprises, utilities, and society. Some of these are:

•Reduction in customer energy bills;
•Reduction in the need for new power plant, transmission, and distribution network;
•Stimulating economic development;
•Creating long-term jobs due to new innovations and technologies;
•Increasing the competitiveness of local enterprises;
•Reduction in air pollution;
•Reduced dependency on foreign energy sources;
•Reduction in peak power prices for electricity.

2.4.3- Energy Efficiency

Energy efficiency is a concept that means use less energy to provide the same level of energy service. The importance of the adoption of these and the expected impact on economy and society are described in more detail at section 2.2. In a dwelling level, energy efficiency measures comprise several measures that have as final objective reduce the energy consumption in a house. That can be made by adopting several strategies. Some of the energy efficiency measures for commercial and residential sectors mentioned at The Institute of Electrical and Electronics Engineers website [34] are:

•Improvements in lighting: 20 to 50 percent reductions in lighting energy consumption can be realized through the proper application of efficient lighting technologies;
•Improvements in the building envelope;
•Improvements in heating, ventilating and air conditioning system technologies;
•Improvements in domestic hot-water system technologies;
•Increased use of energy efficient appliances such as computers, refrigeration, washing and drying, office machines and other appliances;
•Implementation of economical building and equipment energy efficiency standards.

2.5- Study Case: Appliance of the developed model to an urban environment

The model to determinate the best investment strategy for sustainable electricity distribution networks was developed, and is able to work properly either for urban or rural developments.

The main issue is that in terms of the expected implementation and penetration of micro-generation technologies, urban and rural environments have distinct approaches. So, in this study, a deeper research on urban environments and the expected penetration in these of each micro-generation technology described at the model will be made.

2.5.1- Suitability of Solar Electric Photovoltaic in urban environments:

Figure 5: Adoption of PV panels at a Development.

Solar Electric Photovoltaic is perhaps the most suitable of all renewable energy technologies for widespread use in urban environments. In urban environments there is usually a limited amount of space available for mounting PV modules. In these situations mono or polycrystalline modules have the advantage over amorphous silicon because being more efficient, less surface area is required to provide the same output. Conversely, amorphous/thin film modules can be deposited on a wide range of rigid and flexible substrates, making them ideal for integration into new-build dwellings. A key advantage of PV in the urban environment is their potential to be integrated into the fabric of the building. No extra land space is required and the visual aesthetics of a building can be altered – either to be unobtrusive, or to give a clear indication of 'green' credentials. At urban environments, grid-connected PV is likely to be more practical and cost-effective than a stand-alone system. The system is connected to the local electricity network and any excess electricity not consumed by the household can be sold back to the electricity supplier. During periods when the modules are not generating, electricity will need to be imported. PV modules are commercially available in a range of different types for integration into urban dwellings and locations. They vary from traditional aluminium framed modules and roof mounted systems, to products like roof tiles and semi-transparent 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.

This photovoltaic information was gathered from the “Renewable energy sources for homes in urban environments” report [35], British Photovoltaic association [36], Energy Saving Trust webpage [15] and from a European research for Distributed Generation in Europe [37].

2.5.2- Suitability of Solar Thermal Hot Water in urban environments

Figure 6: Adoption of SWH system on a house.

Energy from the sun, as well as converting incoming solar radiation into electricity using PV cells, 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 at urban environments. With solar hot water systems, heat energy transferred to water can be stored in a tank for later use. Therefore, there is a significant potential for SHW systems in urban areas, provided that roof spaces for the location of collectors are unshaded by neighbouring properties and obstructions.

Some of the solar thermal water systems information was gathered from the “Renewable energy sources for homes in urban environments” report [35], Solar Trade Association webpage [38] and Energy Saving Trust webpage [15].

2.5.3- Suitability of Micro-Wind in urban environments

Figure 7: Micro- wind turbine

Harnessing wind as a renewable energy source involves converting the power within a moving air mass (wind) into rotating shaft power. Small variations in wind speed can result in large changes in potential energy output. For a given winds peed, the power available from the wind is given by the equation:

$$P\ (WATTS) = 0.5 \times \rho \times A \times V3 \qquad (2.1)$$

Where,

ρ = Density of air (kg/m3)
A = Swept area (m2)
V = Wind speed (m/s)

The ideal locations for the application of a micro-wind turbine 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 minimized by siting away from obstructions. So, the commercially available small scale wind turbines are generally more suited to rural areas, coast and uplands due to sitting and planning issues, as well as the higher average wind speeds more readily available. So, the implementation of these technologies in an urban environment is unlikely to be viable and should not have a must relevant proliferation. However development work is underway on ‘wind concentrators’, in which the wind speed approaching a small scale turbine is accelerated, increasing the final power output. These devices may be commercially available in the future, and be suitable for adaptation to new and existing buildings in urban areas.

Some of the micro wind turbines information was gathered from the "Renewable energy sources for homes in urban environments" report [35], British Wind Energy Association Webpage [39] and from a European research for Distributed Generation in Europe [37].

2.5.4- Suitability of Ground Source Heating Pumps in urban environments

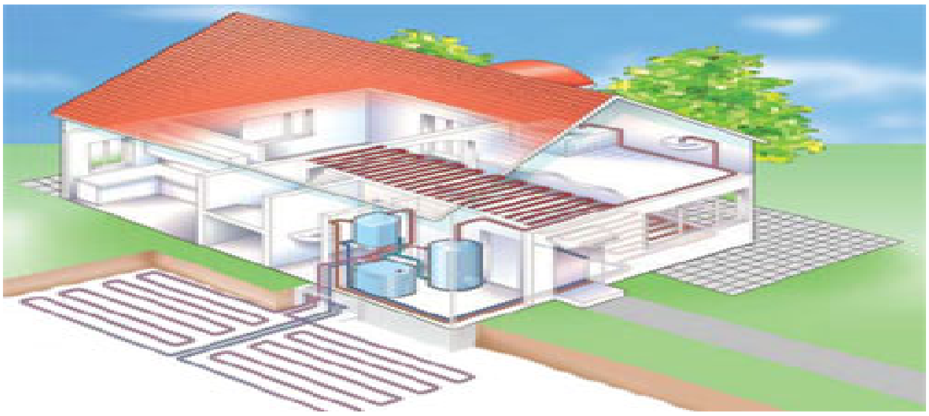

Figure 8: Virtual diagram of implementation of GSHP at a dwelling.

At urban environments GSHP systems are at their most cost-effective in new-build properties where high levels of insulation have been achieved. Where there is a low heating demand, under floor heating and other low temperature heating distribution systems become possible options. There is the possibility of adoption of vertical or horizontal systems but choice depends on the land area available, local ground conditions and excavation costs. Vertical collectors are inserted into boreholes (usually between 15-20m deep) and are ideally suited to dwellings with smaller gardens. In contrast, horizontal collectors require relatively large areas of land for the trench, which for a medium detached new-build house is typically 1-1.5m deep and 40-50m in length. The length of trench required can be reduced by 70 to 80 per cent if the pipe is laid in a series of overlapping coils. This can be placed vertically in a narrow trench, or horizontally in a wider trench. Horizontal collectors are therefore less suited to urban applications where land availability is usually limited.

Ground source heating pumps can be particularly cost effective in areas where main gas is not available or in developments where there is an advantage to simplifying the infrastructure. Once that 75% of the UK housing sector are connected to the national gas grid, primarily in urban areas [40], the application of this microgeneration technology in urban environments (mostly gas connected) should not be viable and therefore, not have a must relevant proliferation.

Some of the ground source heating pumps systems information was gathered from the "Renewable energy sources for homes in urban environments" report [35], IEA Heat Pump Centre Webpage [41], Earth Energy webpage [42] and UK Pump Network Webpage [43].

2.5.5- Suitability of Biomass in urban environments

Figure 9: Biomass boiler (pellet stove with back boiler).

The traditional log burning room heater or stove is ideal for smaller domestic applications (between 2-12kW), and usually consumes wood fuel in the form of logs or pellets. They are most commonly used for providing direct space heating in conjunction with a gas or oil central heating system, although in suitable, well insulated housing, two or three room stoves may be able to provide the entire heat load requirements. Recent improvements in design and production methods mean that many models are approved for use in smokeless zones and can be fitted with back boilers for providing domestic hot water, as well as space heating.

Availability of specific forms of wood fuel is a major factor when considering the suitability of biomass heating. Like any fuel, the security of long term supply needs to be considered, as does the supply infrastructure itself, which in the case of most wood fuels, is yet to become fully established. Storage space for the wood fuel can be a major issue when specifying or designing a system for a domestic application in an urban area. In some automated handling systems, the store needs to be adjacent to the boiler and this can make retro-fitting to existing houses difficult. Further planning issues of particular importance in urban dwellings include: 1º only selecting appliances that burn the fuel cleanly, and 2º planning implications due to the installation of a suitable flue (this may not be required if an existing chimney can be adapted for use). Therefore, the application of biomass boilers on urban developments should not have must proliferation, due especially to the availability (lack of space) to store the specific forms of wood fuel.

Some of this biomass systems information was gathered from the “Renewable energy sources for homes in urban environments” report [35], National Energy Foundation Webpage [44], British Biogen Webpage [45] and from a European research for Distributed Generation in Europe [37].

2.5.6- Suitability of Micro-Combined Heat and Power Systems in urban environments

Figure 10: Wall monted micro-CHP system instaled in kitchen.

Micro-CHP (Combined Heat and Power) systems involve an engine driving an electrical generator that allows individual homes or commerce establishments to generate a proportion of their own electrical supply, whilst also supplying heat and hot water. Micro-CHP systems can provide enough heat for domestic or commerce heating and hot water.

This technology is perfectly suitable for application in urban environments once that these appliances are the same size as a conventional gas boiler, and a CHP unit is fuelled with natural gas (this happens nowadays and is expected to happen also in a near future). For households in an urban environment that are unable to make use of wood fuel, a micro-CHP unit is more appropriate than a Biomass system.

Some of the combined heat and power systems information was gathered from the "Renewable energy sources for homes in urban environments" report [35], "Micro CHP – a sustainable innovation?" report [46], Combined Heat & Power Association Webpage [47], Micro Power Council Webpage [48], Micro-CHP Fact Sheet [49] and from a European research for Distributed Generation in Europe [37].

Chapter 3

Model for Investment Strategies for Sustainable Electricity Networks

3.1 - Introduction

In this chapter a detailed explanation about the conception, structure and results obtained with the developed model in this study will be made.

With the model presented, is proposed the achievement of the best investment solution that DNO's have to make in order to supply the new developments that are expected to happen in U.K. till the year 2020. The referred investment solution is related with the investment that is need to be made by DNO's for connecting the new consumers to the existing primaries substations on the territory or even build a new one to supply the electricity needs of the specific new development area in analyze.

So, this chapter will provide the reader with the appropriate theoretical background critical to understanding the approach made by this model for Investment Strategies for Sustainable Electricity Networks.

3.2- Approach and Overview of the model for Strategic Investment on Sustainable Electricity Networks

In this model, the approach was based on the use of three network scenarios carried out by the Supergen Future Networks Technologies Consortium (the continuing prosperity, environmental awakening and economic concern scenarios have been modelled) and also by the information that was provided by ArcGIS 9, that anticipates for the new developments areas the localization, year of beginning and end of the development, the number of houses, number of jobs, average house consumption, average job consumption and for primaries substations the localization, capacity, actual load, margin and underlying load growth. The information for the connection costs (Millions of pounds per km) for connecting the loads of the new developments to a primary substation was gathered from the EDF energy model

“High-level model for forecasting demand growth and associated load-related expenditure” [50].

According to the Supergen scenario chosen, implementation of energy efficiency measures and micro-generation technologies and maximum distance primary substation to the development selected by the user the best solution for connecting the new development loads from the development to a primary substation is determinate.

3.2.1- Overview of the model for Strategic Investment on Sustainable Electricity Networks

The model is built as an MS Excel workbook with Visual Basic applications.

A generic approach has been taken whereby the user can select the new development, one of the Supergen network scenarios (continuing prosperity, environmental awakening and economic concern), the maximum distance from the primaries substations to the development, the implementations of energy efficiency measures as well as micro-generation technologies and several reduction factors from the excel “Input” sheet and this will result in the appropriate factors and profiles being selected within the body of the model.

This structure facilitates easier updating and modification of the used databases. The individual spreadsheets and their function will now be described.

3.3- Model for Strategic Investment on Sustainable Electricity Networks: Inputs Parameters

The Inputs sheet of the model has two distinct sections. One, that is called “Control” and other called “Info”.

The user will only be able to choose the options displayed and insert the pretended values in the “Control” section. “Info” section will only display the information triggered by the options made by the user in the “Control” section.

3.3.1- Detailed review of Inputs sheet

The definition and functionalities of all the selection options that user can make in Inputs sheet as well as the information triggered by those, in this same sheet, will be presented.

3.3.1.1- Control section of Inputs sheet

(i) Choose Network

Allows selection of DNO licence area (in this study, as the data used was gathered from EDF Energy databases, the list of licence areas presented are the EDF licence areas).

(ii) Choose District

Allows the selection of the local authority districts existent on the previously Network chosen.

(iii) Choose Development

Allows the selection of the new developments that are expected for the previously Location chosen.

(iv) Maximum Distance of Primary Substation to New Development

Here the user can specify the maximum distance that the primaries substations to analyse are gone be to the new development. This can improve or reduce the number of primaries substations to consider in the body of the model according to their distance to the selected development. The number of primaries substations that are gone be analysed must be within the distance chosen from the new development area.

(v) Choose Supergen Scenario

This drop-down list provides three options:

-Continuing Prosperity;

-Environmental Awakening;

-Economic Concern.

The choice of Supergen scenario determines preset factors, profiles and informative recommendations in respect of:

- Micro-Generation technologies and Energy Efficiency measures implementation for domestic dwellings;
- House and Job scaling factor;
- Demand Side Management (DSM).

- <u>Micro-generation technologies and Energy Efficiency measures implementation</u>:

For each of the three Supergen scenarios, the implementation of each micro-generation technology (for domestic dwellings) and energy efficiency measures (for domestic and non-domestic buildings) is considered distinct.

This information is given by the model when the choice of the Supergen scenario. This information enables the user to have a generic idea of the preview implementation that each micro-generation technology or energy efficiency measures could have in that specific scenario.

The information that is given for each Supergen scenario is presented at the follow table:

Table 3: Informative considerations of implementation of micro-generation technologies and energy efficiency measures according to Supergen scenarios.

Supergen Scenario	Technologies/Measures						
	Biomass	**Micro-CHP**	**Heating Pumps**	**Photovoltaic Panels**	**Solar Heating Water**	**Micro-Wind**	**Energy Efficiency**
Continuing Prosperity	strong development	Small but growing proportion	strong development	reasonably strong development	strong development	reasonably strong development	Strongly promoted / maximum of 17%
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 / maximum of 17%
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 / maximum of 17%

The information presented at Table 3 is stored on “Factors” excel sheet.

- 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 model has as part of the database the information about the number of houses and jobs expected for each new development area, the values to consider in the model application will be affected by these factors according to the chosen scenario. So, the percentage of houses and jobs considered for each scenario are presented in the table below:

Table 4: House and Job scaling factor for the Supergen scenarios considered.

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

The information presented at Table 4 is on “Factors” excel sheet.

- Demand Side Management (DSM):

Demand Side Management is applied to the domestic demand and three profiles are shown based on the Supergen scenarios. The percentages considered along the years till the year 2020 are consistent with the understanding of the Supergen forecasts [2] and also with the Energy Networks Association final report “Long Term Capital Expenditure Forecast for the Electricity Networks in Great Britain” [51]. This understanding of DSM percentage of implementation according to Supergen scenarios till the year 2020 is the same that the “High-level model for forecasting demand growth and associated load-related expenditure” report [50] has made.

The assumed implementation of DMS programs along the years and according to Supergen scenarios is now presented:

Table 5: Percentage of reduction of domestic electrical demand due to Demand Side Management programmes

Supergen Scenario	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
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%
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%
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%

The information presented at Table 5 is on “Factors” excel sheet.

(vi) Set % of electrical demand reduction due to Energy Efficiency measures

Here the user inserts the pretended percentage of electrical demand reduction that is expected to be verified when the adoption of energy efficiency measures, both for domestic and commercial buildings.

(vii) Set % of Each Micro-Generation Technology (Domestic Loads)

The user can insert the percentage of houses that have each micro-generation technology implemented. The set of micro-generation technologies considered in the model is:

- Solar Electric Photovoltaic Panels;
- Solar Thermal Hot Water Systems;
- Micro-Wind Turbines;
- Ground Source Heating Pumps;
- Biomass Boilers;
- Micro-Combined Heat and Power Systems.

(viii) Set % of Each Technology (Commercial Load)

Allows the user the possibility to select the percentage of the electrical commerce demand reduction by the adoption of CHP systems both in commerce establishments and non-domestic buildings.

The other micro-generation technologies considered for domestic dwellings aren't considered for commerce establishments and non-domestic buildings because, for this kind of buildings, the suitability is not the same as for domestic dwellings and, for these, the main expected technology is CHP systems. So, in this model, for commerce proposes, the only technology considered is Combined Heat and Power systems.

(ix) Set % of DSM reduction factor:

Allows the user the possibility to select a reduction percentage of the expected implementation of DSM programs (Table 5). The percentages described on Table 5 are considered to be extremely optimistic, so the user has in this cell the possibility of choosing a reduction factor (percentage) to reduce the impact that DSM programs have in reducing the domestic electrical demand.

(x) Set % of Micro-Wind reduction factor:

Allow the user to select a reduction factor for the expected annual micro-wind electric contribution. This reduction factor is for convert the expected annual micro-wind electric contribution in the expected annual electric contribution at peak time. The importance of this reduction factor is that, due to the unpredictability of wind resources, for a windy year the contribution of micro-wind turbines at peak time could be much higher that the contribution at peak times for a year with low wind indices.

(xi) Set % of Photovoltaics reduction factor:

Allow the user to select a reduction factor for the expected annual PV electric contribution. This reduction factor is for convert the expected annual PV electric contribution in the expected annual electric contribution at peak time. The importance of this reduction factor is that, due to the unpredictability of solar resources, for a sunny year the contribution of PV panels at peak time could be much higher that the contribution at peak times for a year with low solar radiation.

3.3.1.2- Informative section from Inputs sheet

In this section of the Inputs excel sheet, the user is able to visualize the information relative to:

- Development time: represent the expected years of beginning and finish of the new development selected in the control section. It is displayed the year in which the development is expected to star (stars at the beginning of that year) and the year in with the development is expected to finish (finishes at the end of that year)

This information is gathered from the database at stored the "All Developments" excel sheet.

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

As it was referred on section 3.3.1.1 (v), this value is affected by a scaling factor that is dependent on the chosen Supergen scenario.

The database with the number of houses information is gathered from “All Developments” excel sheet, and the scaling factor is from “Factors” excel sheet.

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

As it was referred on section 3.3.1.1 (v) and in the same way as the number of houses, this value is affected by a scaling factor that is dependent on the chosen Supergen scenario.

The database with the number of jobs information is gathered from the “All Developments” excel sheet, and the scaling factor is from “Factors” excel sheet.

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

This information is gathered from the “EPN”, “SPN” and “LPN” excel sheets and depending on which local authority district the development chosen is implanted, the model will pick the stored value from the respective “EPN”, “SPN” and “LPN” excel sheet.

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

This information is gathered from the “EPN”, “SPN” and “LPN” excel sheets and depending on which local authority district the development chosen is implanted, the model will pick the stored value from the respective “EPN”, “SPN” and “LPN” excel sheet.

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

As it was referred on section 3.3.1.1 (ix), this value is affected by the DSM reduction factor inserted on the control section of this “Inputs” excel sheet

The database with the information of DSM programs expected implementation is gathered from “Factors” excel sheet.

- Some informative considerations concerning the expected implementation of Energy Efficiency Measures (for domestic and non-domestic buildings) and Micro-Generation Technologies (for domestic dwellings) are made in this section. This information changes according to the Supergen scenario chosen and the way this process occurs was explained in section 3.3.1.1 (v).

- The information of the energy savings that can be made by the implementation of CHP systems at commerce establishments and non-domestic buildings is also displayed in this section. This information was obtained at “The Essential Guide to Small Scale Combined Heat & Power” report [52].

- The information concerning the <u>% of DSM reduction factor</u> reveals the user a possible estimate for this value. The default values displayed in this informative consideration were obtained from the “High-level model for forecasting demand growth and associated load-related expenditure” report [50]. In this report, the impact of DSM programmes at domestic electrical reduction were also considered to be to 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.

The database with the information for the % of DSM reduction factor is gathered from “Factors” excel sheet.

- The information concerning the <u>% of Micro-Wind reduction factor</u> reveals a possible range of values for this factor. This information gives the user the expected minimum value for this factor (year with low wind resources) and the expected maximum value (year with high wind resources). These values were obtained by analysing the bibliographic references [53] and [54].

- The information concerning the <u>% of Photovoltaics reduction factor</u> reveals a possible range of values for this factor. This information gives the user the expected minimum value for this factor (year with low solar radiation indices) and the expected maximum value (sunny years, with high level of solar radiation indices). These values were obtained by analysing the bibliographic references [53] and [54].

3.4- Technological Considerations

The Technological Considerations sheet has the needed information of all the micro-generation technologies and energy efficient measures to be used in the model. In this sheet are expressed the several factors that enables the consideration of all micro-generation technologies and energy efficiency measures for further application at the reduction of the new development electrical demand.

Besides the expressed factors, the assumptions made for each technology and for energy efficiency measures are resumed. This enable the user to understand how the factors were determinate and the assumptions made for each one of those.

3.4.1- Detailed review of Technological Considerations sheet

Now it will be presented for each micro-generation technology the factors used and the respective assumptions made. The factors and assumptions made for energy efficiency measures and for a dwelling electric consumption are also described.

(i) Micro-Wind Turbines

For the determination of the impact that this system could possible have in the energetic dwelling demand a research was made and the main results obtained were:

- Micro wind turbines are typically less than circa 1.5kW and can be building mounted;
- Particularly suitable for remote areas.

This information was gathered from the bibliographic reference [55].

In the model, for micro-wind turbines, was considered a 1.5 kW turbine and as its energetic contribution 1680 kWh/year.

This information was gathered from the bibliographic reference [56]

So, the excel sheet, for micro-wind turbines, assumes:

Table 6: Assumed micro-wind turbine energetic contribution

Technology	Energy Contribution (kWh/yr)
microWind (1.5kW)	1680

(ii) Solar Electric Photovoltaic Panels

For the determination of the impact that these systems could possible have in the energetic dwelling demand a research was made and the main results obtained were:

- For the average domestic system, costs can be around £5,000 to £8,000 per kilowatt (kW) installed, with most domestic systems usually between 1.5 and 3kW;
- Such a system can produce around half a domestic property's electricity requirements;
- Average of 850 kWh/ 1 hKp.

This information was gathered from the bibliographic reference [57] and [58].

In the model, the domestic solar electric photovoltaic panels were considered with 2 kWp, contributing energetically for a single dwelling with 1600 kWh/year.

