University of Strathclyde
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The impact of Energy Efficiency Solutions and Renewable Electricity Generation in three Rural Communities in Scotland

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ABSTRACT

The present dissertation has aimed to assess information provided by the Energy Agency from a survey carried out in households of the communities of Dailly, Barr, Pinwherry and Pinmore. These communities are benefiting from an Energy Efficiency Fund created by Scottish and Southern Energy in connection with their Hadyard Hill Wind Farm.

As most of the households had different characteristics, three scenarios were constructed, where the majority of the households surveyed could be represented. The three scenarios considered were: detached Pre 1918 dwelling, semi-detached 1930-1949 dwelling, and 1950-1963 semi-detached dwelling, all of them with two occupants.

The analysis was divided in three stages for each scenario: evaluation of energy efficiency solutions that were already applied as a first stage of the Community Energy Project, further energy efficiency solutions to be applied, and renewable electricity generation considering photovoltaics and wind turbines. The analysis showed that with the application of energy efficiency solutions, the carbon emissions and the energy use could be reduced in up to 51% increasing the energy rating of the dwelling. The simulations made in the software HOMER concluded that the most optimum resource would be a wind turbine, which will considerably reduce the carbon emissions.

There are still funds remaining in the project budget to allow these rural communities to apply for a partial grand should they decide to install Renewable Electrical Generation.

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1. INTRODUCTION

The Energy White Paper[13] identified energy efficiency as the most cost-effective way to meet all the UK energy efficiency goals, which are listed below.

- Reducing carbon emissions: Using energy as efficiently as possible is the most cost-effective way to manage energy demand, and thus to address the carbon emissions.

- Ensuring security of supply: By reducing demand on the gas and electricity distribution networks, energy efficiency helps to deliver improved resilience and will reduce the dependence on imported energy supplies.

- Maintaining competitiveness: By helping consumers reduce their energy bills, energy efficiency helps UK businesses to be more productive and competitive.

- Tackling fuel poverty: Improving the energy standards of homes has as an important role in reducing spending on fuel by those in fuel poverty.

Furthermore, in order to move to a more clean energy society, more things can be done. Renewable generation can make a significant contribution to tackling climate change, ensuring reliable energy supplies and could help to tackle fuel poverty as well. It can provide a sustainable source of low carbon energy and help to reduce carbon emissions from homes, small commercial buildings, and community buildings. Microgeneration can also have a wider impact, by increasing awareness and engaging the public in tackling climate change.[38]

The communities of Dailly, Barr, Pinwherry and Pinmore located in the southwest of Scotland have recognized this global issue and determined to do something about it. The project, which is managed by the Energy Agency, started last year with money from a fund, created by Scottish and Southern Energy in connection with their Hadyard Hill Wind Farm. Currently, part of this fund has already been used in energy efficiency measures in some of the dwellings, mostly the poorly energy rated, based on a survey carried out recently.

The initial focus of the present project was to present a perspective; thus Chapter 3 gives some basic background information about the common energy efficiency solutions for buildings such as insulation, draught, and lighting, their costs, and their economical and environmental impact. It also gives an insight to the current renewable generation technologies that are used with domestic purpose, and some interactive tools that are used in order to optimize the analysis.

The next part of this study is based in the data gathered in the survey carried out during the first semester of the present year. Chapter 4 gives a summary of the main results from the survey and compares them according to their characteristics (Age band, built form, number of occupants, etc). Based on these comparisons three scenarios are built, which represent the majority of the dwellings, not all of them due to the time constraint.

Chapter 5 assesses the energy efficiency solutions for each one of the scenarios, considering that some initial measures have been already taken in the dwellings as part of the energy project run by the Energy Agency. The outcome of this assessment is optimized scenarios, where the energy consumption and the emissions is less.

This outcome is used as an input for Chapter 6, where renewable generation for domestic use is assessed. The simulation was run in a software called HOMER, therefore the technologies considered for this assessment are only solar photovoltaics and wind turbines.

Finally, Chapter 7 gives the conclusions and recommendations based on the results of the assessments in the previous chapters.