This information was gathered from the bibliographic reference [54]

So, the excel sheet, for domestic solar electric photovoltaic panels, assumes:

Table 7: Assumed domestic solar electric photovoltaic panels energetic contribution

Technology	Energy Contribution (kWh/yr)
PV (2kWp)	1600

(iii) Solar Water Heating Systems

For the determination of the impact that these systems could possibly have in the energetic dwelling demand a research was made and the main results obtained were:

• System savings range from around 454 (kWh)/year/m2 for a flat plate collector – 582 kWh/year/m2 for an evacuated tube system;

• Assumes efficiency of approximately 85% and capacity of 0.7kW/ m2.

This information was gathered from the bibliographic reference [59].

In the model, the domestic solar water heating systems were considered with a 4m2 area, contributing energetically with 1200 kWh/year.

This information was gathered from the bibliographic reference [54]

So, the excel sheet, for domestic solar water heating systems, assumes:

Table 8: Assumed domestic solar water heating systems energetic contribution

Technology	Energy Contribution (kWh/yr)
SHW(4 m^2)	1200

(iv) Ground Source Heating Pumps Systems

For the determination of the impact that these systems could possibly have in the energetic dwelling demand a research was made and the main results obtained were:

• Individual dwellings and small scale community (typically 5kW per dwelling);

• For a small two-bedroom dwelling carbon savings are in the region of 250 kg per annum.

This information was gathered from the bibliographic reference [60] and [61].

In the model, the ground source heating pumps systems were considered to contribute energetically for a single dwelling with 4500 kWh/year.

This information was gathered from the bibliographic reference [54]

So, the excel sheet, for ground source heating pumps systems, assumes:

Table 9: Assumed ground source heating pumps systems energetic contribution

Technology	Energy Contribution (kWh/yr)
GSHP	4500

(v) Biomass Boilers

For the determination of the impact that these boilers could possibly have in the energetic dwelling demand a research was made and the main results obtained were:

• Micro biomass boilers for low thermal demand homes are currently available with 8kWth maximum capacity modulating down to 2kW;

• An individual micro-biomass boiler should be a boiler with less than 10 kW.

This information was gathered from the bibliographic reference [62].

In the model, biomass boilers were considered to contribute energetically for a single dwelling with 6800 kWh/year.

This information was gathered from the bibliographic reference [54]

So, the excel sheet, for domestic biomass boilers, assumes:

Table 10: Assumed biomass boilers energetic contribution

Technology	Energy Contribution (kWh/yr)
Biomass	6800

(vi) Micro Combined Heat and Power Systems

For the determination of the impact that these systems could possibly have in the energetic dwelling demand a research was made and the main results obtained were:

•They are predominantly gas-powered, delivering between 1-3kW of electric power (1-3kWe), and 4-8kW of heat (4-8kWth). They can therefore provide space heating and hot water, as well as the additional benefit of electricity generation;

• CHP technologies are typically sized to meet about 70 - 80% of the heating load.

This information was gathered from the bibliographic reference [63].

In the model, the micro combined heat and power systems were considered to contribute energetically for a single dwelling with 8000 kWh/year.

This value was achieved considering that micro-CHP systems are systems that have the potentiality to supply all the heating needs of a dwelling. According to information gathered at the “Meeting the 10 per cent target for renewable energy in housing” report [54], the average house heating requirements is 6342 kWh/yr. As the relation between the heat and electric power delivered in a micro CHP system is around a 4 to 1 relation, it is assumed that the electric annual contribution of a micro-CHP system is around 1600 kWh. So, the assumed energetic contribution of a micro- CHP system is considered to be around 8000kwh/year (≈6400kWh+1600kWh).

So, the excel sheet, for domestic micro-CHP systems, assumes:

Table 11: Assumed micro combined heat and power systems energetic contribution

Technology	Energy Contribution (kWh/yr)
Micro-CHP	8000

(vii) Energy efficiency measures

For the determination of the impact that these measures could possible have in the energetic buildings demand, a research was made and the main results obtained were:

• A full efficient house has energy consumptions less than 1/6 of an average UK house;

• Energy efficiency measures can reduce energy costs by an average of 17 per cent and improve the comfort and air quality of a home.

This information was gathered from the bibliographic reference [5] and [64].

In the model, energy efficiency measures were considered to contribute energetically with a reduction of the building total electrical consume by the percentage inserted by the user at Inputs sheet (section 3.3.2.1(vi)).

So, the excel sheet, for energy efficiency measures, assumes the percentage inserted by the user at section 3.3.2.1(v,), (it is expected a maximum percentage of 17%).

Table 12: Expected maximum electrical demand reduction in a building by adopting energy efficiency measures

Measure	Reduction in electrical demand (%)
Energy Efficiency	17%

(viii) Dwelling electric consumption

Once the several micro-generation technologies considered in the model can contribute energetically in two distinct ways (electricity contribution and heat contribution), is important to have in consideration the electric diagram of a domestic dwelling to understand the weight that each micro-generation technology could possibly have to reduce the household electric consumption.

The domestic dwelling electric consumption diagram is presented on the figure below and was elaborated with information gathered from the ImpEE project "Domestic Energy Use and Sustainability" [65].

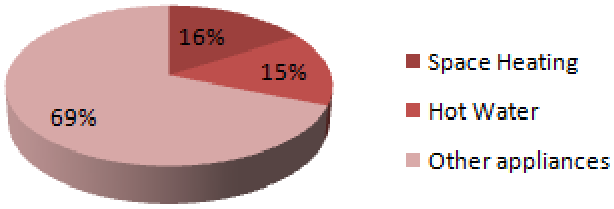

Figure 11: Diagram of a domestic dwelling electrical consumption [65].

(ix) Energetic Analyse

The consideration of the domestic dwelling electric consumption chart is essential to determinate the weigh (in terms of energetic contribution) that each micro-generation technology has for the domestic demand of the new development.

So, with the previous information gathered for each micro-generation technology, the energetic contribution of each one adopted in the model is resumed in the following table:

Table 13: Energetic contribution of each micro-generation technology according to Heat and Electricity contribution

Technology	Energy Contribution (kWh/yr)	Heat Contribution (kWh/yr)	Electricity Contribution (kWh/yr)
SHW(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

- For Solar Water Heating Systems, the energetic contribution will be in the form of heat contribution, once these systems are designed to supply heat and not to produce electric power.

These systems are used to provide hot water and generally do not provide space heating [35]. So, using a solar water heating system, a household could save at the most 15% of its electrical consume. According to Figure 11, this is the percentage of the total electric consume spent for heating water at a single dwelling.

- For Photovoltaic Panels, the energetic contribution will be all in the form of electricity production because these systems are concept to produce only electricity and not supply heat. Although, the expected electrical annual contribution of these systems expressed at Table 13 is 1600kWh, the impact of this contribution on peak times (this information will be further needed) is significantly lower. According to the levels of solar radiation in each year the impact of this technology for reducing the domestic demand at peak times is expected to be between 10% and 50% of the total 1600kWh/yr.

- For Micro-Wind Turbines, the energetic contribution will be all in the form of electricity production because these systems are concept to produce only electricity and not supply heat. Although, the expected electrical annual contribution of these systems expressed at Table 13 is 1680kWh, and the same way as PV panels, the impact of this contribution on peak times is expected to be significantly lower. But, due to the stochastic nature of the wind recourses, it´s very difficult to quantify a micro-wind turbine electrical contribution at peak times. So, depending in the development local and the proper wind resources in that year at peak times, the electrical contribution of micro-wind turbines could be between 0% and 100% of the total 1680 kWh/yr (although these boundaries values are not expected to be achieved in any situation).

- For Ground Source Heating Pumps, the energetic contribution will be in the form of heat contribution, once these systems are designed to supply heat and not to produce electric power.

These systems are used to provide space heating and are also used to heat water [35]. So, using a ground source heating pump system, a household could save upon 31% of its electrical consume. According to Figure 11, the percentage of the total electric consume spent for space heating is 16% and for heating water is 15%. Once this system is able to supply both space and water heating, a system like this can save at most 31% of a household electric consume (16%+15%).

- For Biomass Boilers, the energetic contribution will be in the form of heat contribution, once these systems are designed to supply heat and not to produce electric power.

These systems are used to provide space heating and are also used to heat water [35]. So, using a ground source biomass boiler, a household could save upon 31% of its electrical consume. According to Figure 11, the percentage of the total electric consume spent for space heating is 16% and for heating water is 15%. Once this system is able to supply both space and water heating, a system like this can save at most 31% of a household electric consume (16%+15%).

- For Micro-CHP Systems, the energetic contribution will be both in forms of heat and electric contribution.

So, besides producing electric power, these systems also supply the dwelling with heat. Using a micro-chp system, a household could use the produced heat by these systems to reduce the electrical consumption for heating appliances. Once these systems are used to provide space heating and hot water [35], a household could save upon 31% of its electrical consume. According to Figure 11, the percentage of the total electric consume spent for space heating is 16% and for heating water is 15%. Once this system is able to supply both space and water heating, a system like this can save at most 31% of a household electric consume for heating appliances(16%+15%). The electricity produced by these systems can be used in its totality to reduce the electrical domestic demand.

3.5- Model for Strategic Investment on Sustainable Electricity Networks : Outputs Overview

The Outputs excel sheet is structured in four sections where the user can visualise several information according to the inserted values at Inputs excel sheet.

At the first section, it is displayed the technological information related with the primaries substations that are selected by the model (these primaries substations must be within the distance from the new development selected previously at Inputs excel sheet).

At the second section it is displayed the information related to the new development electrical demand.

At the third section it is displayed, for the selected primaries substations, the information related with the evolution of the demand that the primaries substations are delivering as well as the evolution of the margin (difference between the primary substation capacity and delivered demand).

At the fourth section it is displayed the information regarding the best investment options in terms of connecting the loads from the new development to the selected primaries substations. It is possible to visualize in this section a chart with the evolution of the ratio between each primary substation margin and connection cost (this cost is the equivalent cost of connecting the development loads to the specific primary substation). The best solution for connecting the new development loads will be the primary substation that presents the lower value for the ratio between margin and connection cost at the ending year of the development.

3.5.1- Detailed review of Outputs sheet

Now a detailed description of all the four section mentioned previously is gone be made.

3.5.1.1- Primary Substation Information

In this section is possible to visualize a table with the selected primaries substations and their relevant technical information for the use of the model. The table is presented below

Table 14: Primaries substations technical information

P.S. Reference	Distance to development (km)	P.S. Capacity (MW)	Margin (MW)	Underlying Load Growth (MW)	Connection cost (M£/km)

(i) Primary Substation Reference

At this column will be displayed the reference (names) of the primaries substations that are within the distance selected on Inputs excel sheet (section 3.3.1.1 (iv)) from the new development.

(ii) Distance to development

At this column will be displayed the distance (in kilometres) that the respective primary substation is from the new development. This distance could never be higher that the distance from the primaries to the new development inserted at section 3.3.1.1 (iv).

(iii) Primary Substation Capacity

At this column will be displayed the capacity (in mega watts) from the respective primary substation. This value reports to the maximum demand that the primary substation is able to supply in normal conditions.

(iv) Margin

At this column will be displayed the margin (in mega watts) from the respective primary substation. This value reports to the difference between the primary substation capacity and the demand that the primary is supplying. This value represents the demand value that the primary substation is still capable to supply in the future without reaching their maximum capacity.

(v) Underlying Load Growth

At this column will be displayed the underlying load growth (in mega watts) of the respective primary substation. This value represents the annual load growth that is expected to happen for the respective primary substation. This load growth is the annual estimated load growth that is predicted to happen in the communities that the respective primary substation is supplying, i.e., even if no new consumers are added at the primary substation supplying area, the load related with the existing ones is expected to grow due to several factors like the use of more and more electrical devices at a dwelling.

(vi) Connection Costs

At this column will be displayed an average of the expected connection cost (millions of pounds per kilometre) for connecting the new existing loads to the respective primary substation. This value has in consideration all the cost in equipment, material and labour needed for the connection.

The information related with the primary substation reference, primary substation capacity, margin and underlying load growth is gathered from the stored databases at "Primaries Substations" excel sheet. The information relating the distance to development and the connection costs are stored respectively in the databases "Distance Development-Primaries" and "All Developments" excel sheets.

3.5.1.1- Primary Substation Information

In this section the user will visualize a table with the information for the new development electrical demand. The table is presented below:

Table 15: Constituent fractions of the new development electrical demand

Year	Housing Demand (MWh)	Housing Offset (MWh)	Commercial Demand (MWh)	Commercial Offset (MWh)	DSM Offset (MWh)	Development Demand (MW)
2008						
2009						
2010						
2011						
2012						
2013						
2014						
2015						
2016						
2017						
2018						
2019						
2020						

(i) Housing Demand

At this column will be displayed the expected housing demand (in mega watt hour) for the dwellings built in the new development analyzed.

For the first year that the new development is expected to happen, this value is achieved using the follow formula:

$$\text{Housing Demand} = \frac{\text{N} \times \text{H}}{1000 \times (\text{Yend} - \text{Ystart} + 1)} \tag{3.1}$$

Where,

N: Number of houses;

H: Average house consumption;

Yend: Year of investment end;

Ystart: Year of investment start;

1000: Factor used to convert the average house consumption value from kWh to MWh;

1: This value is added at the investment period time because the model assumes the investment starts at the beginning of the year and finishes at the end of the year.

For the remaining years that the development is expected to last, the same formula is applied and to the obtained value is added the house demand value from the precedent year. So, for a certain year, the housing demand value represents the demand of the houses built in that year plus the previous house demand registered on the development at the precedent year.

(ii) Housing Offset

At this column will be displayed the housing offset (in mega watt hour) for the dwellings built in the new development analyzed. This value represents the electricity savings that the dwellings are expected to have by adopting the selected percentage at Inputs excel sheet from micro-generation technologies, energy efficiency measures and as well as the reduction factors for DSM, micro-wind and PV panels influence. This offset is the expected annual electrical savings that are verified at peak times of the loads diagram.

For the first year that the new development is expected to happen, this value is achieved using the follow formula:

$$\text{Housing Offset} = \frac{\sum (\text{Etech} + \text{Eef})}{1000} \tag{3.2}$$

Where,

Etech: Electricity savings due to micro-generation technologies;

Eef: Electricity savings due to energy efficiency measures.

For the remaining years that the development is expected to last, the same formula is applied and to the obtained value is added the housing offset value from the precedent year. So, for a certain year, the housing offset value represents the offset from the houses built in that year plus the previous house offset value registered on the development at the precedent year.

Now, a detail explanation of the Equation 3.2 will be made.

-**Electricity savings due to each micro generation technology**:

The electricity savings due to micro-generation technologies are calculated in the same way for every technology, applying obviously the correspondent values for each technology. So, the electrical savings due to the adoption of micro-generation technologies is given by the follow formula:

$$Etech = \frac{N \times M}{(Yend - Ystart + 1)} \times Econt \tag{3.3}$$

Where,

Etech: Electricity savings due to micro-generation technologies;

N: Number of houses;

M: Percentage of micro-generation technology chosen;

Econt: Energetic contribution of the micro-generation technology;

Yend: Year of investment end;

Ystart: Year of investment start;

1: this value is added at the investment period time because the model assumes the investment starts at the beginning of the year and finishes at the end of the year.

Having this generic formula now will be presented the approach that each micro-generation technology has on this.

- Micro wind turbines:

For micro wind technology, the energetic contribution considered is only in terms of electricity. The impact of this technology on reducing the domestic electrical demand at peak times will be given by multiplying the micro-wind reduction factor (chosen in Inputs excel sheet) and the annual expected contribution of the technology expressed on Table 13.

- Solar photovoltaic panels:

For PV technology, the energetic contribution considered is only in terms of electricity. The impact of this technology on reducing the domestic electrical demand at peak times will be given by multiplying the photovoltaics reduction factor (chosen in Inputs excel sheet) and the annual expected contribution of this technology expressed on Table 13.

-Solar water heating systems:

For SWH technology, the energetic contribution considered is only in terms of heat. As it was mentioned in section 3.4.1(ix), this kind of technology is modelled to supply the hot water needs of a house. So, as the electricity consumption at single dwelling for hot water is 15% of the total electric demand (consult Figure 11), the electricity reduction obtained by the adoption of SWH systems has in consideration that the maximum value that it can assume is 15% of the average house consumption given at Inputs excel sheet.

- Ground source heating pumps:

For GSHP technology, the energetic contribution considered is only in terms of heat. As it was mentioned in section 3.4.1(ix), this kind of technology is modelled to supply the hot water needs and also space heating of a house. So, as the electricity consumption at single dwelling for hot water and space heating is 31% of the total electric demand (consult Figure 11), the electricity reduction obtained by the adoption of GSHP systems has in consideration that the maximum value that it can assume is 31% of the average house consumption given at Inputs excel sheet.

- Biomass boilers:

For biomass technology, the energetic contribution considered is only in terms of heat. As it was mentioned in section 3.4.1(ix), this kind of technology is modelled to supply the hot water needs and also space heating of a house. So, as the electricity consumption at single dwelling for hot water and space heating is 31% of the total electric demand (consult figure 11), the electricity reduction obtained by the adoption of biomass boilers has in consideration that the maximum value that it can assume is 31% of the average house consumption given at Inputs excel sheet.

- Micro combined heat and power systems:

For micro CHP systems, the energetic contribution is considered in terms of heat and electric production

So, for the electric contribution, it is assumed that these systems are able to use all the expected annual electrical production (see Table 13) on reducing the domestic electrical demand at peak times.

For the heat contribution, and as it was mentioned in section 3.4.1(ix), this kind of technology is modelled to supply the hot water needs and also space heating of a house. So, as the electricity consumption at single dwelling for hot water and space heating is 31% of the total electric demand (consult Figure 11), the electricity reduction obtained by the adoption of micro CHP systems has in consideration that the maximum value that it can assume is 31% of the average house consumption given at Inputs excel sheet.

-**Electricity savings due to energy efficiency measures:**

$$\mathrm{Def} = \mathrm{Dred} \times (\mathrm{Hd} - \mathrm{DSMof}) \tag{3.4}$$

Where,

Def: Domestic demand reduction due to energy efficiency measures;

Dred: percentage of demand reduction;

DSMof: Demand side management offset.

(iii) Commercial Demand

At this column will be displayed the expected commercial demand (in mega watt hour) that the new jobs that are expected to be created in the new development area will be responsible to.

For the first year that the new development is expected to happen, this value is achieved using the follow formula:

$$\mathrm{Cd} = \frac{\mathrm{Nj} \times \mathrm{J}}{1000 \times (\mathrm{Yend} - \mathrm{Ystart} + 1)} \tag{3.5}$$

Where,

Cd: Commercial demand

Nj: Number of jobs

J: Average commercial consumption per job

Yend: Year of investment end

Ystart: Year of investment start

1000: Factor used to convert the average commercial consumption per job value from kWh to MWh

1: This value is added at the investment period time because the model assumes the investment starts at the beginning of the year and finishes at the end of the year

For the remaining years that the development is expected to last, the same formula is applied and to the obtained value is added the commercial demand value from the precedent year. So, for a certain year, the commercial demand value represents the demand of the new jobs created in that year, plus the previous commercial demand registered on the development at the precedent year.

(iv) Commercial Offset

At this column will be displayed the commercial offset (in mega watt hour) for the jobs created in the new development area. This value represents the electricity savings that are expected to occur by the adoption of CHP systems in commerce establishments and non-domestic buildings as well as the impact of adoption of energy efficiency measures. The user at Inputs excel sheet is able to chose the percentage for the commercial electrical consume reduction that these systems would have in commercial establishments and the percentage of the electrical demand reduction that energy efficiency measures are responsible to.

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

$$\mathrm{Cof} = \mathrm{Cd} \times (\mathrm{C} + \mathrm{E}) \tag{3.6}$$

Where,

Cof: Commercial offset;

Cd: Commercial demand;

C: Percentage of Electrical consume reduction by adopting CHP systems;

E: Percentage of Electrical demand reduction by the adoption of energy efficiency measures.

(v) Demand Side Management Offset

At this column will be displayed the offset (in mega watt hour) of Demand Side Management programmes. This value represents the domestic electrical savings that are expected to be achieved due to the adoption of DSM programmes.

As it is explained in section 3.3.2.1(v), the expected impact of DSM programmes will vary according the years and also according to the chosen Supergen scenario chosen. The model also incorporates a reduction factor for the DSM impact, once the impact predicted at bibliographic references [2], [50] and [51] was considered to be too optimistic.

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

$$\mathrm{DSMof} = \frac{\mathrm{N} \times H}{1000 \times (\mathrm{Yend} - \mathrm{Ystart} + 1)} \times D \times DSMrf \tag{3.7}$$

Where,

DSMof: DSM offset;

N: Number of houses;

H: Average house consumption;

Yend: Year of investment end;

Ystart: Year of investment start;

D: percentage of DSM;

DSMrf: DSM reduction factor;

1000: Factor used to convert the average house consumption value from kWh to MWh;

1: This value is added at the investment period time because the model assumes the investment starts at the beginning of the year and finishes at the end of the year.

(vi) Development Demand

At this column will be displayed the expected electrical demand (in Mw) from all the new development.

So, for the years that the development is expected to last, the formula adopted in the model to determinate the development demand is:

$$\mathrm{Dd} = \frac{\mathrm{Hd} + \mathrm{Cd} - \mathrm{Hof} - \mathrm{DSMof} - \mathrm{Cof}}{3300} \tag{3.8}$$

Where,

Dd: Development demand;

Cd: Commercial demand;

Hof: Housing offset;

DSMof: DSM offset;

Cof: Commercial offset;

3300: Factor to convert the house and commercial demand and house, commercial and DSM offset values from MWh to MW.

3.5.1.3- Primary Substation Margin Evolution

At this section, it will be displayed the demand and the margin evolution for each primary substation that is being analyzed for the period of time since the beginning of the new development till the year 2020.

The primary substation demand evolution is determinate using the following formula:

$$\text{P.S. Demand} = \text{P.S. previous demand} + \text{Underlying Load Growth} + \text{Development Demand} \tag{3.9}$$

Where,

P.S. previous demand: Primary substation demand that is verified in the previous year of analyzes;

Underlying Load Growth: Annual underlying load growth verified at the primary substation;

Development Demand: Electrical demand of the development.

So, since the beginning of the new development till the year 2020 the primary substation demand will be determinate by adding the P.S. demand in the previous year plus the underlying load growth plus the development demand in that year.

The primary substation margin evolution is calculated by the following formula:

$$\text{Margin} = \text{P.S. Capacity} - \text{P.S. Demand} \tag{3.10}$$

Where,

P.S. Capacity: Primary substation capacity;

P.S. Demand: Primary substation demand.

The primary substation margin evolution since the first year of the development till the year 2020 will be calculated for each year by subtracting to the primary substation capacity the respective demand value for each year.

3.5.1.4- Primary Substation Ratio Evolution

At this section it will be displayed the ratio between the connection cost to link the new development to the selected primary substation and the margin of each primary substation. This ratio is determinate from the first year of the new development till the year 2020.

$$\text{Ratio}=\frac{\text{Connection Cost}\times\text{Distance}}{\text{Margin}} \tag{3.11}$$

Where,

Connection Cost: Connection cost in millions of pounds per km;

Distance: Distance from the P.S. to the development;

Margin: P.S. margin in a specific year.

The calculated ratio evolution for all primaries substations that are being analysed along the years (from the first year of the development till 2020) is also displayed in a chart. This chart enables the user to have a better visualization of the best primary substation to connect the new development loads. The best solution will be the primary substation that has the lowest value for the analysed ratio.

3.6- Model for Strategic Investment on Sustainable Electricity Networks: Databases

The model presented in this study was developed in the way that is completely adaptable for application in any other geographical areas besides the considered in this study. The only changes needed are the databases with specific information for the considered area to be analysed.

In this study, the databases were imported from the ArcGIS 9 software and stored in several excel sheets.

The databases obtained from the ArcGIS 9 software were:

- For each local district council, the domestic average consumption, commercial average consumption per job and the expected new developments. For each one of these new development was also obtained the expected year of beginning and end, the location (coordinates) and the number of houses and jobs,

- For each primary substation the location (coordinates), capacity, demand, margin and underlying load growth.

The information related with the connections costs per kilometre for connecting the new development loads to a primary substation was gathered from the “High-level model for forecasting demand growth and associated load-related expenditure” report [50] and were incorporated in the model three expected values for connection costs per km according to the network areas EPN, LPN and SPN.

3.7- Model for Strategic Investment on Sustainable Electricity Networks: Assumptions

For the elaboration of the present model some assumptions were made. Those assumptions are:

• The connection between the developments loads and a primary substation is made just to one primary substation. It´s not considered in the model the option of connecting the new development loads at more than one existing primary substation;

• Exceptional loads (occasional events with huge amount on electrical energy needs) aren´t considered in this model. Normally, when the occurrence of these events a temporary primary substation is installed with the finality of supplying those exceptional loads;

• It is not considered the impact of micro-generation technologies on the underlying load growth due to the its adoption on the non-evaluated developments;

• From ArcGIS 9 software is obtained, for a certain development, the number of houses and jobs to be created in that development as well as the number of years that the development is expected to last. It´s made the assumption that the number of houses and jobs to be created per year is an average of the total expected number of houses and jobs and the number of years that is expected to last the development;

• It is assumed, in case of having negative loads in the network, that the existing electrical network is able to handle with no further reinforcement or investment, those negative loads. A negative load from a development could eventually happen in the case of the offset of the micro-generation technologies adopted in the development have a higher value than the value of the development electrical needs. In this case, it will be verified a negative value for the development demand and, instead of consuming electricity from the network, the development would export the surplus to the same network and to these eventual energy exported to the network is called negative loads;

• At the model, for the different power values used, 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). Therefore all the power values expressed at the models are in MW.

3.8- Model for Strategic Investment on Sustainable Electricity Networks: Author Contribution

The flowchart of the model with its main stages will be now presented. This flowchart briefly resumes the model structure and the way it operates.

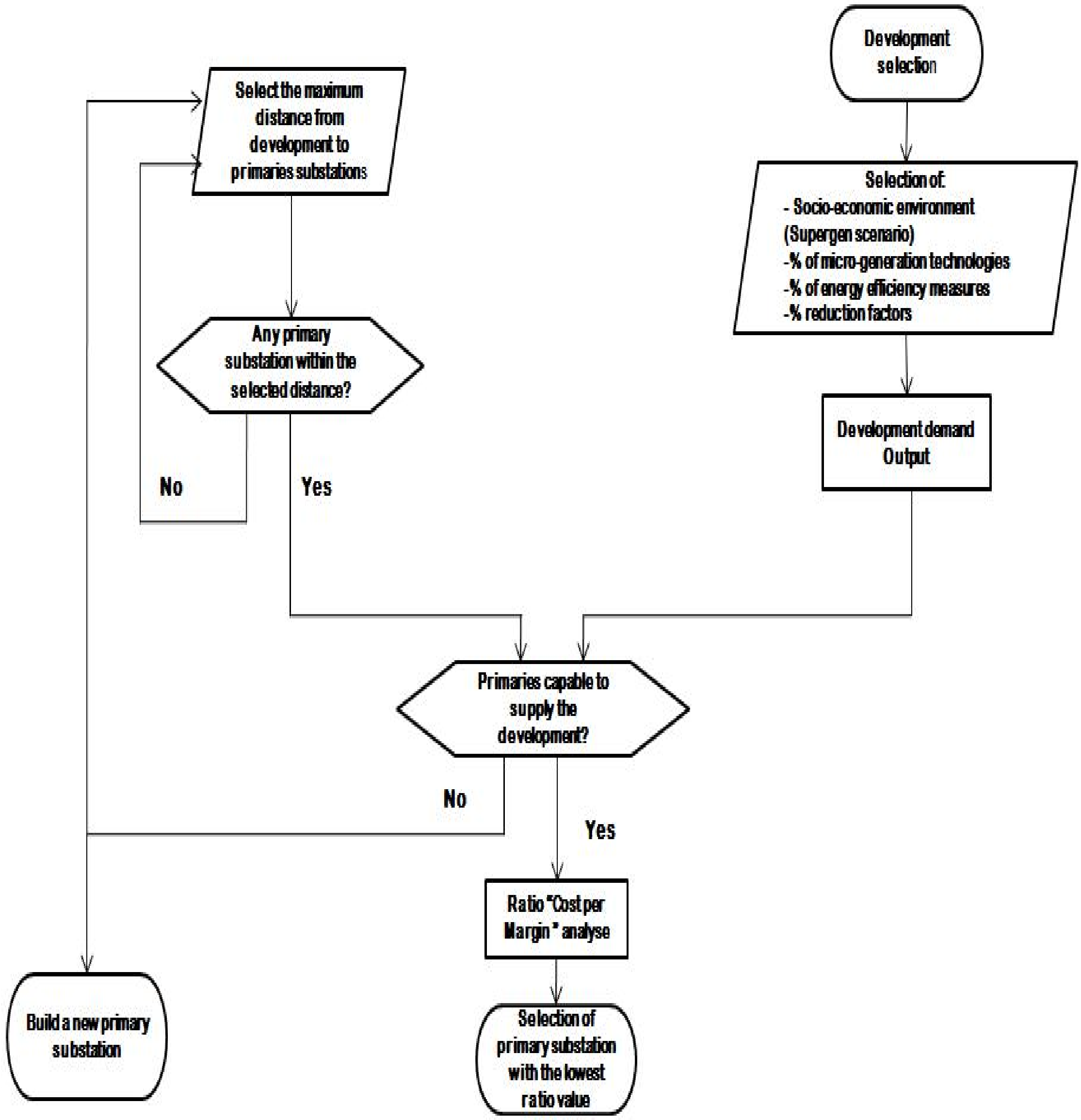

Figure 12: Model for Strategic Investment on Sustainable Electricity Networks flowchart

The model for Strategic Investment on Sustainable Electricity Networks represented with the previous flowchart at Figure 12 was developed in collaboration with Ricardo Azevedo (University of Porto student) at EDF Energy, United Kingdom. The model development was a combined effort and the author contribution for develop the model for Strategic Investment on Sustainable Electricity Networks will be now detailed.

The author was responsible for researching the aspects regarding socio-economic backgrounds, governmental measures related with micro-generation and sustainable measures and to incorporate these aspects in the developed model.

The author was also responsible for elaborating the routines to link GIS databases to the model and for suit and modelling the imported information from GIS into the excel databases.

Chapter 4

Investment Strategies for Sustainable Electricity Networks - Urban Environments

In this chapter it will be addressed the main issues and results obtained by using the developed model at new developments that are expected to happen in urban environments (cities). Although the presented model could be both used at urban or rural developments, each one of these environments has specific constrains and the main ones for the application of this model at urban environments will be exposed within this chapter.

4.1 - Major constraints to obtain the best investment solution

For a specific development, there could be several possible solutions for connecting the loads from that development to a primary substation. The best solution for this investment could vary according several factors. Those factors are:

- Impact of energy efficiency measures at the electrical demand of the new development;
- Penetration of specific domestic micro-generation technologies (each one of them have different impacts on the domestic electrical demand);
- Impact of CHP systems for the reduction of commercial electric demand;
- Impact of DSM programmes at the electrical domestic demand of the new development;
- Impact that seasonal weather has in the electrical production from the micro-generation technologies;
- Impact of the selected Supergen scenario;
- Distance of primaries substations to new developments (for longer distances the number of primaries substations considered will be higher).

As it is possible to see, there are several scenarios that could occur, according to different possible applications of these factors. So, a sensitivity analyze of these factors will be made in the further section.

4.2 - Sensitivity Analyse: backgrounds

As it was previously mentioned, in this section it will be analysed the factors that can affect the model solution for the best investment strategy for connecting the loads from a development to a primary substation.

This analyse will be made having in consideration that the new development is at an urban environment. This means that the sensitivity and fluctuation of the factors analysed are according to the expectations for an urban environment. The expected fluctuation of each factor for an urban environment will be review in the first sub-chapter of this section (Sensitivity Analyse-Background for Urban Environments), and the obtained results from these will be presented at the second sub-chapter of this section (Sensitivity Analyse-Results).

4.2.1- Energy efficiency measures

Energy efficiency measures are measures that could be either in terms of the building construction (double glazing, building insulation, efficient lighting appliances, etc) or behavioural measures (turning off all the electrical equipments when they are not needed, adoption of the most suitable electrical tariff for each specific costumer, etc). The adoptions of these measures are assumed, in this study, to have reduction in a building electrical demand of a maximum value of 17% [5], [64].

The percentage of the impact of energy efficiency measures is selected by the user at Inputs excel sheet and is the same percentage of the development demand that will be reduced due to the adoption of these measures.

4.2.2- Penetration of specific micro-generation technologies

As it was detailed documented at section 2.5, some of the micro-generation technologies that the model enables the user to choose are not suitable for urban developments applications. So, for an urban development, the application of micro- wind turbines, ground source heating pumps and biomass boilers will not be considered in this analyse.

So, according to geographical and social characteristics of each development, several solutions for micro-generations technologies can be adopted. For the adoption of the best option of micro-generation technology to implement in a specific development, and according to the “Urban Planning for a Low Carbon Future” report [66], there are several requirements:

- Understanding local requirements and opportunities for decentralised energy to supply existing and new development. This could take the form of a GIS-based heat or energy plan.

- Setting CO_2 and/or decentralised (i.e. on-site and near-site) renewable and low carbon energy targets for the local authority area as a whole. These should be supported by the evidence gathered under the previous condition. In addition, where particular local opportunities exist, higher site or area specific targets can be set. These should be set out in Site Specific Allocations or Area Action Plans.

- Facilitate the creation of local decentralised energy networks. Policies will need to ensure that developers consider the opportunities for on-site energy systems in new developments to contribute to wider decentralised networks. This can be facilitated by policies that require new developments to connect to existing decentralised energy networks. These could be further enabled 'on the ground' by Local Development Orders.

There are three micro-generation technologies that are suitable and expected, according to the items above, to be implemented at urban developments. Those micro generation-technologies are Micro-CHP systems, PV panels and SWH systems. Considering these technologies, there are several different scenarios for the application of the same at an urban development. Those scenarios will be described below but for each there´s a common factor.

The common factor is that although for a new development it seems logical that all the new houses built adopt the same micro-generation technology, it´s not a completely certain that all the houses adopt the micro-generation technology and have the equipments always working properly. The adoption for micro-generation technologies by the user are in most cases related with incentives and contributions that are given by governmental institutions and organizations. So, according to the incentives available at the moment of the installation of micro-generation equipments (these values will depend on multiple factors like, for example, the country policy for supporting renewables, economy or CO_2 emissions targets), this incentives could be interesting for costumers but not for all and so, the adoption for a certain micro-generation technology at a new development could be different from 100%. Besides this, there's a probability that even the costumers that adopt the micro-generation systems, do not have them at their ideal operation mode or working properly all the time.

Due to the previous uncertainties, for all micro-generation technology will be considered four values for their implementation at the development dwellings. Those values are 25%, 50%, 75% and 100% of implementation.

(i) New development with the adoption of micro-CHP systems

In this scenario, it will be simulated the impact that the adoption of micro-CHP systems has in the development electrical demand. As it was previously explained, it will be considered an implementation of 25%, 50%, 75% and 100% of micro CHP systems at domestic dwellings.

(ii) New development with the adoption of micro-CHP systems and photovoltaic panels

In this scenario, it will be simulated the impact that the simultaneously adoption of micro-CHP systems and PV panels has in the development electrical demand. It is assumed a 25%, 50%, 75% and100% implementation of PV panels and micro-CHP systems.

The hypothetical scenario of the simultaneously adoption of micro-CHP and SWH systems will not be considered because the SWH are systems that are designed to provide heat (hot water) at a dwelling, but, as micro-CHP supply integrally the dwelling needs of heat, the investment in a supplementary SWH system would be unnecessary and therefore, this hypothetical scenario is extremely unlikely to happen.

(iii) New development with the adoption of photovoltaic panels

In this scenario, it will be simulated the impact that the adoption of PV panels has in the development electrical demand. In this scenario it will be considered an implementation of 25%, 50%, 75% and 100% of PV panels.

(iv) New development with the adoption of photovoltaic panels and solar water heating systems

In this scenario, it will be simulated the impact that the simultaneously adoption of PV panels and SWH systems has in the development electrical demand. It is assumed a 25%, 50%, 75% and 100% implementation of PV panels and SWH systems.

(v) New development with the adoption of solar water heating systems

In this scenario, it will be simulated the impact that the adoption of SWH systems has in the development electrical demand. In this scenario it will be considered an implementation of 25%, 50%, 75% and 100% of SWH systems.

4.2.3- Impact of CHP systems in commerce establishments and other non-domestic buildings

Combined heat and power systems are considered to have an impact at reducing the expected commercial demand caused by the adoption of these systems by the commerce establishments and other non-domestic buildings built in the urban development. So, it is expectable that some of the commerce establishments and non-domestic buildings expected for that development adopt CHP systems for supplying their heating needs and also produce electric energy. In this study it is assumed that the adoption of CHP systems in commerce establishments and non-domestic buildings will have as its maximum impact, a reduction of 25% of commerce electrical demand [52]. But, depending on each urban environment analyzed and the specific typology (number of stores, shopping, hospitals, etc), the eventual needs for the adoption of CHP systems for commercial establishments and non-domestic buildings may vary significantly and as a consequence, the impact that these systems have at reducing the commercial demand varies also.

So, to understand the impact that the percentage of commercial demand reduction (due to the application of CHP systems) have on the total development demand, the formula to determinate the development demand is now presented,

$$\text{Development demand} = \text{Total domestic demand} + \text{Total commercial demand} \qquad (3.12)$$

As it is possible to see at the equation 3.12, the development demand is the sum of the total domestic demand (this already includes the offset from DSM programmes, from energy efficiency measures and micro-generation systems installed) plus the total commercial demand (this already includes the offset from energy efficiency measures). So, the impact of the percentage of commercial demand reduction (due to the adoption of CHP systems) have on the development demand is reducing the total commercial demand from the equation 3.12 in the same percentage. This impact can be formulated in the follow equation:

$$\text{Development demand} = \text{Total Domestic Demand} + (1-\chi) \times \text{Total Commercial Demand} \qquad (3.13)$$

Where,

χ : percentage of the commercial demand reduction due to the adoption of CHP systems at commercial establishments and other non-domestic buildings.

4.2.4- Impact of Demand Side Management programs

The implementation of demand side management programmes on domestic costumers is considered to have an impact on reduction the domestic demand from the urban development and, as a consequence, the total development electrical demand also. The domestic electrical demand reduction that DSM programmes are expected to cause are different according to the year in analyze as well as the selected Supergen scenario, but these reduction percentage (determinate by the understanding of the bibliographic references [2], [50], [51]) are considered to be to optimistic and the model incorporates the possibility of choosing a factor that enables a reduction of the DSM considered values. For each one of the three Supergen scenarios considered, and according to the bibliographic reference [50], it is proposed a value for this reduction factor. So, for continuing prosperity scenario this proposed value is 30% of the previous considered value for DSM, for economic concern scenario the proposed value is 15% and for environmental awakening scenario is 50%.

The impact that the DSM reducing factor will have at reducing the development demand will be now formulated.

As it was previously presented, the development demand is determinate by the follow equation:

$$\text{Development demand} = \text{Total Domestic Demand} + \text{Total Commercial Demand} \qquad (3.14)$$

And the total domestic demand is obtained by the equation:

$$\text{Total Domestic Demand} = \text{housing demand} - \\ - (\text{energy efficiency offset} - \text{microgeneration offset} - \text{DSM offset}) \quad (3.15)$$

So, the impact that DSM reducing factor has on reducing the domestic demand can be shown in the follow equation:

$$\text{Total Domestic Demand} = \text{housing demand} - \\ - [\text{energy efficiency offset} - \text{microgeneration offset} - ((1 - \chi) \times \text{DSM offset})] \quad (3.16)$$

Where,

χ : percentage of the DSM reducing factor

So, the impact that DSM reducing factor has on the development demand is:

$$\text{Development demand} = \{\text{housing demand} - [\text{energy efficiency offset} - \text{microgeneration offset} - ((1 - \chi) \times \text{DSM offset})]\} + \\ + \text{Total Commercial Demand} \quad (3.17)$$

4.2.5- Impact that seasonal weather has on micro-generation technologies

Energetic performances and possible energetic contribution of each micro-generation technology is an issue that is well documented and there are several studies that make a prediction of the different micro-generation technologies energetic contribution per year. But, for the study here proposed, the energetic impact of each micro-generation technology has to be the expected impact of the respective technology on the peak time of the daily load profile of the development (this fact is related to the necessary determination of the development electrical demand at the peak time, and further analyze of possible primaries substation that are able to supply that demand at their peak time). So, to determinate the technology energetic contribution at the peak time, the expected typical daily load profile and the specific technology daily generation profile are analysed. According to this analyse and the expected contribution of each micro-generation technology per year is possible to determinate the contribution of the specific technology for reducing the development electrical demand at the peak time.

One major factor that has implication on the generation of each micro-generation technology is the weather. So, and for the expectable micro-generation technologies to be applied in an urban environment (micro-CHP, PV, and SWH), the influence of the weather and meteorological conditions will have an impact on the generation of photovoltaic panels and solar water heating systems. Micro-CHP is a technology that uses as a fuel mostly gas, and the weather will not have impact on the technology expected production at the peak time.

Although the meteorological conditions will have an impact at the annual generation of PV panels and SWH systems, the approach for these two technologies need to be distinct. The main reason for that is that SWH systems have the capability to store the heat water at tanks and use that heat water when it is most needed (peak times), so the average annual contribution of this technology is, in the same way that micro-CHP systems, expected to be used mostly in the peak times.

Therefore, for PV panels, due to the fact that this systems produce electricity whenever is sun and not mostly at peak times, and due to the fact that in urban environments these systems are connected to the electrical grid and it is not expectable the adoption of batteries (too expensive), there is not possible to store the produced energy for further use at peak times. So, a factor for reduction the average energetic contribution per year of this technology is implemented at the model. According the load daily profile, technologies daily generation profile and also the weather, it is expected a possible contribution for PV panels of 10% (of the annual energetic contribution) for low sunny years and 50% (of the annual energetic contribution) for sunny years. For a year with average levels of solar radiation it is expected a contribution of around 25% of the total annual contribution of this kind of technology. To understand the impact that the weather conditions could have at the development electrical demand, it will be presented the follow equation of the development demand:

$$\text{Developmen t demand} = \text{Total Domestic Demand} + \text{Total Commercial Demand} \tag{3.18}$$

And the total domestic demand is obtained by the equation:

$$\begin{aligned}\text{Total Domestic Demand} = {} & \text{housing demand} - \\ & (\text{microgeneration offset} - \text{energy efficiency offset} - \text{DSM offset})\end{aligned} \tag{3.19}$$

So, for the scenarios where the micro-generation adopted at a new development is photovoltaic panels, the impact that PV reducing factor has on reducing the domestic demand can be shown in the follow equation:

$$\begin{aligned}\text{Total Domestic Demand} = {} & \text{housing demand} - \\ & -[(1-\chi) \times \text{microgeneration offset} - \text{energy efficiency offset} - \text{DSM offset}]\end{aligned} \tag{3.20}$$

Where,

χ :percentage of the PV reducing factor

The impact that PV reducing factor has on the development demand is (when PV panels are the micro-generation technology adopted):

$$\text{Developmen t demand} = \{\text{housing demand} - [(1-\chi) \times \text{microgener ation offset} - \text{energy efficiency offset} - \text{DSM offset}]\} + \\ + \text{Total Commercial Demand} \tag{3.21}$$

4.2.6- Impact of Supergen scenarios

The choice for one of the three Supergen scenarios will have an impact on the development demand. This is due to the fact that the Supergen scenario chosen by the user at Inputs excel sheet would affect the expected number houses and jobs at the development, the DSM percentages to reduce the development demand and for each Supergen scenario a recommendation for the DSM reduction factor is also made. These considerations were further detailed at section 3.3.1.1(v).

To see the impact on the development demand that the choice of one Supergen scenario has, there were simulated in the model all the three Supergen scenarios and the differences at the development electrical demand were registered. For each Supergen scenario simulated was selected a specific value for the DSM reduction factor. This is due to the fact that for each Supergen scenario a specific value for the DSM reduction factor is predicted (see section 3.3.1.2). To analyze the impact of the Continuing Prosperity scenario at the development electrical demand, besides choosing this scenario, was simulated a reduction factor for DSM of 30%. For Economic Concern scenario was simulated a DSM reduction factor of 15% and for Environmental Awakening scenario the DSM reduction factor simulated was 50%.

4.2.7- Distance of primaries stations to new development

The model developed in this study, enables the user to choose the best primary substation to connect the new development loads from the list of primaries that are being analysed. That number of primaries substations to appear in that list will vary according to the maximum distance of primaries substation to the new development chosen in the model. So, if the user chooses a distance of 2 km, the primaries that are gone be analysed are the ones that are within 2km from the development. Although this parameter will have influence on choosing the best primary substation to connect the loads, it is not possible to “generalize” for a specific distance, the number of primaries substations to analyse will be a specific number. This is because depending on the geographical location of the selected development, within a specific number of km, the number of primaries could be completely different from another development located in another area.

4.3- Sensitivity Analyse: Results

In this section, it will be presented the results of the sensitivity analyse made for some of the factors presented at section 4.1. So, for study the micro-generation technologies and Supergen scenarios it will be simulated in the model the impact of those on the development demand.

For energy efficiency measures, CHP systems in commercial establishments, DSM programmes and seasonal weather there´s not need any simulation using the model once the way that this factors influence the development demand were already quantified and detailed at section 4.2.

4.3.1- Impact of micro-generation technologies

According to the type/types of micro-generation technology adopted in the development, the electrical demand will be significantly different. So, for the possible combinations of micro-generation technologies the development demand behaviour will be analyzed.

It was several times mentioned that the development demand is obtained by adding the total domestic demand plus the total commercial demand. As the adoption of micro-generation technologies has only impact at reducing the domestic demand (these technologies are not considered to have an impact at commercial demand), it is important to specify the percentage of commercial and domestic demand at the total demand of the specific development.

Therefore, to analyse the impact of micro-generation technologies on reducing the development demand, it was simulated a development where the total domestic demand was responsible for 72% of the development demand and the commercial demand responsible for 28% of the development demand (this values were the corresponding to the development further analysed at section 4.4.1.2

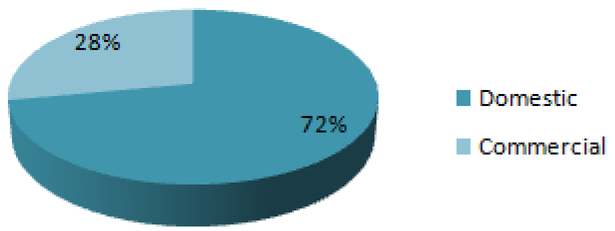

Figure 13: Weight of domestic and commercial demand at the total development demand

For analyze the impact of micro-generation at the development demand were simulated several scenarios and for those who adopt photovoltaics panels as the micro-generation technology implanted at the development, a reduction factor for the PV electrical contribution of 25% was chosen. The choice of 25 % was based on the fact that this is the expected contribution of this technology at peak times for an average year. In extreme years where there´s very low levels of solar radiation this value can be as low as 10% or if the solar radiation values are very high this value can be up to 50%. Once these boundary levels are extremely unlikely to happen and the most common value for PV´s contribution at peak times is around 25% of its total electric contribution in a year, the value of 25% for PV reduction factor was chosen for the scenarios simulation.

Having this, it will be now presented the obtained results for the implementation of different possibilities of micro-generation technologies at the development dwellings. It was considered four different implementation values, 25%, 50%, 75% and 100%.

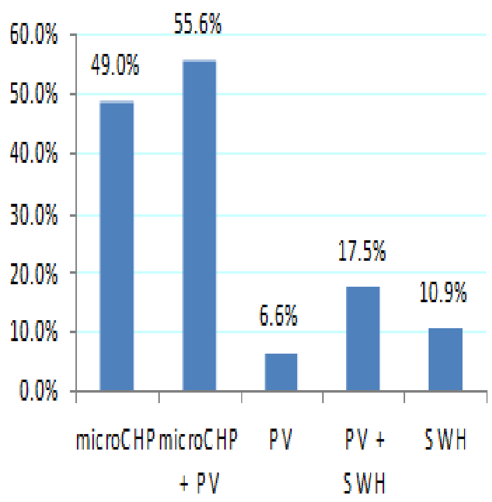

Figure 14: Development electrical demand reduction according to 100% implementation of different micro-generation technologies

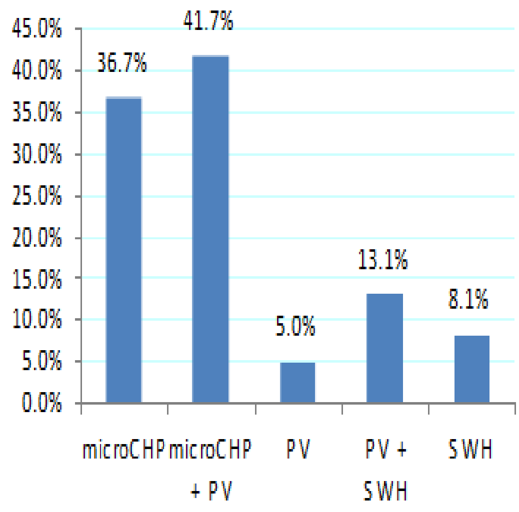

Figure 15: Development electrical demand reduction according to 75% implementation of different micro-generation technologies

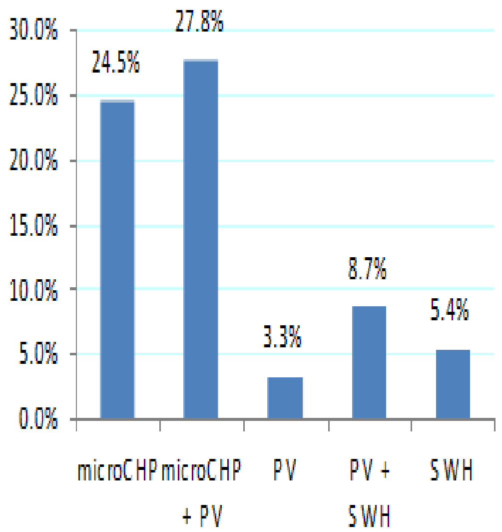

Figure 16: Development electrical demand reduction according to 50% implementation of different micro-generation technologies

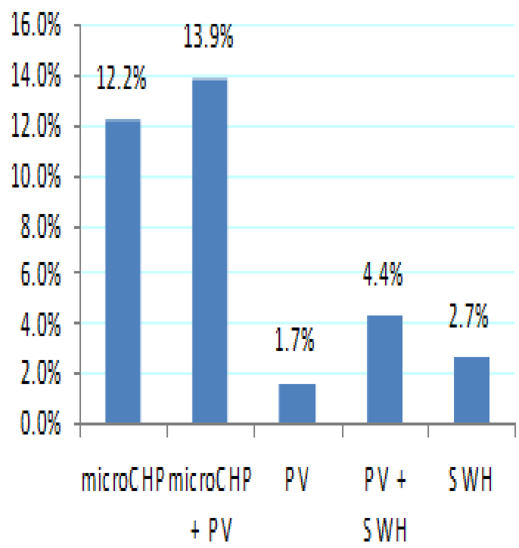

Figure 17: Development electrical demand reduction according to 25% implementation of different micro-generation technologies

The charts expressed from Figure 14 to Figure 17 are extremely elucidative about the expected impact that each micro-generation technology, according to their implementation at development dwellings, could have to reduce the development demand in peak times.

By analysing these charts it's possible to conclude that the simultaneously adoption of micro-CHP systems and PV panels is the scenario where it's verified a greater reduction on development demand. The scenario that has the smaller impact on reducing the development demand, at peak times, is the one in which there's only adopted PV panels, which means that CHP systems have much more influence at reducing the development demand, at peak times, than PV panels. This fact can be visualized at Figure 18.

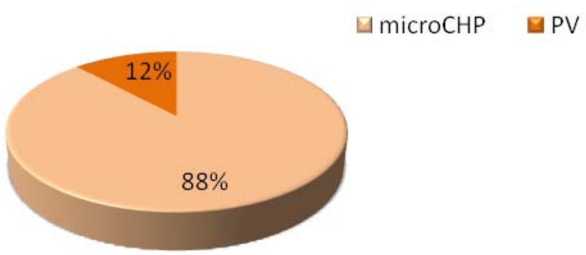

Figure 18: Comparative contribution of PV pannels and micro-CHP systems (when applied simultaneously) for reducing the development demand

In the same way, when it's adopted at development dwellings PV panels and SWH systems, it's possible to determinate which contribution will have each system to reduce the development demand. This can be visualized at Figure 19.

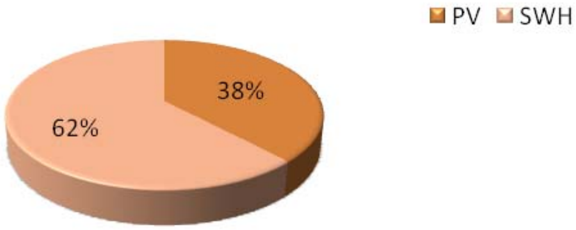

Figure 19: Comparative contribution of PV pannels and SWH systems (when applied simultaneously) for reducing the development demand

So, when applied simultaneously at development dwellings, micro-CHP systems are responsible for 88% of the total development demand reduction and PV panels are responsible only for 12% of that value. When applied simultaneously PV panels and SWH systems, SWH systems are responsible for 62% of the total development demand reduction and PV panels are responsible only for 38%.

4.3.2- Impact of Supergen scenarios

The development electrical demand is expected to vary according to the Supergen scenario adopted in the model. So, the analyse between the impacts that the choice of each Supergen scenario has on the development electrical demand will be made.

Supergen scenarios, as it was described at section 4.2.6, will affect the development domestic and commercial demand. But Supergen scenarios do not affect them exactly in the same proportion. Supergen scenarios adopted have influence in the number of houses and jobs predicted for the development as well as for the values predicted for DSM impact on domestic demand. Once the DSM programmes are supposed, in this model, to reduce only the domestic demand and not the commercial demand, the impact that the selection of Supergen scenarios has on the development demand will vary (even in a not much significant way) from development to development according to the percentage that the domestic and commercial demand assume for each development.

Therefore, to analyse the impact of Supergen scenarios on reducing the development demand, and in the same way as in section 4.3.1, it was simulated in the model a development where the total domestic demand was responsible for 72% of the development demand and the commercial demand responsible for 28% of the development demand (this values were the corresponding to the development further analysed at section 4.4.1.2.

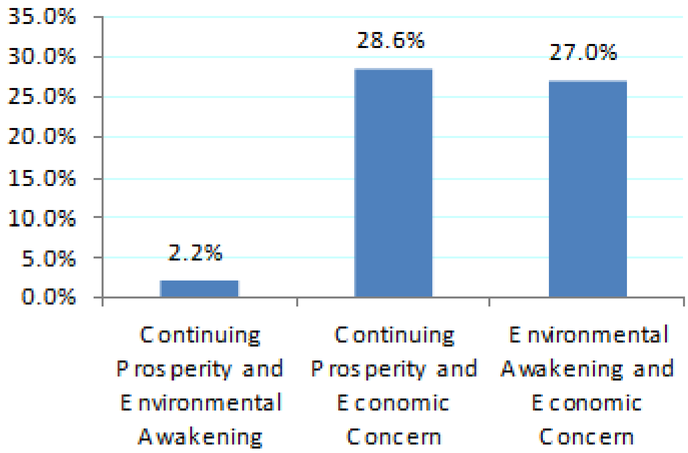

Figure 20: Development electrical demand reduction according to adoption of different Supergen scenarios

Analyzing Figure 20 is possible to understand the impact that the choice of Supergen scenarios will have in the development electrical demand.

It was verified a development electrical demand reduction of 2.2% between the Continuing Prosperity and Environmental Awakening scenarios. This means that the development demand will be 2.2% lower by adopting the Environmental Awakening scenario (and a DSM reduction factor of 50%) than it would be if the scenario adopted was Continuing Prosperity (and a DSM reduction factor of 30%).

The development electrical demand reduction will be 28.6% when are compared the Continuing Prosperity and the Economic Concern scenarios. The Economic Concern scenario (with a DSM reduction factor of 15%) would enable a development electrical demand reduction of 28.6% instead of the adoption of Continuing Prosperity scenario.

A 27.0% reduction of the development electrical demand was verified when were compared the Environmental Awakening and Economic Concern scenarios. The development demand was verified to be 27.0% lower with the Economic Concern scenario that it would be with the adoption of Environmental Awakening scenario.

With these sensitivity analyses results it's is possible to understand that if the user, for a specific analyse using the model, predicts that the Supergen scenario will be the Continuing Prosperity scenario and, in the future, when the development finishes its construction and all loads were connected to primary substation, the socio-economic situation was closer to the one predicted with the Environment Awakening scenario, the development demand predicted will be probably around 2.2% higher that the real one verified after all developments loads where connected (this difference is considering that only the prediction of the Supergen scenario was different from what happen in reality and considering that for all the other factors, the values predicted were the same that in fact happen after the development finishes).

As it's possible to understand, a variation of 2.2% of the predicted demand using the model is not much, but if the user predicts that the Supergen scenario would be Continuing Prosperity or Environmental Awakening and, matter of fact, happen that the socio-economic situation at the development time is similar to the one estimated in Economic Concern Supergen scenario, the predicted demand would be much higher than the one verified in reality, 28.6% and 27.0% respectively.

This is a great variation for the development demand values considering that the only difference from the prediction made and reality was the socio-economical scenario, and all the other factor like energy efficiency measures, micro-generation technologies adopted at the development dwellings and CHP systems installed for commercial and non-domestic buildings had exactly the same values that the ones predicted. So using this model, the choice of the pretended Supergen scenario could have a great impact at the expected development demand once the predicted impact on development demand of Continuing Prosperity and Environment Awakening Supergen scenarios is very different from the one considered for Economic Concern Supergen scenario.

4.4 - Investment Assessment

In this section it will be analysed several investment solutions for a specific urban development. There will be defined a set of possible scenarios, and the impact that each one have on determinate the possible investment solutions will be detail analysed and a critical analyse will be made.

The inherent risk of the expected development be postponed or anticipated will be also analysed and the impact on the investment solutions described.

4.4.1 - Development Details and Scenarios Consideration

To analyse the investment solutions for connect the loads from a new development to a primary substation a predicted new urban development will be selected and subsequently defined and analysed a set of possible scenarios that may happen in that development.

4.4.1.2- Development Details

Using the ArcGIS 9 software, it was selected an expected new development within Cambridge local authority district, located near the Cambridge city centre (therefore a development in an urban environment). The selected development is a new development predicted to start at the beginning of the year 2014 and finishes by the end of 2015. There are predicted for the development 1580 new houses and 470 new jobs. This information is given by the ArcGIS 9 software. Cambridge local authority district is located in EPN area and some screenshots obtained with ArcGIS 9 software will be now presented.

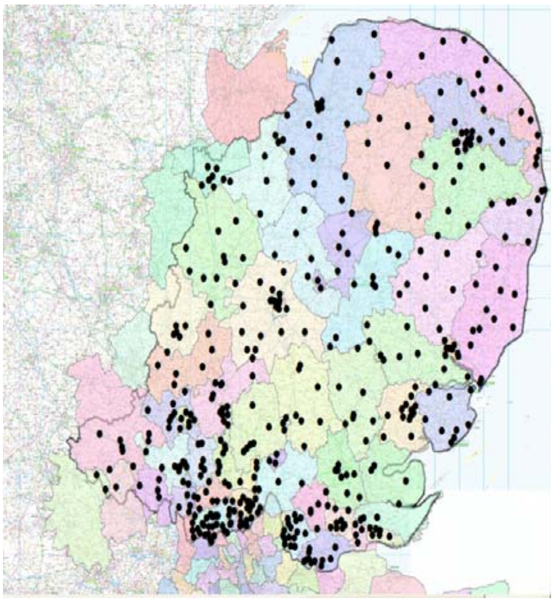

Figure 21: Map of the location of the existing Primaries Substations within EPN area

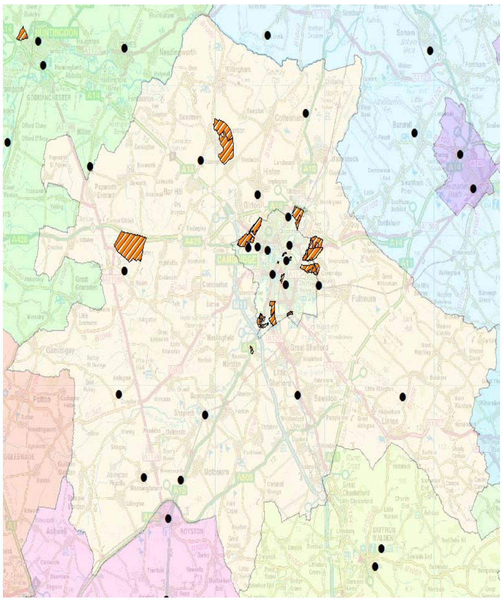

Figure 22: Map of the new developments expected to be built till the 2020 year within Cambridge Local Authority District

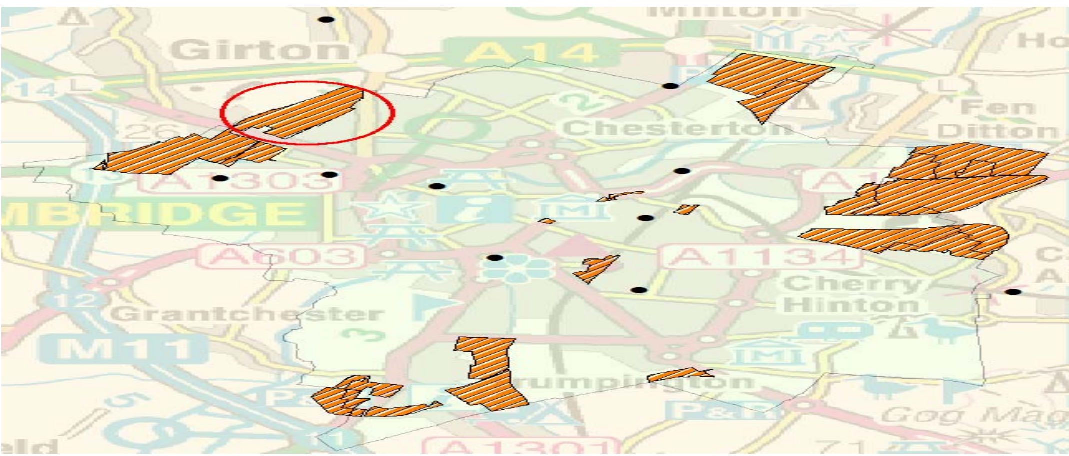

Figure 23: Map of the location of the new development selected for this study and location of the Primaries Substation within the city of Cambridge

4.4.1.3- Simulated Future Scenarios Considerations

Having the new development defined, for study the several options for connecting that new development loads to a primary substation a set of possible scenarios will be simulated with the model.

The set of scenarios were formulated considering that the development dwellings could adopt different kinds of micro-generation systems and even for each micro-generation systems adopted, there could be several values for their implementation as well as for other factors that influence the development demand.

Therefore, once that for urban environments were considered the possible adoption of PV panels, micro-CHP systems, SWH systems, PV panels + CHP systems and SWH systems + PV panels, for each one of these five options of micro-generation technologies adoption at the development, were considered three different scenarios. These three different scenarios incorporate each one, different values for the model Inputs. They were selected in a way to try to predict a plausible future according to socio-economical situation that may be verified at the time of the development implementation.

(i) Environmental Awakening Scenario

The first scenario is defined as the Environmental Awakening scenario. This name definition for this scenario was made because the Supergen scenario selected was the Environmental Awakening scenario.

Under this scenario the selected percentage of electrical demand reduction due to energy efficiency measures is 17%. This is the maximum demand reduction that is expected to be achieved by adopting energy efficiency measures at the new development. The consideration of the expected maximum value in this scenario was made because under the Supergen Environmental Awakening scenario it is expected a high level of environmental and ecological concerns, and the commitment with measures that prove themselves to be economical viable and environmental-friendly, will have great acceptance.

The expected penetration of each micro-generation technology is considered to be 100% under this scenario. This is because under Environmental Awakening scenario besides people more sensitized to the environmental advantages of onsite generation, the expected governmental support and incentives for the adoption of micro-generation technologies is likely to be appealing and compensatory for all the development costumers.

The commercial demand reduction in commerce establishments and other non-domestic buildings by adopting CHP systems is considered, under this scenario, to be 20%. The “The Essential Guide to Small Scale Combined Heat & Power” report [52], refers that the adoption of CHP systems can reduce up to 25% of the electrical demand of the establishment that adopts these systems. As it is not likely that every non-domestic buildings at the new development adopt these systems (some of them may not be as suitable as others), the consideration that the adoption of these would reduce the commercial demand in 20% is made because under the Supergen Environmental Awakening scenario, the adoption of these systems are expected to be high due to the fact of being economically compensatory (due to governmental incentives) and the general receptivity for adopting micro-generation solutions that are environmental friendly.

The DSM reduction factor is considered to be 50%. The adoption of this value is due to the fact that this is the expected value for the percentage of the DSM reduction factor under the Supergen Environmental Awakening scenario (c.f. [50]).

The reduction factor for the photovoltaic panels contribution is considered to be 25%, because this is the previewed value for this factor considering a year with average levels of solar radiation (consult section 4.2.5)

(ii) Continuing Prosperity Scenario

The second scenario is defined as the Continuing Prosperity scenario. This name definition for this scenario was made because the Supergen scenario selected was the Continuing Prosperity scenario.

Under this scenario the selected percentage of electrical demand reduction due to energy efficiency measures is 10%. The most optimistic expected value for this Input is 17% but this is only likely to happen under conditions where the environmental concerns are high. As under the Supergen Continuing Prosperity scenario energy efficiency measures are expected to be strongly promoted, the 10% value for electrical demand reduction due to energy efficiency measures (of a possible maximum of 17%) was assumed.

In this scenario, the expected penetration of each micro-generation technology is considered to be 75%. Under the Supergen Continuing Prosperity scenario is expected governmental incentives to have strong implementation although not in the same proportion as in the Environmental Awakening scenario. The level of public concern with environment issues is also, not as high as is supposed to be in the Environmental Awakening scenario. So, the consideration of 75% of implementation of micro-generation technology is considered a reasonable estimation because the incentives may not be enough attractive for a minority of the development costumers.

The commercial demand reduction in commerce establishments and other non-domestic buildings by adopting CHP systems is considered, under this scenario, to be 10%. Under the Environmental Awakening scenario the considered value for this factor was 20%. Due to the fact that under the Supergen Continuing Prosperity scenario the expected governmental incentives and the general costumers receptivity are not as high as it is supposed to be at Environmental Awakening scenario, the consideration of 10% of electrical consume reduction in commerce establishments and other non-domestic buildings by adopting CHP systems was assumed.

The DSM reduction factor is considered to be 30%. The adoption of this value is due to the fact that this is the expected value for the percentage of the DSM reduction factor under the Supergen Continuing Prosperity scenario (c.f. [50]).

The reduction factor for the photovoltaic panels contribution is considered to be 25%, because this is the previewed value for this factor considering a year with average levels of solar radiation (consult section 4.2.5).

(iii) Economic Concern Scenario

The third scenario is defined as the Economic Concern scenario. This name definition for this scenario was made because the Supergen scenario selected was the Economic Concern scenario.

Under this scenario the selected percentage of electrical demand reduction due to energy efficiency measures is 10%. The most optimistic expected value for this Input is 17% but this is only likely to happen under conditions where the environmental concerns are high. But at Supergen Economic Concern scenario energy efficiency measures are also expected to be promoted and adopted because costumers under this scenario are supposed to the concerned about the economy and all the measures that enable savings are expected to have a high level of adoption. So, the 10% value for electrical demand reduction due to energy efficiency measures (of a possible maximum of 17%) was assumed.

In this scenario, the expected penetration of each micro-generation technology is considered to be only 25%. This value is quite lower from the ones assumed for Environmental Awakening or Continuing Prosperity scenarios. This is due to the fact that under the Supergen Economic Concern scenario, the governmental support and incentives for the adoption of micro-generation technologies are not expected to be strong and therefore, not likely to be appealing and compensatory the majority of the development costumers. The fact that the economy under this scenario is expected to be “retracted”, the option of a significant investment for implementing a micro-generation technology is supposed to be very unattractive for most costumers.

The commercial demand reduction in commerce establishments and other non-domestic buildings by adopting CHP systems is considered, under this scenario, to be 5%. The considered 5% commercial demand reduction was made because, in the same way the governmental incentives and supports for domestic micro-generation technologies are not expected to be attractive enough for the majority of the costumers, for the adoption of CHP systems at non-domestic buildings the incentives are also unlikely to be attractive for commercial customers. Therefore, the impact for the commercial reduction due to the adoption of CHP systems at non-domestic buildings is not supposed to be very high, assuming the 5% value under the Supergen Economic Concern scenario.

The DSM reduction factor is considered to be 15%. The adoption of this value is due to the fact that this is the expected value for the percentage of the DSM reduction factor under the Supergen Economic Concern scenario (c.f. [50]).

The reduction factor for the photovoltaic panels contribution is considered to be 25%, because this is the previewed value for this factor considering a year with average levels of solar radiation (consult section 4.2.5).

4.4.2 - Investment Solutions: Model Outputs

In this section it will be presented a detailed analyse of the obtained results for the scenarios simulation with the developed model.

The charts presented at the further section do not represent the cost/margin evolution from those primaries that, at the year of start of development, are expected to have a negative value for its free margin, i.e., the full capacity of the primary substation was achieved and the demand supplied is higher than the primary substation capacity. Due to this fact, these primaries substation were not considered in this analyse because they are not capable to cope with the demand asked by the expected development loads.

So, for each scenario, the model results will be presented and a further discussion of them will be made.

4.4.2.1-Simulation Results

The charts and tables obtained with the model simulation for the several defined scenarios will be now displayed.

4.4.2.1.1- New development with adoption of PV panels

(i) Environmental Awakening Scenario

Table 16: Primaries Demand and Margin evolution for PV adoption and Environmental Awakening scenario

Primaries	2014		2015		2016		2017		2018		2019		2020	
	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin
E13 RADNOR PRIMARY	28,6	9,6	30,1	8,0	30,8	7,4	31,4	6,8	32,0	6,2	32,6	5,6	33,2	5,0
E11 STOREYS WAY PRIMARY	27,0	-4,9	28,6	-6,6	29,3	-7,2	30,0	-7,9	30,6	-8,5	31,3	-9,2	31,9	-9,9
E65 SLEAFORD ST PRIMARY	29,9	8,3	31,5	6,7	32,2	6,0	32,8	5,4	33,5	4,7	34,1	4,0	34,8	3,4
E12 ST ANTHONY ST PRIMARY	15,5	6,6	16,7	5,4	17,0	5,1	17,2	4,9	17,5	4,6	17,7	4,4	18,0	4,1
E06 THOMPSONS LN PRIMARY	14,5	2,0	15,9	0,6	16,4	0,2	16,8	-0,3	17,3	-0,8	17,7	-1,2	18,2	-1,7
E07 BARNWELL PRIMARY	8,5	5,3	9,9	3,9	10,3	3,5	10,7	3,1	11,1	2,6	11,6	2,2	12,0	1,8
E73 MADINGLEY RD PRIMARY	17,3	-2,0	18,4	-3,0	18,4	-3,1	18,5	-3,1	18,5	-3,2	18,5	-3,2	18,6	-3,3
E08 MILTON RD PRIMARY	28,6	-6,4	30,3	-8,2	31,1	-9,0	31,9	-9,8	32,7	-10,6	33,4	-11,3	34,2	-12,1
E05 HISTON PRIMARY	22,7	-0,6	24,3	-2,2	24,9	-2,8	25,5	-3,4	26,1	-4,0	26,7	-4,6	27,4	-5,3

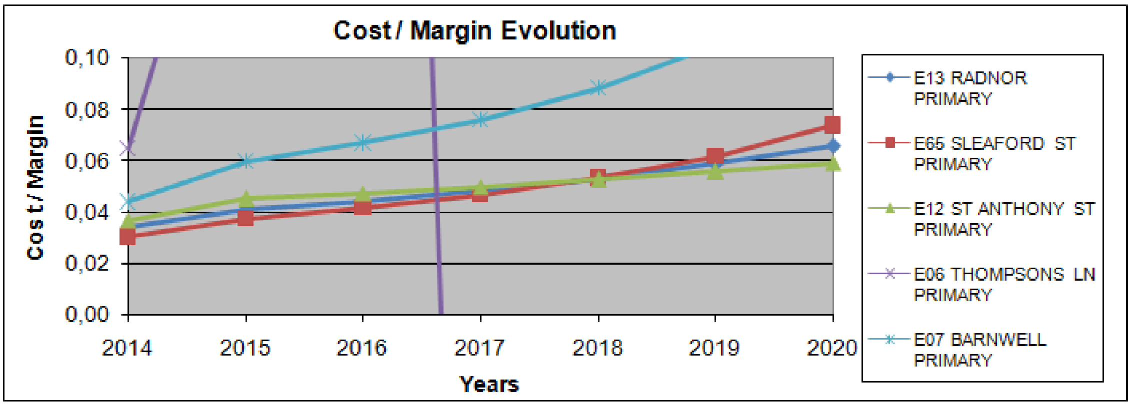

Figure 24: Chart with the Cost/Margin evolution for PV adoption and Environmental Awakening Scenario

(ii) Continuing Prosperity Scenario

Table 17: Primaries Demand and Margin evolution for PV adoption and Continuing Prosperity scenario

Primaries	2014		2015		2016		2017		2018		2019		2020	
	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin
E13 RADNOR PRIMARY	28,7	9,4	30,5	7,7	31,1	7,0	31,7	6,4	32,4	5,8	33,0	5,2	33,6	4,6
E11 STOREYS WAY PRIMARY	27,2	-5,1	29,0	-6,9	29,7	-7,6	30,3	-8,3	31,0	-8,9	31,7	-9,6	32,3	-10,2
E65 SLEAFORD ST PRIMARY	30,1	8,1	31,9	6,3	32,5	5,6	33,2	5,0	33,8	4,3	34,5	3,7	35,2	3,0
E12 ST ANTHONY ST PRIMARY	15,7	6,4	17,1	5,0	17,4	4,7	17,6	4,5	17,9	4,2	18,1	4,0	18,4	3,7
E06 THOMPSONS LN PRIMARY	14,7	1,8	16,3	0,2	16,8	-0,2	17,2	-0,7	17,7	-1,1	18,1	-1,6	18,6	-2,0
E07 BARNWELL PRIMARY	8,7	5,1	10,3	3,5	10,7	3,1	11,1	2,7	11,5	2,3	11,9	1,8	12,4	1,4
E73 MADINGLEY RD PRIMARY	17,5	-2,2	18,7	-3,4	18,8	-3,4	18,8	-3,5	18,9	-3,5	18,9	-3,6	19,0	-3,6
E08 MILTON RD PRIMARY	28,7	-6,6	30,7	-8,6	31,5	-9,4	32,3	-10,1	33,0	-10,9	33,8	-11,7	34,6	-12,5
E05 HISTON PRIMARY	22,9	-0,8	24,6	-2,5	25,3	-3,2	25,9	-3,8	26,5	-4,4	27,1	-5,0	27,7	-5,6

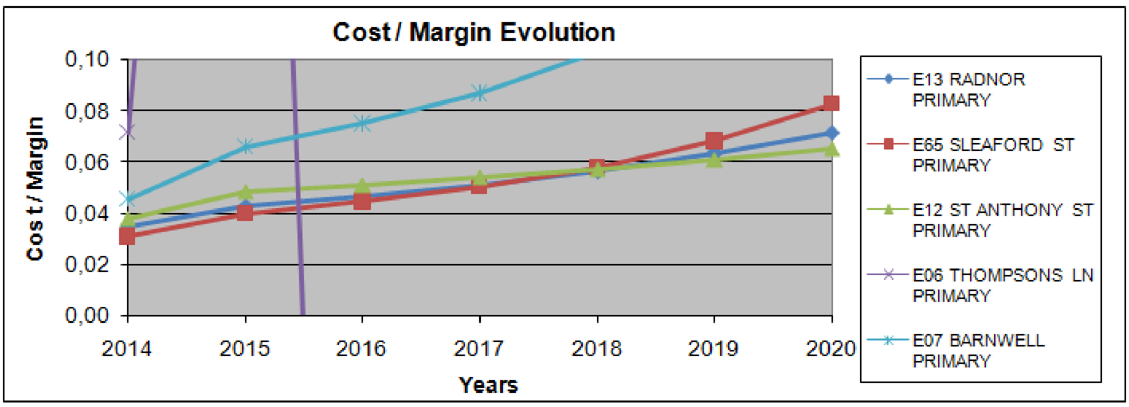

Figure 25: Chart with the Cost/Margin evolution for PV adoption and Continuing Prosperity scenario

(iii) Economic Concern Scenario

Table 18: Primaries Demand and Margin evolution for PV adoption and Economic Concern scenario

Primaries	2014		2015		2016		2017		2018		2019		2020	
	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin
E13 RADNOR PRIMARY	28,5	9,7	30,0	8,2	30,6	7,6	31,2	7,0	31,8	6,4	32,4	5,8	33,0	5,2
E11 STOREYS WAY PRIMARY	26,9	-4,8	28,4	-6,4	29,1	-7,0	29,8	-7,7	30,4	-8,4	31,1	-9,0	31,7	-9,7
E65 SLEAFORD ST PRIMARY	29,8	8,4	31,3	6,8	32,0	6,2	32,6	5,5	33,3	4,9	33,9	4,2	34,6	3,6
E12 ST ANTHONY ST PRIMARY	15,4	6,7	16,5	5,6	16,8	5,3	17,0	5,1	17,3	4,8	17,5	4,5	17,8	4,3
E06 THOMPSONS LN PRIMARY	14,4	2,1	15,7	0,8	16,2	0,3	16,6	-0,1	17,1	-0,6	17,6	-1,0	18,0	-1,5
E07 BARNWELL PRIMARY	8,4	5,4	9,7	4,1	10,1	3,7	10,5	3,2	11,0	2,8	11,4	2,4	11,8	2,0
E73 MADINGLEY RD PRIMARY	17,3	-1,9	18,2	-2,8	18,2	-2,9	18,3	-2,9	18,3	-3,0	18,4	-3,0	18,4	-3,1
E08 MILTON RD PRIMARY	28,5	-6,4	30,1	-8,0	30,9	-8,8	31,7	-9,6	32,5	-10,4	33,3	-11,1	34,0	-11,9
E05 HISTON PRIMARY	22,6	-0,5	24,1	-2,0	24,7	-2,6	25,3	-3,2	25,9	-3,8	26,5	-4,4	27,2	-5,1

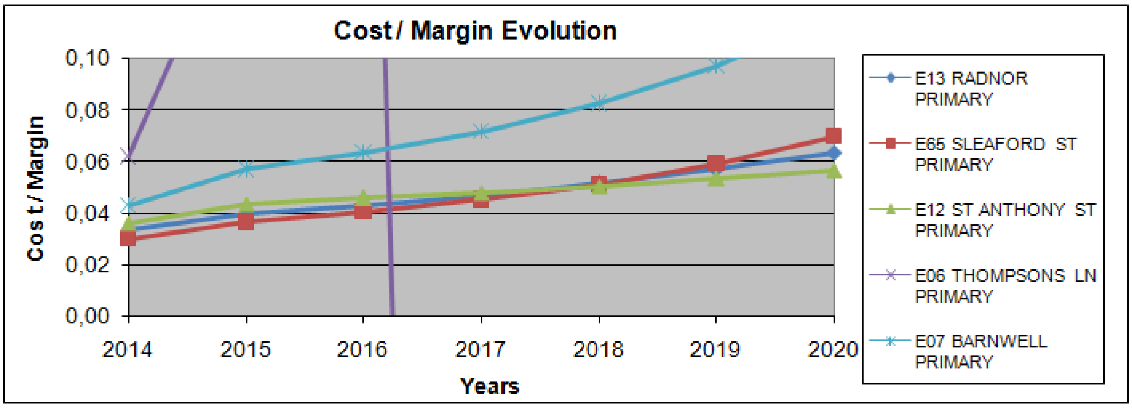

Figure 26: Chart with the Cost/Margin evolution for PV adoption and Economic Concern scenario

4.4.2.1.2- New development with adoption of micro-CHP systems

(i) Environmental Awakening Scenario

Table 19: Primaries Demand and Margin evolution for micro-CHP adoption and Environmental Awakening Scenario

Primaries	2014		2015		2016		2017		2018		2019		2020	
	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin
E13 RADNOR PRIMARY	27,9	10,2	28,9	9,3	29,5	8,6	30,1	8,0	30,8	7,4	31,4	6,8	32,0	6,2
E11 STOREYS WAY PRIMARY	26,4	-4,3	27,4	-5,3	28,1	-6,0	28,7	-6,7	29,4	-7,3	30,1	-8,0	30,7	-8,6
E65 SLEAFORD ST PRIMARY	29,3	8,9	30,3	7,9	30,9	7,2	31,6	6,6	32,2	5,9	32,9	5,3	33,6	4,6
E12 ST ANTHONY ST PRIMARY	14,9	7,2	15,5	6,6	15,8	6,3	16,0	6,1	16,3	5,8	16,5	5,6	16,8	5,3
E06 THOMPSONS LN PRIMARY	13,9	2,6	14,7	1,8	15,2	1,4	15,6	0,9	16,1	0,5	16,5	0,0	17,0	-0,4
E07 BARNWELL PRIMARY	7,9	5,9	8,7	5,1	9,1	4,7	9,5	4,3	9,9	3,9	10,3	3,4	10,8	3,0

Primaries	2014		2015		2016		2017		2018		2019		2020	
	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin
E73 MADINGLEY RD PRIMARY	16,7	-1,4	17,1	-1,8	17,2	-1,8	17,2	-1,9	17,3	-1,9	17,3	-2,0	17,4	-2,0
E08 MILTON RD PRIMARY	27,9	-5,8	29,1	-7,0	29,9	-7,8	30,7	-8,5	31,4	-9,3	32,2	-10,1	33,0	-10,9
E05 HISTON PRIMARY	22,1	0,0	23,0	-0,9	23,7	-1,6	24,3	-2,2	24,9	-2,8	25,5	-3,4	26,1	-4,0

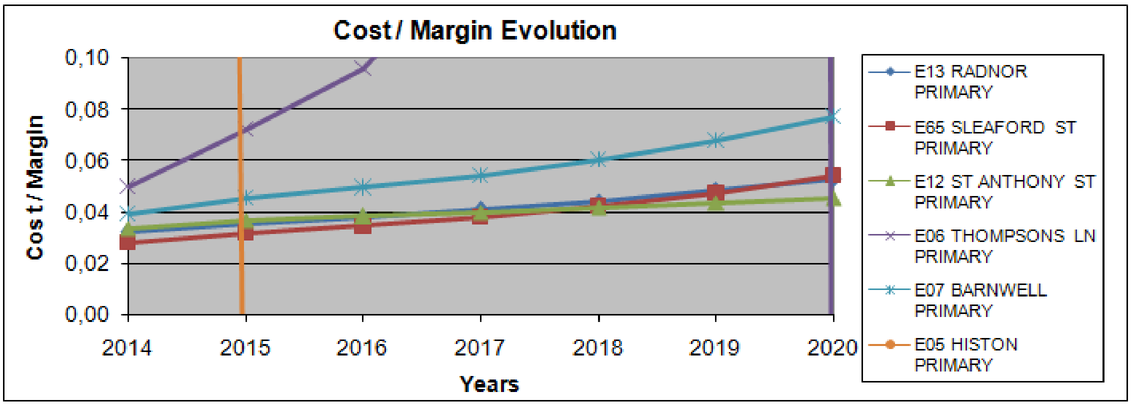

Figure 27: Chart with the Cost/Margin evolution for micro-CHP adoption and Environmental Awakening Scenario

(ii) Continuing Prosperity Scenario

Table 20: Primaries Demand and Margin evolution for micro-CHP adoption and Continuing Prosperity scenario

Primaries	2014		2015		2016		2017		2018		2019		2020	
	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin
E13 RADNOR PRIMARY	28,3	9,9	29,6	8,6	30,2	8,0	30,8	7,3	31,4	6,7	32,1	6,1	32,7	5,5
E11 STOREYS WAY PRIMARY	26,7	-4,7	28,1	-6,0	28,8	-6,7	29,4	-7,3	30,1	-8,0	30,7	-8,7	31,4	-9,3
E65 SLEAFORD ST PRIMARY	29,6	8,6	31,0	7,2	31,6	6,5	32,3	5,9	32,9	5,2	33,6	4,6	34,2	3,9
E12 ST ANTHONY ST PRIMARY	15,2	6,9	16,2	5,9	16,4	5,7	16,7	5,4	16,9	5,2	17,2	4,9	17,5	4,6
E06 THOMPSONS LN PRIMARY	14,2	2,3	15,4	1,1	15,8	0,7	16,3	0,2	16,8	-0,2	17,2	-0,7	17,7	-1,1
E07 BARNWELL PRIMARY	8,2	5,6	9,3	4,4	9,8	4,0	10,2	3,6	10,6	3,2	11,0	2,7	11,4	2,3
E73 MADINGLEY RD PRIMARY	17,1	-1,7	17,8	-2,5	17,9	-2,5	17,9	-2,6	18,0	-2,6	18,0	-2,7	18,1	-2,7
E08 MILTON RD PRIMARY	28,3	-6,2	29,8	-7,7	30,6	-8,4	31,3	-9,2	32,1	-10,0	32,9	-10,8	33,7	-11,6
E05 HISTON PRIMARY	22,4	-0,3	23,7	-1,6	24,3	-2,2	25,0	-2,9	25,6	-3,5	26,2	-4,1	26,8	-4,7

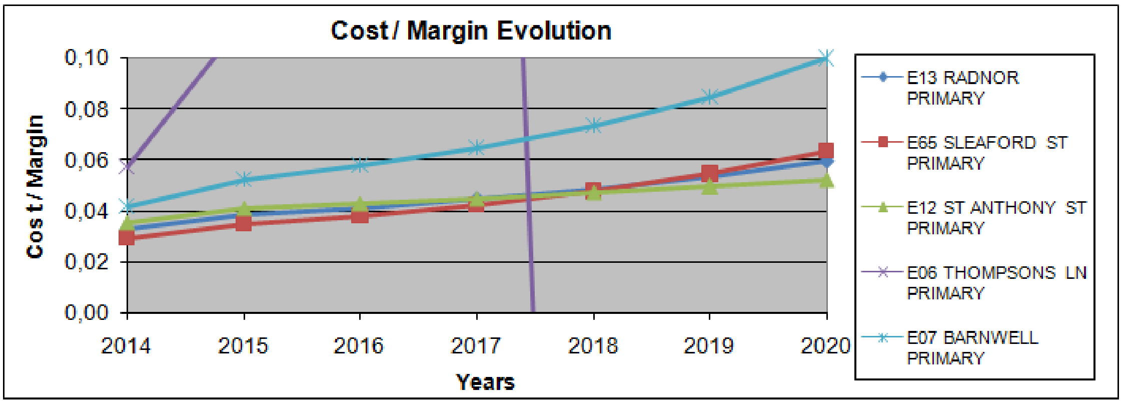

Figure 28: Chart with the Cost/Margin evolution for micro-CHP adoption and Continuing Prosperity scenario

(iii) Economic Concern Scenario

Table 21: Primaries Demand and Margin evolution for micro-CHP adoption and Economic Concern scenario

Primaries	2014		2015		2016		2017		2018		2019		2020	
	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin
E13 RADNOR PRIMARY	28,4	9,8	29,7	8,4	30,4	7,8	31,0	7,2	31,6	6,6	32,2	6,0	32,8	5,4
E11 STOREYS WAY PRIMARY	26,8	-4,7	28,2	-6,2	28,9	-6,8	29,6	-7,5	30,2	-8,1	30,9	-8,8	31,5	-9,5
E65 SLEAFORD ST PRIMARY	29,7	8,5	31,1	7,1	31,8	6,4	32,4	5,8	33,1	5,1	33,7	4,5	34,4	3,8
E12 ST ANTHONY ST PRIMARY	15,3	6,8	16,3	5,8	16,6	5,5	16,8	5,3	17,1	5,0	17,3	4,8	17,6	4,5
E06 THOMPSONS LN PRIMARY	14,3	2,2	15,5	1,0	16,0	0,6	16,4	0,1	16,9	-0,4	17,3	-0,8	17,8	-1,3
E07 BARNWELL PRIMARY	8,3	5,5	9,5	4,3	9,9	3,9	10,3	3,5	10,7	3,0	11,2	2,6	11,6	2,2
E73 MADINGLEY RD PRIMARY	17,1	-1,8	18,0	-2,6	18,0	-2,7	18,1	-2,7	18,1	-2,8	18,1	-2,8	18,2	-2,9
E08 MILTON RD PRIMARY	28,4	-6,2	29,9	-7,8	30,7	-8,6	31,5	-9,4	32,3	-10,1	33,0	-10,9	33,8	-11,7
E05 HISTON PRIMARY	22,5	-0,4	23,9	-1,8	24,5	-2,4	25,1	-3,0	25,7	-3,6	26,3	-4,2	27,0	-4,9

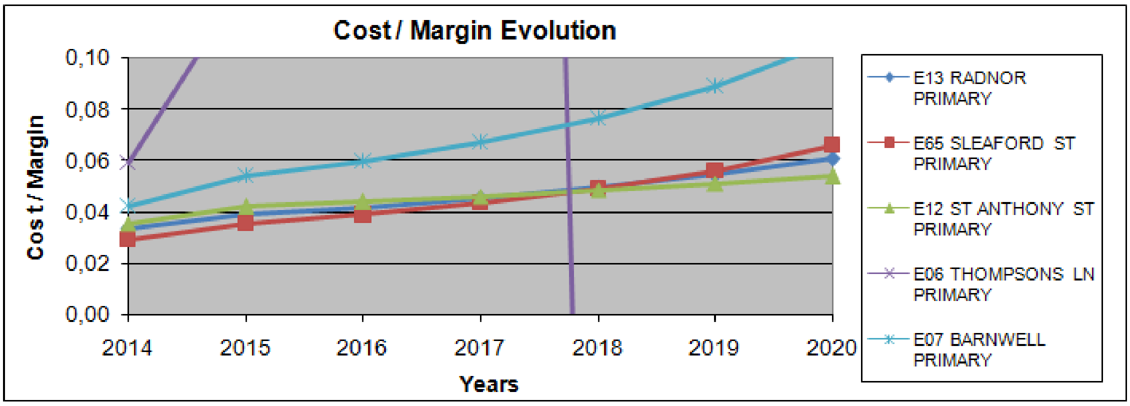

Figure 29: Chart with the Cost/Margin evolution for micro-CHP adoption and Economic Concern scenario

4.4.2.1.3- New development with adoption of SWH systems

(i) Environmental Awakening Scenario

Table 22: Primaries Demand and Margin evolution for SWH adoption and Environmental Awakening scenario

Primaries	2014		2015		2016		2017		2018		2019		2020	
	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin
E13 RADNOR PRIMARY	28,5	9,7	30,0	8,2	30,6	7,5	31,2	6,9	31,9	6,3	32,5	5,7	33,1	5,1
E11 STOREYS WAY PRIMARY	26,9	-4,9	28,5	-6,4	29,2	-7,1	29,8	-7,8	30,5	-8,4	31,2	-9,1	31,8	-9,7
E65 SLEAFORD ST PRIMARY	29,8	8,3	31,4	6,8	32,0	6,1	32,7	5,5	33,3	4,8	34,0	4,2	34,7	3,5
E12 ST ANTHONY ST PRIMARY	15,4	6,7	16,6	5,5	16,9	5,2	17,1	5,0	17,4	4,7	17,6	4,5	17,9	4,2
E06 THOMPSONS LN PRIMARY	14,4	2,1	15,8	0,7	16,3	0,3	16,7	-0,2	17,2	-0,6	17,6	-1,1	18,1	-1,5
E07 BARNWELL PRIMARY	8,4	5,4	9,8	4,0	10,2	3,6	10,6	3,2	11,0	2,8	11,4	2,3	11,9	1,9
E73 MADINGLEY RD PRIMARY	17,3	-1,9	18,2	-2,9	18,3	-2,9	18,3	-3,0	18,4	-3,0	18,4	-3,1	18,5	-3,1
E08 MILTON RD PRIMARY	28,5	-6,4	30,2	-8,1	31,0	-8,9	31,8	-9,6	32,5	-10,4	33,3	-11,2	34,1	-12,0
E05 HISTON PRIMARY	22,6	-0,5	24,1	-2,0	24,8	-2,7	25,4	-3,3	26,0	-3,9	26,6	-4,5	27,2	-5,1

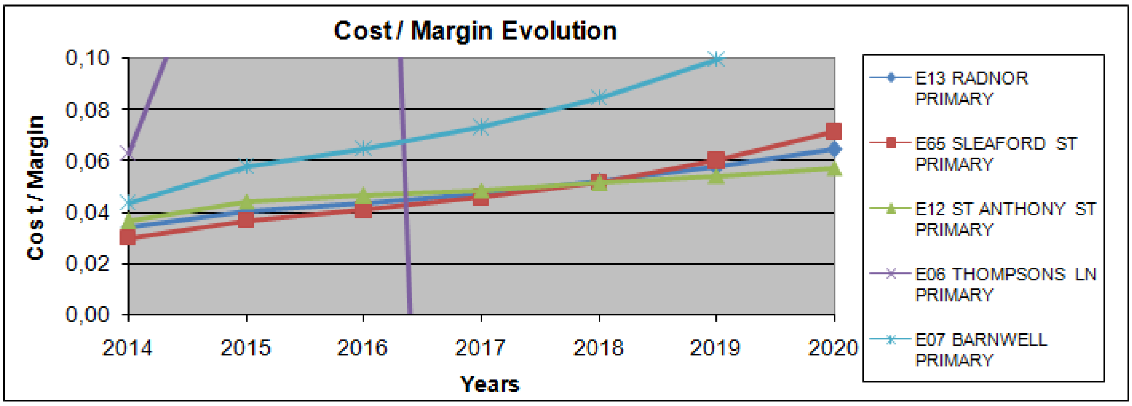

Figure 30: Chart with the Cost/Margin evolution for SWH adoption and Environmental Awakening Scenario

(ii) Continuing Prosperity Scenario

Table 23: Primaries Demand and Margin evolution for SWH adoption and Continuing Prosperity scenario

Primaries	2014		2015		2016		2017		2018		2019		2020	
	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin
E13 RADNOR PRIMARY	28,7	9,5	30,4	7,7	31,0	7,1	31,7	6,5	32,3	5,9	32,9	5,3	33,5	4,7
E11 STOREYS WAY PRIMARY	27,2	-5,1	28,9	-6,8	29,6	-7,5	30,2	-8,2	30,9	-8,8	31,6	-9,5	32,2	-10,1
E65 SLEAFORD ST PRIMARY	30,0	8,1	31,8	6,4	32,5	5,7	33,1	5,1	33,8	4,4	34,4	3,8	35,1	3,1
E12 ST ANTHONY ST PRIMARY	15,6	6,5	17,0	5,1	17,3	4,8	17,5	4,6	17,8	4,3	18,0	4,1	18,3	3,8
E06 THOMPSONS LN PRIMARY	14,6	1,9	16,2	0,3	16,7	-0,1	17,1	-0,6	17,6	-1,0	18,0	-1,5	18,5	-2,0
E07 BARNWELL PRIMARY	8,6	5,1	10,2	3,6	10,6	3,2	11,0	2,8	11,4	2,3	11,8	1,9	12,3	1,5
E73 MADINGLEY RD PRIMARY	17,5	-2,2	18,6	-3,3	18,7	-3,4	18,7	-3,4	18,8	-3,4	18,8	-3,5	18,9	-3,5
E08 MILTON RD PRIMARY	28,7	-6,6	30,6	-8,5	31,4	-9,3	32,2	-10,1	33,0	-10,8	33,7	-11,6	34,5	-12,4
E05 HISTON PRIMARY	22,8	-0,7	24,6	-2,5	25,2	-3,1	25,8	-3,7	26,4	-4,3	27,0	-4,9	27,6	-5,5

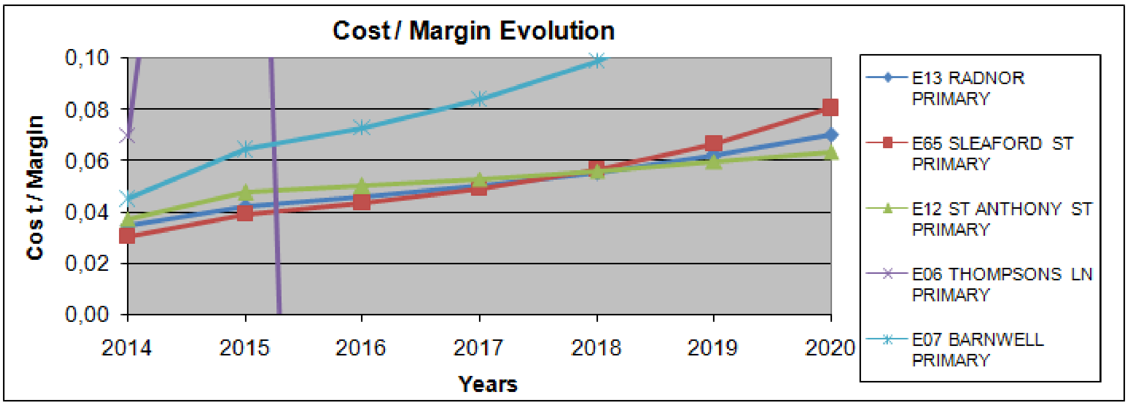

Figure 31: Chart with the Cost/Margin evolution for SWH adoption and Continuing Prosperity scenario

(iii) **Economic Concern Scenario**

Table 24: Primaries Demand and Margin evolution for SWH adoption and Economic Concern scenario

Primaries	2014		2015		2016		2017		2018		2019		2020	
	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin
E13 RADNOR PRIMARY	28,5	9,7	29,9	8,2	30,5	7,6	31,2	7,0	31,8	6,4	32,4	5,8	33,0	5,2
E11 STOREYS WAY PRIMARY	26,9	-4,8	28,4	-6,4	29,1	-7,0	29,7	-7,7	30,4	-8,3	31,1	-9,0	31,7	-9,7
E65 SLEAFORD ST PRIMARY	29,8	8,4	31,3	6,9	32,0	6,2	32,6	5,6	33,3	4,9	33,9	4,3	34,6	3,6
E12 ST ANTHONY ST PRIMARY	15,4	6,7	16,5	5,6	16,8	5,3	17,0	5,1	17,3	4,8	17,5	4,6	17,8	4,3
E06 THOMPSONS LN PRIMARY	14,4	2,1	15,7	0,8	16,2	0,4	16,6	-0,1	17,1	-0,5	17,5	-1,0	18,0	-1,5
E07 BARNWELL PRIMARY	8,4	5,4	9,7	4,1	10,1	3,7	10,5	3,3	10,9	2,8	11,4	2,4	11,8	2,0
E73 MADINGLEY RD PRIMARY	17,2	-1,9	18,2	-2,8	18,2	-2,9	18,2	-2,9	18,3	-3,0	18,3	-3,0	18,4	-3,0
E08 MILTON RD PRIMARY	28,5	-6,3	30,1	-8,0	30,9	-8,8	31,7	-9,6	32,5	-10,3	33,2	-11,1	34,0	-11,9
E05 HISTON PRIMARY	22,6	-0,5	24,1	-2,0	24,7	-2,6	25,3	-3,2	25,9	-3,8	26,5	-4,4	27,1	-5,0

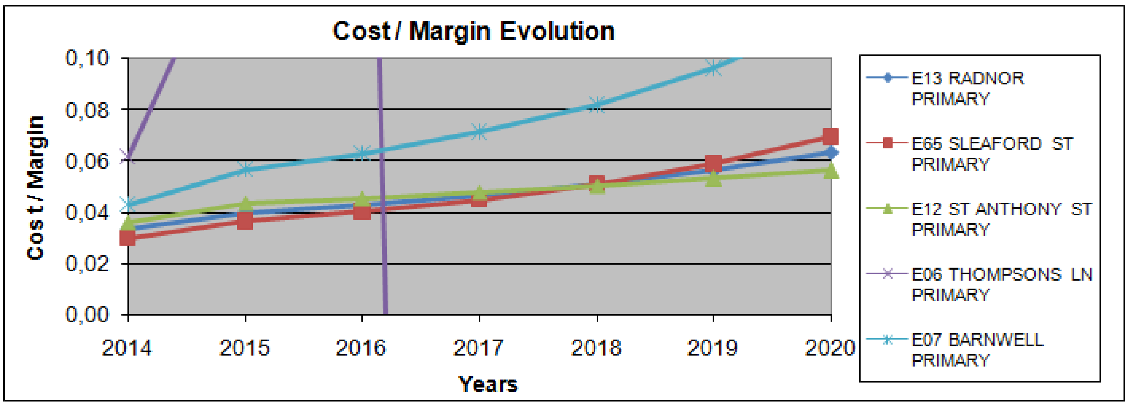

Figure 32: Chart with the Cost/Margin evolution for SWH adoption and Economic Concern scenario

4.4.2.1.4- New development with simultaneously adoption of PV panels and micro-CHP systems

(i) Environmental Awakening Scenario

Table 25: Primaries Demand and Margin evolution for PV + micro-CHP adoption and Environmental Awakening Scenario

Primaries	2014		2015		2016		2017		2018		2019		2020	
	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin
E13 RADNOR PRIMARY	27,8	10,3	28,7	9,4	29,3	8,8	30,0	8,2	30,6	7,6	31,2	7,0	31,8	6,4
E11 STOREYS WAY PRIMARY	26,3	-4,2	27,2	-5,1	27,9	-5,8	28,5	-6,5	29,2	-7,1	29,9	-7,8	30,5	-8,4
E65 SLEAFORD ST PRIMARY	29,2	9,0	30,1	8,1	30,8	7,4	31,4	6,8	32,1	6,1	32,7	5,5	33,4	4,8
E12 ST ANTHONY ST PRIMARY	14,8	7,3	15,3	6,8	15,6	6,5	15,8	6,3	16,1	6,0	16,3	5,8	16,6	5,5
E06 THOMPSONS LN PRIMARY	13,8	2,7	14,5	2,0	15,0	1,6	15,4	1,1	15,9	0,7	16,3	0,2	16,8	-0,3
E07 BARNWELL PRIMARY	7,8	6,0	8,5	5,3	8,9	4,9	9,3	4,5	9,7	4,0	10,1	3,6	10,6	3,2
E73 MADINGLEY RD PRIMARY	16,6	-1,3	17,0	-1,6	17,0	-1,7	17,0	-1,7	17,1	-1,7	17,1	-1,8	17,2	-1,8
E08 MILTON RD PRIMARY	27,9	-5,7	28,9	-6,8	29,7	-7,6	30,5	-8,4	31,3	-9,1	32,0	-9,9	32,8	-10,7
E05 HISTON PRIMARY	22,0	0,1	22,9	-0,8	23,5	-1,4	24,1	-2,0	24,7	-2,6	25,3	-3,2	25,9	-3,8

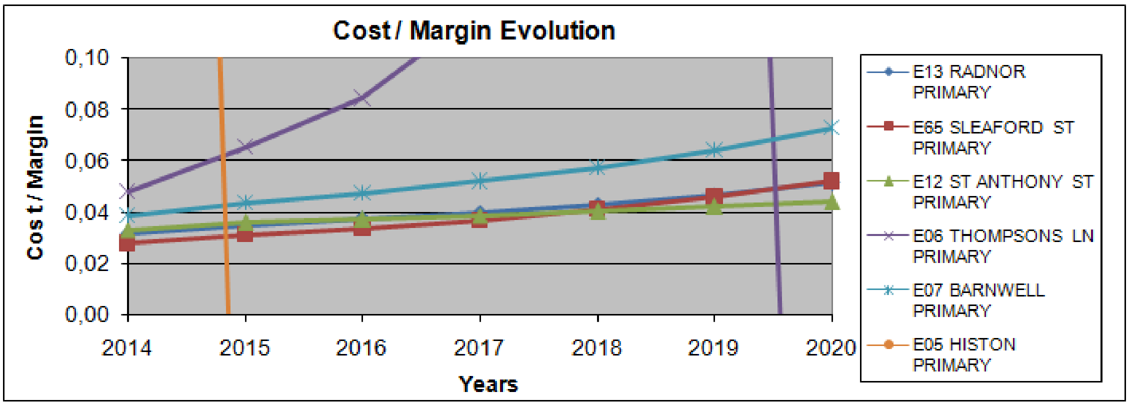

Figure 33: Chart with the Cost/Margin evolution for PV + micro-CHP adoption and Environmental Awakening Scenario

(ii) Continuing Prosperity

Table 26: Primaries Demand and Margin evolution for PV + micro-CHP adoption and Continuing Prosperity scenario

Primaries	2014		2015		2016		2017		2018		2019		2020	
	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin
E13 RADNOR PRIMARY	28,2	10,0	29,5	8,7	30,1	8,1	30,7	7,5	31,3	6,9	31,9	6,3	32,5	5,6
E11 STOREYS WAY PRIMARY	26,7	-4,6	28,0	-5,9	28,6	-6,5	29,3	-7,2	29,9	-7,9	30,6	-8,5	31,3	-9,2

Primaries	2014		2015		2016		2017		2018		2019		2020	
	Demand	Margin	Demand	Margin	Demand	Margin	Demand		Demand	Margin	Demand	Margin	Demand	Margin
E65 SLEAFORD ST PRIMARY	29,5	8,6	30,8	7,3	31,5	6,7	32,1	6,0	32,8	5,4	33,4	4,7	34,1	4,1
E12 ST ANTHONY ST PRIMARY	15,2	6,9	16,0	6,1	16,3	5,8	16,5	5,5	16,8	5,3	17,1	5,0	17,3	4,8
E06 THOMPSONS LN PRIMARY	14,2	2,4	15,2	1,3	15,7	0,8	16,2	0,4	16,6	-0,1	17,1	-0,5	17,5	-1,0
E07 BARNWELL PRIMARY	8,1	5,6	9,2	4,6	9,6	4,2	10,0	3,7	10,5	3,3	10,9	2,9	11,3	2,5
E73 MADINGLEY RD PRIMARY	17,0	-1,7	17,7	-2,3	17,7	-2,4	17,8	-2,4	17,8	-2,5	17,9	-2,5	17,9	-2,6
E08 MILTON RD PRIMARY	28,2	-6,1	29,6	-7,5	30,4	-8,3	31,2	-9,1	32,0	-9,9	32,8	-10,7	33,6	-11,4
E05 HISTON PRIMARY	22,3	-0,2	23,6	-1,5	24,2	-2,1	24,8	-2,7	25,4	-3,3	26,1	-4,0	26,7	-4,6

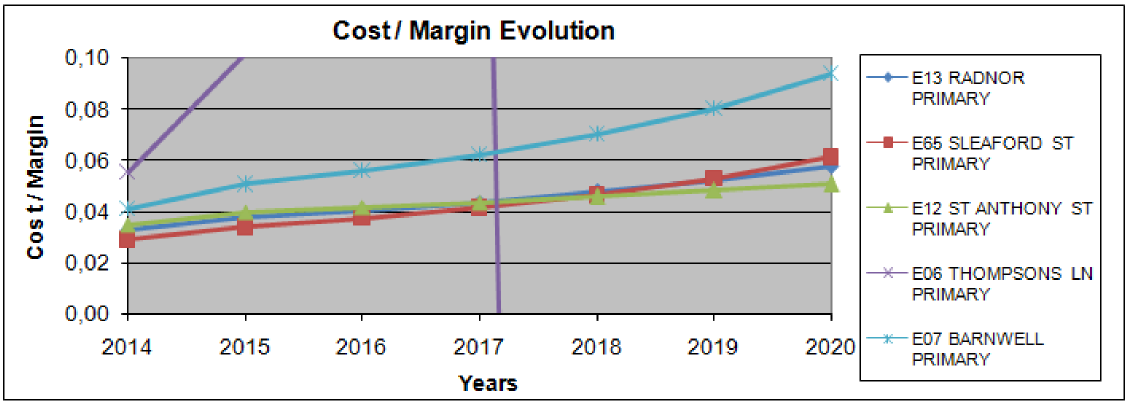

Figure 34: Chart with the Cost/Margin evolution for PV + micro-CHP adoption and Continuing Prosperity scenario

(iii) Economic Concern Scenario

Table 27: Primaries Demand and Margin evolution for PV + micro-CHP adoption and Economic Concern scenario

Primaries	2014		2015		2016		2017		2018		2019		2020	
	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin
E13 RADNOR PRIMARY	28,3	9,8	29,7	8,5	30,3	7,9	30,9	7,2	31,5	6,6	32,2	6,0	32,8	5,4
E11 STOREYS WAY PRIMARY	26,8	-4,7	28,2	-6,1	28,9	-6,8	29,5	-7,4	30,2	-8,1	30,8	-8,8	31,5	-9,4
E65 SLEAFORD ST PRIMARY	29,7	8,5	31,1	7,1	31,7	6,4	32,4	5,8	33,0	5,1	33,7	4,5	34,3	3,8
E12 ST ANTHONY ST PRIMARY	15,3	6,8	16,3	5,8	16,5	5,6	16,8	5,3	17,0	5,0	17,3	4,8	17,6	4,5
E06 THOMPSONS LN PRIMARY	14,3	2,3	15,5	1,0	15,9	0,6	16,4	0,1	16,9	-0,3	17,3	-0,8	17,8	-1,2
E07 BARNWELL PRIMARY	8,3	5,5	9,4	4,3	9,9	3,9	10,3	3,5	10,7	3,1	11,1	2,6	11,5	2,2
E73 MADINGLEY RD PRIMARY	17,1	-1,8	17,9	-2,6	18,0	-2,6	18,0	-2,7	18,1	-2,7	18,1	-2,8	18,2	-2,8
E08 MILTON RD PRIMARY	28,3	-6,2	29,9	-7,8	30,7	-8,5	31,4	-9,3	32,2	-10,1	33,0	-10,9	33,8	-11,7
E05 HISTON PRIMARY	22,5	-0,4	23,8	-1,7	24,4	-2,3	25,1	-3,0	25,7	-3,6	26,3	-4,2	26,9	-4,8

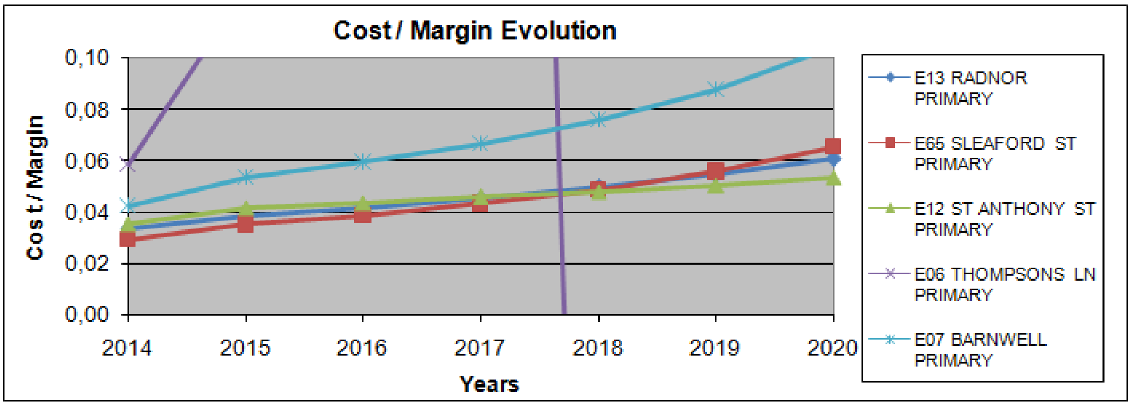

Figure 35: Chart with the Cost/Margin evolution for PV + micro-CHP adoption and Economic Concern scenario

4.4.2.1.5- New development with simultaneously adoption of PV panels and SWH systems

(i) Environmental Awakening Scenario

Table 28: Primaries Demand and Margin evolution for PV + SWH adoption and Environmental Awakening Scenario

Primaries	2014		2015		2016		2017		2018		2019		2020	
	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin
E13 RADNOR PRIMARY	28,4	9,8	29,8	8,3	30,4	7,7	31,1	7,1	31,7	6,5	32,3	5,9	32,9	5,3
E11 STOREYS WAY PRIMARY	26,9	-4,8	28,3	-6,2	29,0	-6,9	29,6	-7,6	30,3	-8,2	31,0	-8,9	31,6	-9,5
E65 SLEAFORD ST PRIMARY	29,7	8,4	31,2	7,0	31,9	6,3	32,5	5,7	33,2	5,0	33,8	4,4	34,5	3,7
E12 ST ANTHONY ST PRIMARY	15,3	6,8	16,4	5,7	16,7	5,4	16,9	5,2	17,2	4,9	17,4	4,7	17,7	4,4
E06 THOMPSONS LN PRIMARY	14,3	2,2	15,6	0,9	16,1	0,5	16,5	0,0	17,0	-0,4	17,4	-0,9	17,9	-1,4
E07 BARNWELL PRIMARY	8,3	5,4	9,6	4,2	10,0	3,8	10,4	3,4	10,8	2,9	11,2	2,5	11,7	2,1
E73 MADINGLEY RD PRIMARY	17,2	-1,9	18,1	-2,7	18,1	-2,8	18,1	-2,8	18,2	-2,8	18,2	-2,9	18,3	-2,9
E08 MILTON RD PRIMARY	28,4	-6,3	30,0	-7,9	30,8	-8,7	31,6	-9,5	32,4	-10,2	33,1	-11,0	33,9	-11,8
E05 HISTON PRIMARY	22,5	-0,4	24,0	-1,9	24,6	-2,5	25,2	-3,1	25,8	-3,7	26,4	-4,3	27,0	-4,9

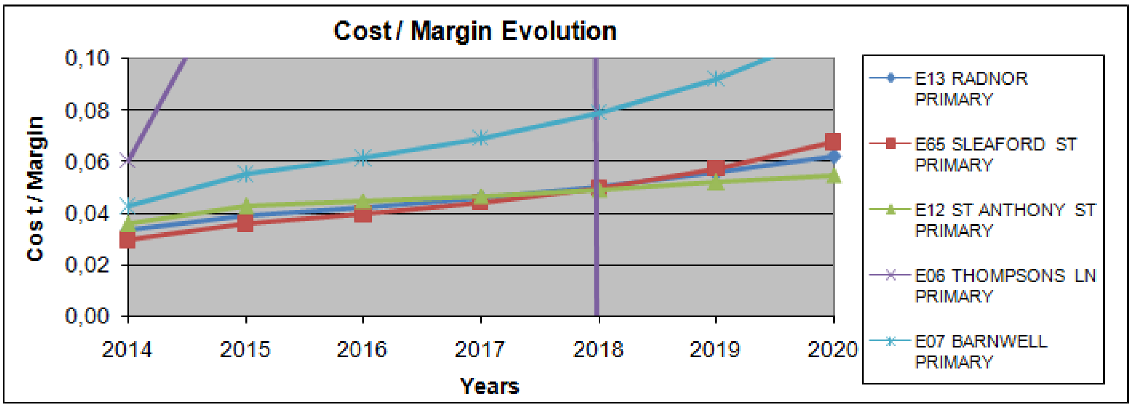

Figure 36: Chart with the Cost/Margin evolution for PV + SWH adoption and Environmental Awakening Scenario

(ii) Continuing Prosperity Scenario

Table 29: Primaries Demand and Margin evolution for PV + SWH adoption and Continuing Prosperity scenario

Primaries	2014		2015		2016		2017		2018		2019		2020	
	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin
E13 RADNOR PRIMARY	28,6	9,5	30,3	7,9	30,9	7,3	31,5	6,7	32,1	6,1	32,7	5,4	33,3	4,8
E11 STOREYS WAY PRIMARY	27,1	-5,0	28,8	-6,7	29,4	-7,4	30,1	-8,0	30,8	-8,7	31,4	-9,3	32,1	-10,0
E65 SLEAFORD ST PRIMARY	30,0	8,2	31,7	6,5	32,3	5,9	33,0	5,2	33,6	4,6	34,3	3,9	34,9	3,3
E12 ST ANTHONY ST PRIMARY	15,6	6,5	16,9	5,2	17,1	5,0	17,4	4,7	17,6	4,5	17,9	4,2	18,1	4,0
E06 THOMPSONS LN PRIMARY	14,6	2,0	16,1	0,5	16,5	0,0	17,0	-0,4	17,4	-0,9	17,9	-1,4	18,3	-1,8
E07 BARNWELL PRIMARY	8,6	5,2	10,0	3,8	10,4	3,3	10,9	2,9	11,3	2,5	11,7	2,1	12,1	1,6
E73 MADINGLEY RD PRIMARY	17,4	-2,1	18,5	-3,2	18,6	-3,2	18,6	-3,3	18,6	-3,3	18,7	-3,4	18,7	-3,4
E08 MILTON RD PRIMARY	28,6	-6,5	30,5	-8,3	31,2	-9,1	32,0	-9,9	32,8	-10,7	33,6	-11,5	34,4	-12,3
E05 HISTON PRIMARY	22,7	-0,6	24,4	-2,3	25,0	-2,9	25,6	-3,5	26,3	-4,2	26,9	-4,8	27,5	-5,4

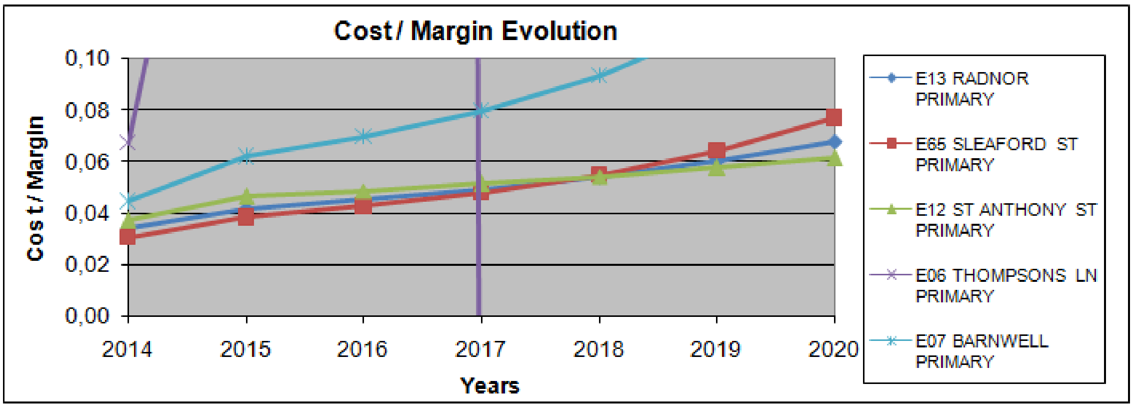

Figure 37: Chart with the Cost/Margin evolution for PV + SWH adoption and Continuing Prosperity scenario

(iii) Economic Concern Scenario

Table 30: Primaries Demand and Margin evolution for PV + SWH adoption and Economic Concern scenario

Primaries	2014		2015		2016		2017		2018		2019		2020	
	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin
E13 RADNOR PRIMARY	28,4	9,7	29,9	8,3	30,5	7,7	31,1	7,0	31,7	6,4	32,3	5,8	33,0	5,2
E11 STOREYS WAY PRIMARY	26,9	-4,8	28,4	-6,3	29,1	-7,0	29,7	-7,6	30,4	-8,3	31,0	-9,0	31,7	-9,6
E65 SLEAFORD ST PRIMARY	29,8	8,4	31,3	6,9	31,9	6,3	32,6	5,6	33,2	4,9	33,9	4,3	34,5	3,6
E12 ST ANTHONY ST PRIMARY	15,4	6,7	16,5	5,6	16,7	5,4	17,0	5,1	17,2	4,9	17,5	4,6	17,7	4,3
E06 THOMPSONS LN PRIMARY	14,4	2,2	15,7	0,9	16,1	0,4	16,6	-0,1	17,0	-0,5	17,5	-1,0	18,0	-1,4
E07 BARNWELL PRIMARY	8,4	5,4	9,6	4,1	10,1	3,7	10,5	3,3	10,9	2,9	11,3	2,5	11,7	2,0
E73 MADINGLEY RD PRIMARY	17,2	-1,9	18,1	-2,8	18,2	-2,8	18,2	-2,9	18,3	-2,9	18,3	-3,0	18,4	-3,0
E08 MILTON RD PRIMARY	28,4	-6,3	30,1	-8,0	30,9	-8,7	31,6	-9,5	32,4	-10,3	33,2	-11,1	34,0	-11,9
E05 HISTON PRIMARY	22,6	-0,5	24,0	-1,9	24,6	-2,5	25,3	-3,2	25,9	-3,8	26,5	-4,4	27,1	-5,0

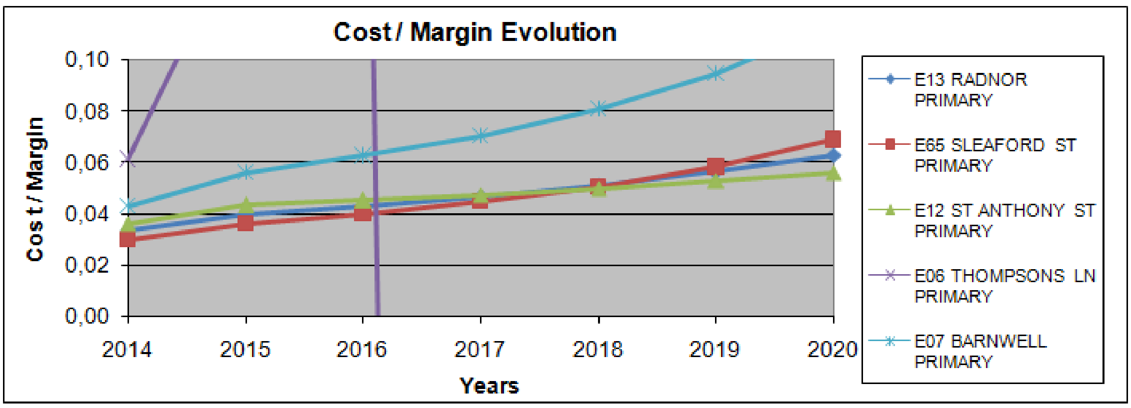

Figure 38: Chart with the Cost/Margin evolution for PV + SWH adoption and Economic Concern scenario

4.4.3- Simulation Results Analyse

The figures and tables obtained (displayed at section 4.4.2.1) with the model simulation will be now analysed and discussed.

4.4.3.1- Best Investment Solution Analyse

For all the simulated scenarios there was verified a common factor. The common factor is that the primary substation that is the best option to connect the new development loads in the early years of the development implementation is different from the one that is the best option to connect the new development at later years. Therefore for the simulated scenarios, E65 Sleaford St primary substation is the best solution in a short term and the E12 St Anthony St primary substation is the best solution for a long term period.

For every simulated scenario it was verified that E65 Sleaford St primary substation is the best option for a short term period because when analysed the previous charts, this primary is the one that presents the lowest value for the ratio Cost/Margin Left, for the years till the 2018. For the years after 2019, it was verified that the best option given by the ratio Cost/ Margin Left was the E12 St Anthony St primary substation.

For these two primaries substation, the explained Connection Cost/Margin Left ratio behaviour from the development start till the 2020 year can be explained by the fact that for the E65 Sleaford primary substation the underlying load growth is substantial higher (0.65 MW/year) than the one verified for the E12 ST Anthony ST primary substation (0.25 MW/year). The underlying load growth is the expected load growth in a year for every primary substation, and this value varies from primary station to primary station according to their location and the type and quantity of loads connected to them.

So, for every simulated scenario, the user has two investment options for connecting the new development loads. Now it will be presented a table of the connecting costs that are expected for connecting the new development loads to the several primaries substations analysed.

Table 31: Distance and Connection Costs from the analysed primaries substations to the new development

Primary	Distance (km)	Connection cost (k£)
E13 Radnor	4.8	331.2
E65 Sleaford St	3.6	248.4
E12 St Anthony St	3.5	241.5
E06 Thompsons Ln	1.9	131.1
E07 Barnwell	3.4	234.6
E05 Histon	2.2	151.8

Analysing the Table 31 it is possible to note that the cheaper solution for connecting the new developments loads to a primary substation is to connect them to the E06 Thompson Ln primary substation. Although for the simulated scenarios this option was never verified as the best connection option due to the margin left in this solution presents a lower value than the ones presented at other primaries substation. For every simulated scenario, 06 Thompson Ln primary substation demand will pass the respective capacity and the margin becomes negative before the year 2020.

So, from the two possible solutions that the model indicates as the best ones, one for the short and another for the long term (E65 Sleaford St primary substation and E12 St Anthony St primary substation respectively), the cheaper solution is to connect the loads to the E12 St Anthony St primary substation. This option is 2.8% cheaper than the one considering the connection to E65 Sleaford St primary substation.

The investor, according to the model outputs from the simulated scenarios has two investment options, and also according to the same outputs, the solution that is predicted to be the best from the 2019 year is also the cheaper one (the investment to connect the development loads to the E65 Sleaford St primary substation is 2.8% lower than the one that is needed for connect the same loads to the E65 Sleaford St primary substation).

So, if the underlying load growth that is predicted for the E65 Sleaford St primary substation and E12 St Anthony St primary substation, in reality is verified with the same value of the expected ones, the option for connecting to E12 St Anthony St primary substation should be the most reasonable option once the needed investment is 2.8% lower than the one for connecting to Sleaford St primary substation and, for 2019 on, the free margin in E12 St Anthony St primary substation is higher than the one verified in E65 Sleaford St primary substation.

Otherwise if the investor for whatever reason, thinks that the underlying load growth in reality will be lower than the one expected on the databases obtained from the ArcGIS 9 software, the solution of connecting to the E65 Sleaford St primary substation will probably be the most interesting one, once that even with the expected underlying load growth values this is the solution that presents the best values from the ratio Connection Cost/ Margin Left from the development beginning at 2014 till the year 2018 for every simulated scenarios.

4.4.3.2- Scenarios Analyse

At section 4.4.2.1 it is possible to see from Tables 16 to 30, for each simulated scenario, the margin left in each analysed primary substation since the start of the development (year 2014) till the 2020 year.

For the different simulated scenarios it is obtained different values for the margin left in each year. So, it is possible to compare those values and obtain the highest value for the margin in each primary substation. This shows that for different scenarios the development demand is different and if a primary substation, for the same year of analyses, presents a higher value for the margin than in the other scenario, this indicates that the respective primary substation has a lowest demand to supply.

Therefore, for each micro-generation system implemented, the scenarios will be ranked in order that the best scenario is the one in which the margin left at the analysed primaries substations, for a certain year, has the highest value and the worst scenario is the one that has the lowest value for the same margin left.

• **For application of PV technology:**
- Best scenario: Economic Concern
- Intermediate scenario: Environmental Awakening
- Worst scenario: Continuing Prosperity

• **For application of CHP technology:**
- Best scenario: Environmental Awakening
- Intermediate scenario: Continuing Prosperity
- Worst scenario: Economic Concern

• **For application of SWH technology:**
- Best scenario: Economic Concern
- Intermediate scenario: Environmental Awakening
- Worst scenario: Continuing Prosperity

• **For application of PV+CHP technologies:**
- Best scenario: Environmental Awakening
- Intermediate scenario: Continuing Prosperity
- Worst scenario: Economic Concern

• **For application of PV+SWH technologies:**
- Best scenario: Environmental Awakening
- Intermediate scenario: Economic Concern
- Worst scenario: Continuing Prosperity

For these simulated scenarios it was verified that for all of them, the development demand seen from the primary substation side is lower under the Environmental Awakening scenario than the one under the Continuing Prosperity scenario. Therefore the Environmental Awakening scenario is always better than the Continuing Prosperity scenario (represents lower demand for the primaries to supply).

For the simulated scenarios in which are applied PV panels and for the ones in which are applied SWH systems, it was verified that under Economic Concern scenario, the development demand seen from the primary substation side is lower than the one under the Environmental Awakening scenario. So, for PV or SHW systems adoption, Economic Concern scenario is better than the Environmental Awakening. This evidence can be understand due to the fact than even in Environmental Awakening scenario the technology implementation is 100% (versus 25% in Economic Concern scenario), energy efficiency measures have an 17% impact on reducing the development demand (versus 10% in Economic Concern scenario) and the commercial demand reduction due to adoption of CHP systems for non-domestic buildings is 20% (versus

5% in Economic Concern scenario), the number of houses and jobs predicted are 30% less under the Economic Concern scenario than under the Environmental Awakening scenario. This fact leads to a lowest demand under Economic Concern scenario than under the Environmental Awakening scenario especially because the impact of PV and SWH technologies for reducing the development demand are not as high as others technologies where even with 30% more houses and jobs under Environmental Awakening scenario than Economic Concern scenario, the total development demand would be lower.

For the scenarios where is applied PV panels and SWH systems simultaneously, the development demand, seen from the primary substation side, was verified to be lower under the Environmental Awakening scenario follow by the Economic Concern scenario and Continuing Prosperity scenario. So, for PV and SHW systems simultaneously adoption, Environmental Awakening scenario is the best scenario, the intermediate scenario is the Economic Concern scenario and the worst is the Continuing Prosperity scenario.

4.4.3.3- Cost/Margin Evolution chart behaviour

The Cost/Margin ratio evolution presented at section 4.4.2.1 charts, are obtained, for each year, dividing the connection cost (constant for each primary substation) by the primary substation margin at that year. So, when the user analyses the charts, need to have that fact in attention because, for example, if the ratio value between the year 2018 and 2019, in a certain chart, changes from a positive to a negative value, the only information that can be "read" from that chart is only that one. It cannot be known if the changing from the positive to a negative value was made soon or later in the year just by analysing the chart ratio.

That fact can be illustrated by analysing the ratio behaviour for the E06 Thompsons Ln primary substation at charts presented at Figures 27 (New development with adoption of micro-CHP systems and Environmental Awakening scenario) and 33 (New development with simultaneously adoption of PV panels and micro-CHP systems and Environmental Awakening scenario). For each of one of these two scenarios, the ratio behaviour for the E06 Thompsons Ln primary substation will be presented.

(i) **New development with adoption of micro-CHP systems and Environmental Awakening scenario**

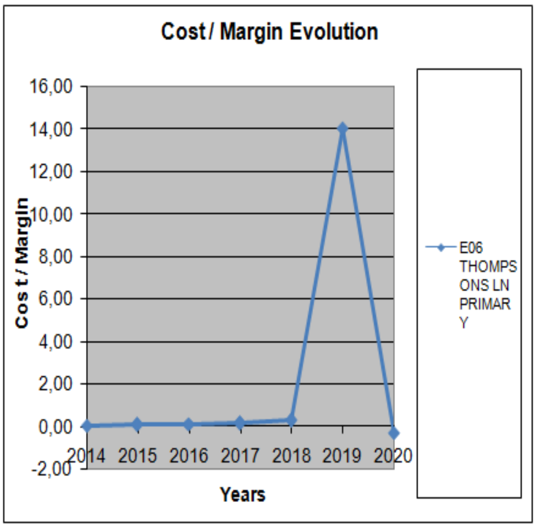

Figure 39: E06 Thompsons Ln P.S. ratio evolution (large scale) for CHP adoption and Environmental Awakening scenario

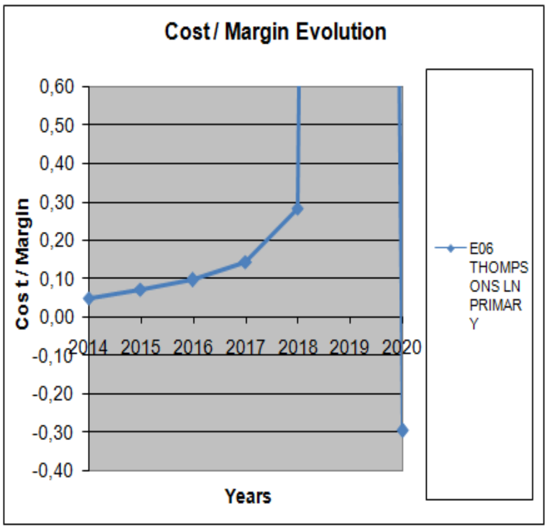

Figure 40: E06 Thompsons Ln P.S. ratio evolution (small scale) for CHP adoption and Environmental Awakening Scenario

Table 32: Demand, Margin and ratio evolution for E06 Thompsons Ln P.S. for CHP adoption and Environmental Awakening scenario

2017		2018		2019		2020	
Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin
15.61476	0.919811	16.06996	0.464611	16.52516	0.009411	16.98036	-0.44579

2017	2018	2019	2020
ratio	ratio	ratio	ratio
0.142529299	0.282171608	13.93067925	-0.294085242

(ii) New development with simultaneously adoption of PV panels and micro-CHP systems and Environmental Awakening scenario

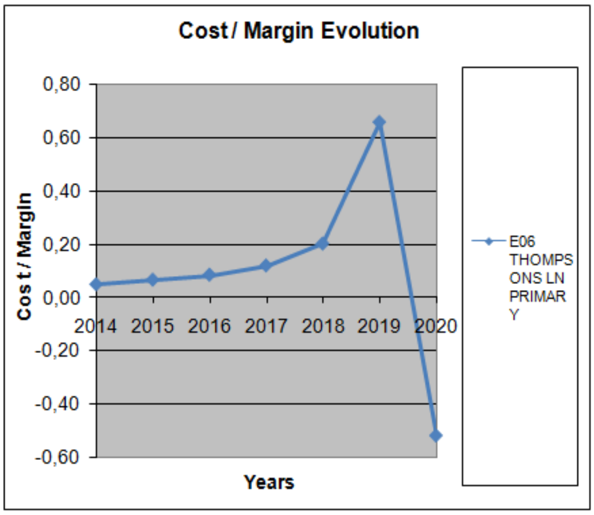

Figure 41: E06 Thompsons Ln P.S. ratio evolution (large scale) for PV+CHP adoption and Environmental Awakening Scenario

Table 33: Demand, Margin and ratio evolution for E06 Thompsons Ln P.S. for PV+CHP adoption and Environmental Awakening scenario

2017		2018		2019		2020	
Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin
15.42325	1.111326	15.87845	0.656126	16.33365	0.200926	16.78885	-0.25427

2017	2018	2019	2020
ratio	ratio	ratio	ratio
0.117967181	0.199809172	0.652478908	-0.515585621

As it is possible to see analysing the charts presented at Figures 39, 40 and 41, the ratio between connection costs and margin left evolutes in a way that achieves negatives values between the years 2019 and 2020. Analysing the same charts it is possible to see that at Figures 39 and 40 the ratio changing from positives to negatives values is made very close to the year 2020 and at Figure 41 the same changing is visualized sensitively in the middle of the year 2019 and the year 2020.

Although, by analysing the Tables 32 and 33 it is verified that the primary substation margin for each year of analyse is always higher under the scenario where PV + CHP systems are applied simultaneously than in the one where is applied only CHP systems.

Another situation that is visualized in the Figures 39, 40 and 41 and could be badly interpreted or misunderstood is that for negatives ratio values, as smaller this value is, the higher is the primary substation margin. This is the reason why Figures 39 and 40 represents a higher value for the ratio at the year 2020 than the Figure 41.

4.4.4- Risk Assessment

In this section it will be analysed the impact that the development construction anticipation or postpone has on determinate the best investment solution.

The anticipation or postpone of a development that is expected to start and finishes in certain years is a situation that can occur and have implication on determinate the best investment solution for connecting the new development loads to a primary substation.

For analyse the impact of postpone or anticipate a development construction it was chosen a different urban development from the one previously analysed that was expected to be implemented at Cambridge city centre. The impact of postpone or anticipate the previous development could be studied but the obtained results were nor as elucidative as the ones obtained by choosing a development implemented at Huntingdon with 1050 expected new houses and 390 new jobs planned to start at the beginning of 2013 and finish at the end of 2014.

For this development, it was simulated the implementation of SWH systems under the Continuing Prosperity scenario.

4.4.4.1- Investment Solutions

Table 34: Primaries Demand and Margin evolution for SWH adoption and Continuing Prosperity scenario

Primaries	2013		2014		2015		2016	
	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin
B61 GODMANCHESTER PRIMARY	15,6	7,5	16,6	6,5	16,9	6,2	17,2	5,9
B59 HUNTINGDON GRID	30,6	5,9	31,9	4,6	32,4	4,0	33,0	3,5
Primaries	**2017**		**2018**		**2019**		**2020**	
	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin
B61 GODMANCHESTER PRIMARY	17,4	5,7	17,7	5,4	17,9	5,2	18,2	4,9
B59 HUNTINGDON GRID	33,5	3,0	34,0	2,4	34,6	1,9	35,1	1,4

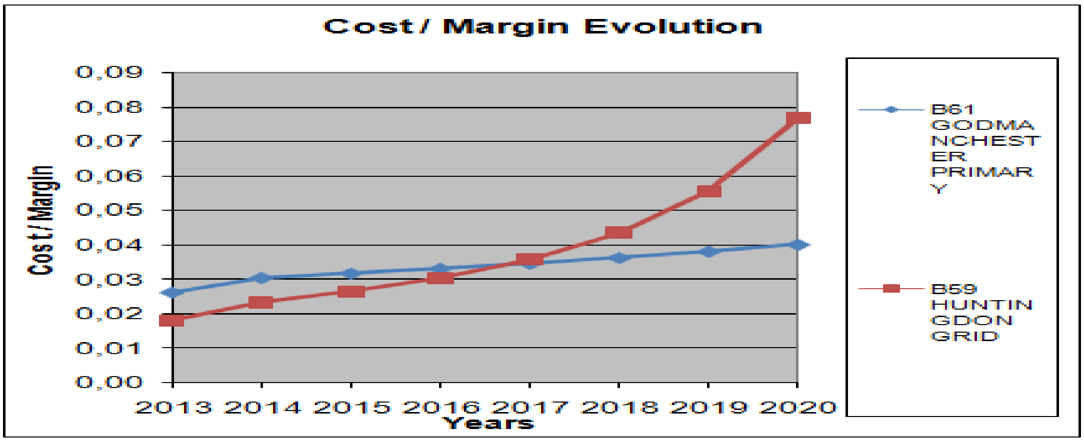

Figure 42: Chart with the Cost/Margin evolution for SWH adoption and Continuing Prosperity scenario

Table 35: Distance and Connection Costs from the analysed primaries substations to the new development

Primary	Distance (km)	Connection cost (k£)
B61 Godmanchester	2.9	200.1
B59 Huntingdon Grid	1.5	103.5

For the simulated scenario, it was obtained two investment solutions. Connecting the new development loads to the B59 Huntingdon Grid primary substation is the best investment in a short term (from the beginning of the development till 2016) and connecting the new development loads to the B61 Godmanchester primary substation is the best investment in a long term (from 2017 on).

By Analysing Table 35 with the connection costs for the two possible investment options, it is possible to note that connecting the new development loads to B59 Huntingdon Grid primary substation is 48.3% cheaper than connecting to B61 Godmanchester primary substation.

As it is possible to see, the cheaper solution (B59 Huntingdon Grid primary substation) is the best investment solution only for the first 4 years of the development (2013-2016) due to the fact that this primary has a underlying load growth higher (0.53 MW/year) than the one predicted for the B61 Godmanchester primary substation (0.26 MW/year).

So, the investment option for connecting the development loads to B59 Huntingdon Grid primary substation or B61 Godmanchester primary substation has to be made by the investor considering what is his predisposition for investing at a solution that is better for the first 4 years of the investment and worst in the others (considering that this solution is 48.3% cheaper than the long term investment option).

4.4.4.2- Anticipate Investment

Table 36: Primaries Demand and Margin evolution for SWH adoption and Continuing Prosperity scenario

Primaries	2010		2011		2012		2013		2014		2015		2016		2017		2018		2019		2020	
	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin
B61 GODMANCHESTER PRIMARY	14,8	8,3	15,9	7,2	16,1	7,0	16,4	6,7	16,6	6,5	16,9	6,2	17,2	5,9	17,4	5,7	17,7	5,4	17,9	5,2	18,2	4,9
B59 HUNTINGDON GRID	29,0	7,5	30,3	6,2	30,8	5,6	31,4	5,1	31,9	4,6	32,4	4,0	33,0	3,5	33,5	3,0	34,0	2,4	34,6	1,9	35,1	1,4

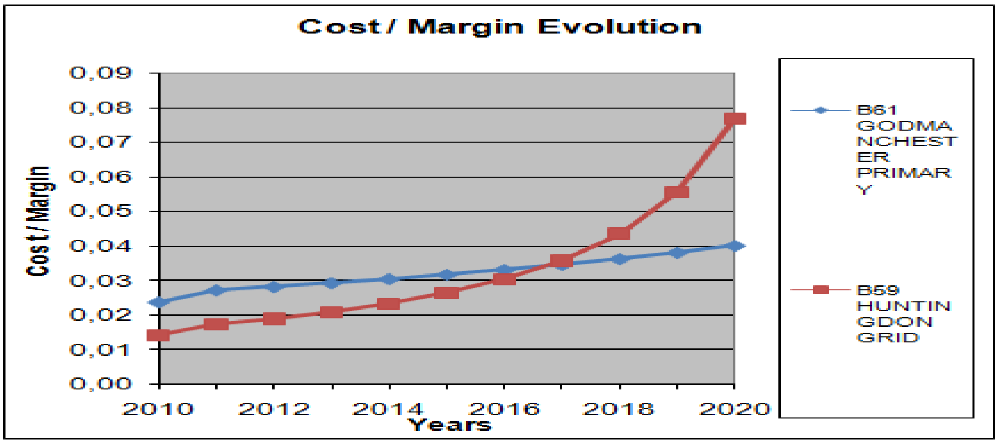

Figure 43: Chart with the Cost/Margin evolution for SWH adoption and Continuing Prosperity scenario

In this simulation, it was considered that the development implementation was anticipated in three years (stars at 2013 and finishes at 2014). It was verified that the demand that was required to the primaries substations analysed during the years that the investment was anticipated was higher when compared to the one expected if the investment was not anticipated. This is due to the fact that if the investment was anticipated, that loads were not expected at that time and obviously for those years, the demand required to a primary substation will be far higher than it was initially predicted. Although, for the year that the development was initially planned to be finished (in this case 2014), the total demand required to a primary substation will be exactly the same than the one that would be if the development wasn't anticipated. This happens due to the fact that the underlying load growth for each primary substation is a constant value for each year.

Therefore, in this case, the best option at a short term (connect to B59 Huntingdon Grid primary substation) is the best option for seven years, since the start of development (2010) till the year 2016.

Once the option for connecting the new development loads to B59 Huntingdon Grid primary substation is 48.3% cheaper than connecting the same loads to B61 Godmanchester primary substation, in the case where the investment is anticipated, this option is a better solution comparing to the case where the development starts on the planned time because, the number of years where this investment option is better than the one to connect to B61 Godmanchester primary substation is higher (in this particular case, where the investment was anticipated in three years, this is a better option for three years more).

4.4.4.3- Postpone Investment

Table 37: Primaries Demand and Margin evolution for SWH adoption and Continuing Prosperity scenario

Primaries	2016		2017		2018		2019		2020	
	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin	Demand	Margin
B61 GODMANCHESTER PRIMARY	16,4	6,7	17,4	5,7	17,7	5,4	17,9	5,2	18,2	4,9
B59 HUNTINGDON GRID	32,2	4,3	33,5	3,0	34,0	2,4	34,6	1,9	35,1	1,4

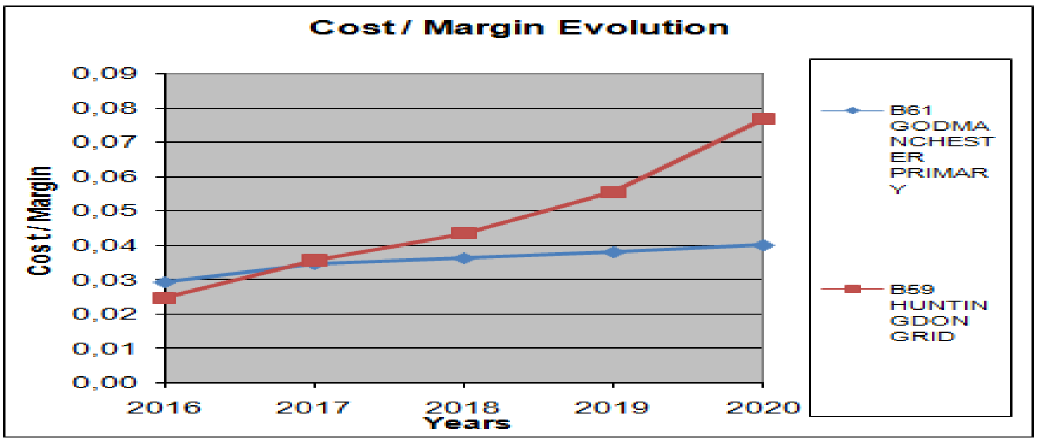

Figure 44: Chart with the Cost/Margin evolution for SWH adoption and Continuing Prosperity scenario

In this simulation, it was considered that the development implementation was postponed in three years (stars at 2016 and finishes at 2017). It was verified that the demand that was required to the primaries substations analysed during the years that the investment was postponed was lower when compared to the one expected if the investment was not postponed. This is due to the development postponing where, during those years, it was expected certain loads from the new development (initially planned to start three years sooner), and those would be inexistent during the years that the development was postponed (in this particular case, three years). Although, after the number of years of development postpone (in this case, the finish of development occurs at 2017), the total demand required to a primary substation will be exactly the same than the one that would be if the development wasn't postponed. This happens due to the fact that the underlying load growth for each primary substation is a constant value for each year.

Therefore, in this case, the best option at a short term period (connect to B59 Huntingdon Grid primary substation) is the best option nether for a year. The development implementation starts at 2016 and at 2017 the best option to connect the new development loads is the B61 Godmanchester primary substation.

So, in this particular case of postponing the investment in three years, the option for connecting the new development loads to the B59 Huntingdon Grid primary substation is not very reasonable because this is the best option nether for a year. The option of connecting the new development loads to the B61 Godmanchester primary substation seems to be much more reasonable once this is the best connection option from the year 2017 on.

Chapter 5

Conclusions and Future Work

5.1 – Introduction

During the elaboration of this proposed study in which are analyzed strategies for investment in sustainable electricity networks in an urban environment were achieved several results and the major concerns and conclusions obtained during the elaboration of the same study will be now presented in this chapter.

5.2 – Study Conclusions

The main aim of the developed study was to obtain strategic investment solutions in electricity network in a city environment in order to connect the expected loads from a new development to the existing primaries substations. The impact that demand side management programmes, energy efficiency measures and micro-generations technologies have on reducing the electric demand from a certain new development and its influence on the investment connection solution was studied and analysed.

Within this study a research in order to understand the suitability of each micro-generation technology for implementation at urban developments was made and it was concluded that micro combined heat and power systems, photovoltaic panels and solar water heating systems were the most suitable technologies, considering the ones analysed, for implementation at an urban environments.

So, for those urban suitable micro-generation technologies, a study of the impact that those could possibly have on determinate the best investment solution for connecting the expected loads from a new development to a primary substation was made using the developed model (simulation of specific urban environment as a study case).

According to the specific study case simulated, the technology that was verified to have a higher impact on reducing the development demand at peak times was micro-CHP systems. For PV panels and SWH systems it was obtained a contribution of 13.6% and 22.1% respectively on reducing the development demand when compared with micro-CHP systems. I.e., PV panels contribution to reduce the development demand at peak times was only 13.6% from the expected reduction predicted for the adoption of micro-CHP systems. These obtained results can be explained by the fact that micro-CHP systems are technologies that enable the production of electricity and heat simultaneously and, normally relies on fuels as combustible and not in intermittent resources like the solar for PV panels and SWH systems.

The impact for all the other simulated parameters were previously discussed in the previous chapter and what can be concluded is that all of them (DSM programmes, energy efficiency measures, socio-economical environment) could have a great impact on reducing the development demand, and therefore on the determination of the best investment solution for connect the development loads to a primary substation. This makes the model a complete tool, in which is considered a range of different parameters, in order to obtain the expected impact of those on determinate the best investment solution.

Therefore, and as it was planned at the beginning of this work, this study can eventually provides an auxiliary decision maker tool for the investor (DNO's) in terms of predict which will the best connection option for an analyzed new development.

One of the possible benefit for DNO's of the study here presented, besides the advantage that is to have a prediction of the investment that they possible have to make in the future, is according to the investment predicted for the different scenarios simulated, the possibility for them to support or not some kind of programs that favour the expansion of the adoption of energy efficiency measures and micro-generation technologies in order to reduce or optimise the investment predicted by the model.

5.3 – Limitations and Future Work

In this section the main limitations of the developed study will be presented as well as the future work that can be done in order to try to improve this same study.

• The electrical contribution of the studied micro-generation technologies can vary according to the location of the development analyzed, because for technologies such as PV panels and SWH systems that relies on the solar resources, a exhaustive study for the contribution that these systems could have according to their location and expected quality of solar resources for that location could be made. In this presented study, the contribution of these technologies were considered to be the same for every location within U.K. and therefore a more detailed research for the preview contribution of these technologies would improve the accuracy of the developed model.

• The governmental incentives for the appliance of micro-generation technologies at the expected new developments could vary according the localization of the development analysed, i.e., for developments situated within a certain local authority district the incentives for the appliance of a certain micro-generation technology could be different from another according to natural recourses like wind or sun. So, if an exhaustive research of the expected incentives and support for each micro-technology would be made for each local authority district, the expected implementation of each technology would be easily predicted according to the location of the analysed development.

• According to the location of the analyzed development, an exhaustive research to understanding the sources and nature of demand growth could be made in order to help identify practicable and cost-effective demand-related measures that could defer larger capital investment. For example, a detailed examination of load duration curves for analysed areas where the network capacity is approaching its limits in relation to the likely demand offsets that would be realised by the introduction of micro-generation or other demand side measures.

• The databases used in the model should be actualized as often as possible in order to have the accurate values for the actual demand and underlying load growth for each primary substation.

References

[1] Secretary of State for Trade and Industry, “Meeting the Energy Challenge: A White Paper on Energy”, Presented to Parliament by the Secretary of State for Trade and Industry, May 2007
http://www.berr.gov.uk, June 2008

[2] Graham Ault, Ian Elders, Jim McDonald, Graeme Burt, Ryan Tumilty “Electricity Network Scenarios for 2020”, SuperGen Future Network Technologies Consortium, July 2006
http://www.supergen-networks.org.uk, May 2008

[3] European Commission Energy webpage: “Energy Polices”
http://ec.europa.eu/energy, June 2008

[4] Geographic Information System webpage: “The guide to Geographical Information System”
http://www.gis.com, June 2008

[5] British Columbia,” Energy Efficiency for Homeowners- A Worthwhile Investment”, http://www.em.gov.bc.ca, April 2008

[6] Secretary of State for Trade and Industry, “Meeting the Energy Challenge: A White Paper on Energy”, Presented to Parliament by the Secretary of State for Trade and Industry, 125, May 2007
http://www.berr.gov.uk, 09-06-08

[7] European Commission, “Energy: Let us overcome our dependence”, 2-3, 2002
http://ec.europa.eu/energy, June 2008

[8] Royal Commission on Environmental Pollution, “Twenty-sixth Report: The Urban Environment”, 91, March 2007
http://www.official-documents.gov.uk, May 2008

[9] Royal Commission on Environmental Pollution, "Twenty-sixth Report: The Urban Environment", 94, March 2007
http://www.official-documents.gov.uk, May 2008

[10] Royal Commission on Environmental Pollution, "Twenty-sixth Report: The Urban Environment", 97 March 2007
http://www.official-documents.gov.uk, June 2008

[11] Department for Business Enterprise & Regulatory Reform webpage "Micro generation"
http://www.berr.gov.uk, May 2008

[12] United Nations, "Kyoto Protocol to the United Nations Framework Convention on Climate Change", 1998
http://unfccc.int, June 2008

[13] Commission of the European Communities, "GREEN PAPER: A European Strategy for Sustainable, Competitive and Secure Energy", 10, 2006
http://ec.europa.eu/energy, June 2008

[14] Secretary of State for Trade and Industry, "Meeting the Energy Challenge: A White Paper on Energy", Presented to Parliament by the Secretary of State for Trade and Industry, 10, May 2007
http://www.berr.gov.uk, June 2008

[15] Energy Saving Trust webpage: "Your Impact on Climate Change"
http://www.energysavingtrust.org.uk, June 2008

[16] Secretary of State for Trade and Industry, "Meeting the Energy Challenge: A White Paper on Energy", Presented to Parliament by the Secretary of State for Trade and Industry, 11, May 2007
http://www.berr.gov.uk, June 2008

[17] Secretary of State for Trade and Industry, "Meeting the Energy Challenge: A White Paper on Energy", Presented to Parliament by the Secretary of State for Trade and Industry, 10-11, May 2007
http://www.berr.gov.uk, June 2008

[18] Communities and Local Government webpage “Building a Greener Future: Towards Zero Carbon Development”
http://www.communities.gov.uk, June 2008

[19] Secretary of State for Trade and Industry, “Meeting the Energy Challenge: A White Paper on Energy”, Presented to Parliament by the Secretary of State for Trade and Industry, 88, May 2007
http://www.berr.gov.uk, June 2008

[20] Secretary of State for Trade and Industry, “Meeting the Energy Challenge: A White Paper on Energy”, Presented to Parliament by the Secretary of State for Trade and Industry, 89, May 2007
http://www.berr.gov.uk, June 2008

[21] Ofgem Publications, “Annex: Scenarios Development Methodology, Long-Term Electricity Network Scenarios (LENS) Project”, 2007
http://www.ofgem.gov.uk, June 2008

[22] Graham Ault, Ian Elders, Jim McDonald, Graeme Burt, Ryan Tumilty “Electricity Network Scenarios for 2020”, SuperGen Future Network Technologies Consortium, 6, July 2006
http://www.supergen-networks.org.uk, May 2008

[23] Graham Ault, Ian Elders, Jim McDonald, Graeme Burt, Ryan Tumilty “Electricity Network Scenarios for 2020”, SuperGen Future Network Technologies Consortium, 7, July 2006
http://www.supergen-networks.org.uk, May 2008

[24] Graham Ault, Ian Elders, Jim McDonald, Graeme Burt, Ryan Tumilty “Electricity Network Scenarios for 2020”, SuperGen Future Network Technologies Consortium, 9-23, July 2006
http://www.supergen-networks.org.uk, May 2008

[25] Tyndall Centre for Climate Change Research” Integrating Renewables and CHP into the UK Electricity System”, 20-26, 2004
http://www.tyndall.ac.uk, May 2008

[26] A report from the Renewables Advisory Board, “The Role of Onsite Energy Generation in Delivering Zero Carbon Homes”, 2007
http://www.renewables-advisory-board.org.uk, May 2008

[27] A report from the Renewables Advisory Board, “The Role of Onsite Energy Generation in Delivering Zero Carbon Homes”, 9, 2007

http://www.renewables-advisory-board.org.uk, May 2008

[48] Department for Business, Enterprise and Regulatory Reform, “Potential for Microgeneration Study and Analysis”, 4, November 2005
http://www.berr.gov.uk, June 2008

[49] Department for Business, Enterprise and Regulatory Reform, “Potential for Microgeneration Study and Analysis”, 10-15, November 2005
http://www.berr.gov.uk, June 2008

[30] Department for Business, Enterprise and Regulatory Reform, “Potential for Microgeneration Study and Analysis”, 75, November 2005
http://www.berr.gov.uk, June 2008

[31] US Department of Energy webpage
http://www.doe.gov, May 2008

[32] Energy Information Administration webpage
http://www.eia.doe.gov, May 2008

[33] The Demand Side Management webpage
http://www.demandsidemanagement.com, May 2008

[34] The Institute of Electrical and Electronics Engineers webpage
http://www.ieeeusa.org, May 2008

[35] Energy Saving Trust, “Renewable energy sources for homes in urban environments”, November 2005
www.energysavingtrust.org.uk, May 2008

[36] British Photovoltaic Association webpage
http://www.pv-uk.org.uk, June 2008

[37] New ERA for electricity in Europe, “Distributed Generation: Key Issues, Challenges and Proposed Solutions”, 2003
http://www.smartgrids.eu, June 2008

[38] Solar Trade Association webpage
http://www.solartradeassociation.org.uk, May 2008

[39] British Wind Energy Association webpage
http://www.bwea.com, May 2008

[40] Dr. Robin Curtis, “Earth energy in the UK”, 24, 2001
http://geoheat.oit.edu, May 2008

[41] IEA Heat Pump Centre webpage
http://www.heatpumpcentre.org, May 2008

[42] Earth Energy webpage
http://www.earthenergy.co.uk, May 2008

[43] UK Heat Pump Association webpage
http://www.heatpumpnet.org.uk, May 2008

[44] National Energy Foundation webpage
http://www.nef.org.uk, May 2008

[45] British Biogen webpage
http://www.britishbiogen.co.uk, May 2008

[46], Martin Pehnt, Barbara Praetorius, Corinna Fischer, Lambert Schneider, Martin Cames, Jan-Peter Voß, “Micro CHP – a sustainable innovation?” Transformation and Innovation in Power Systems, 13, 2004
http://www.tips-project.de, June 2008

[47] Combined Heat & Power Association webpage
http://www.chpa.co.uk, May 2008

[48] Micro Power Council webpage
http://www.micropower.co.uk, May 2008

[49] Cogen Europe Fact “Micro-CHP Fact Sheet-United Kingdom”, 2004
http://www.cogen.org, June 2008

[50], Bob Bassett, “High-level model for forecasting demand growth and associated load-related expenditure” Engineering Regulatory Strategy, February 2008

[51] Energy Networks Association, “Long Term Capital Expenditure Forecasts for the Electricity Networks in Great Britain”, July 2007
http://www.energynetworks.org, June 2008

[52] Ener•g Combined Power, “The Essential Guide to Small Scale Combined Heat & Power”, 5, 2007
http://www.energ.co.uk, May 2008

[53] DTI's Distributed Generation Programme,”System Integration of Additional Microgeneration”, 53-58, September 2004
http://www.berr.gov.uk, June 2008

[54] Energy Saving Trust, “Meeting the 10 per cent target for renewable energy in housing – a guide for developers and planners”, 17, September 2006
http://www.energysavingtrust.org.uk, June 2008

[55] British Wind Energy Association, “Small Wind Turbine FAQ”, 2007
http://www.bwea.com

[56] Watson J, Sauter R, Bakr B, James P, Myers Luke, Wing R, “Unlocking the Power House: Policy and System Change for domestic micro-generation in the UK”, Imperial College, University of Sussex, University of Southampton, 10, October 2006
http://www.sussex.ac.uk, May 2008

[57] European Commission fact, “PV in Regions”, 2007
http://re.jrc.cec.eu.int, May 2008

[58] A report from the Renewables Advisory Board,”The Role of Onsite Energy Generation in Delivering Zero Carbon Homes”, 134, 2007
http://www.renewables-advisory-board.org.uk, June 2008

[59] A report from the Renewables Advisory Board, “The Role of Onsite Energy Generation in Delivering Zero Carbon Homes”, 143, 2007
http://www.renewables-advisory-board.org.uk, June 2008

[60] A report from the Renewables Advisory Board, “The Role of Onsite Energy Generation in Delivering Zero Carbon Homes”, 29, 2007
http://www.renewables-advisory-board.org.uk, June 2008

[61] James Fisher, Chris Jessop, Karen McGuire, Andrew Waddelove:"A Review of Microgeneration and Renewable Energy Technologies", NHBC Foundation, 23, January 2008
http://www.nhbcfoundation.org, June 2008

[62] A report from the Renewables Advisory Board, "The Role of Onsite Energy Generation in Delivering Zero Carbon Homes", 154, 2007
http://www.renewables-advisory-board.org.uk, June 2008

[63] Energy Saving Trust, "Energy- Efficient Refurbishment of existing housing", 30, 2007
http://www.energysavingtrust.org.uk, May 2008

[64] Baufritz webpage:
http://www.baufritz.co.uk/energy_efficiency.asp, May 2008

[65] Iain Johnston, Tamás Bertényi," Domestic Energy Use and Sustainability", ImpEE Project, Department of Engineering, University of Cambridge, October 2005

http://www-g.eng.cam.ac.uk/impee, June 2008

[66] Community Energy, "Urban Planning for a Low Carbon Future", 22, 2008
http://www.chpa.co.uk, June 2008