2. AIM AND METHODOLOGY

2.1 Aim

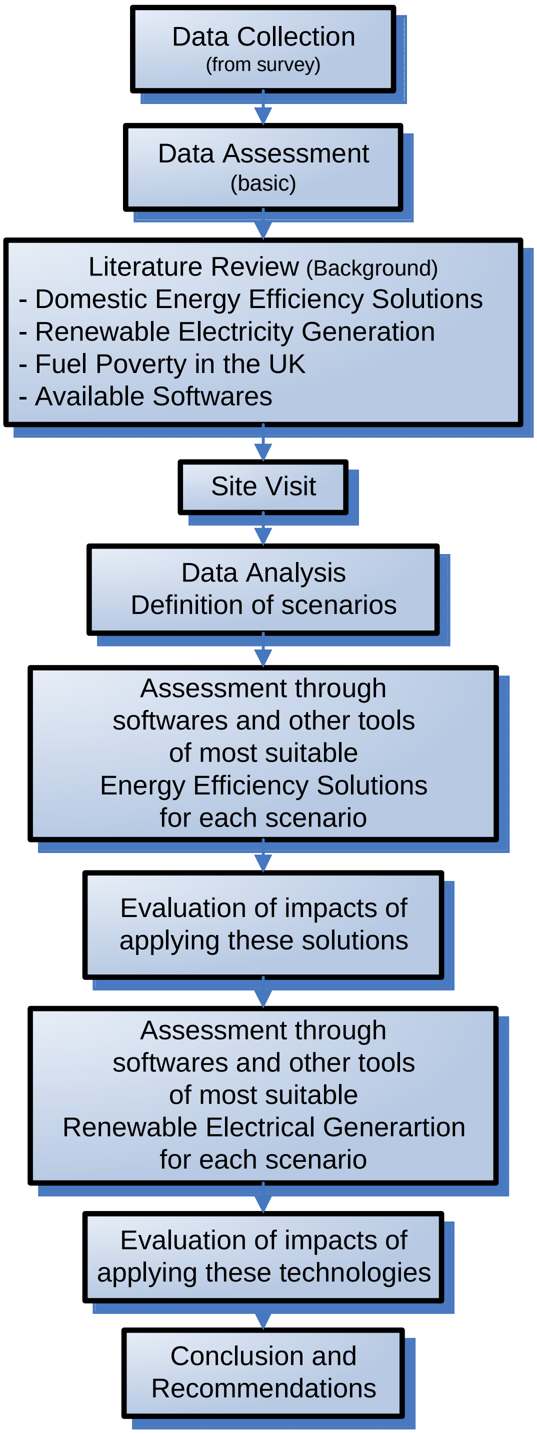
To establish the impact of applying energy efficiency solutions and renewable electricity generation in dwellings from three rural communities in Scotland: Barr, Dailly and Pinmore and Pinwherry. The assessment will be based on data gathered by surveys already performed by the Councils.

- To determine the most suitable energy efficiency solutions that can be applied to the majority of houses in the communities.

- To assess renewable electricity generation to be used in the communities through the simulation based on the energy demand of the majority of the houses in the communities.

- To evaluate the economical and environmental impacts of applying these solutions and technologies.

2.2 Methodology



3. BACKGROUND

Energy use is one of the most important issues our current society. The final energy consumption in the UK for the year 2006 was mainly accounted for by the transport sector (35%) and the domestic sector (27%)[10]. These figures are shown in Figure 3.2.

	2004 Mtoe	2005 Mtoe	2006 Mtoe
Industry	33,175	33,555	32,561
Transport	57,753	59,062	59,780
Domestic	48,587	47,161	45,563
Other	20,308	20,315	19,888
Non energy use	12,429	12,583	11,814
TOTAL	**172,252**	**172,676**	**169,606**

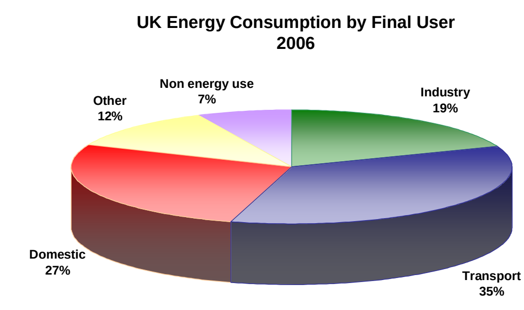


Figure 3.1: UK Energy Consumption by Final User [10]

The domestic sector contributes to 27% of the total CO_2 emissions (see Figure 3.1).[32] Tackling these emissions will contribute meeting the goal set by the Energy White Paper[13] of cutting the UK's carbon emissions - the main contributor to global warming - by some 60% by about 2050, with real progress by 2020.

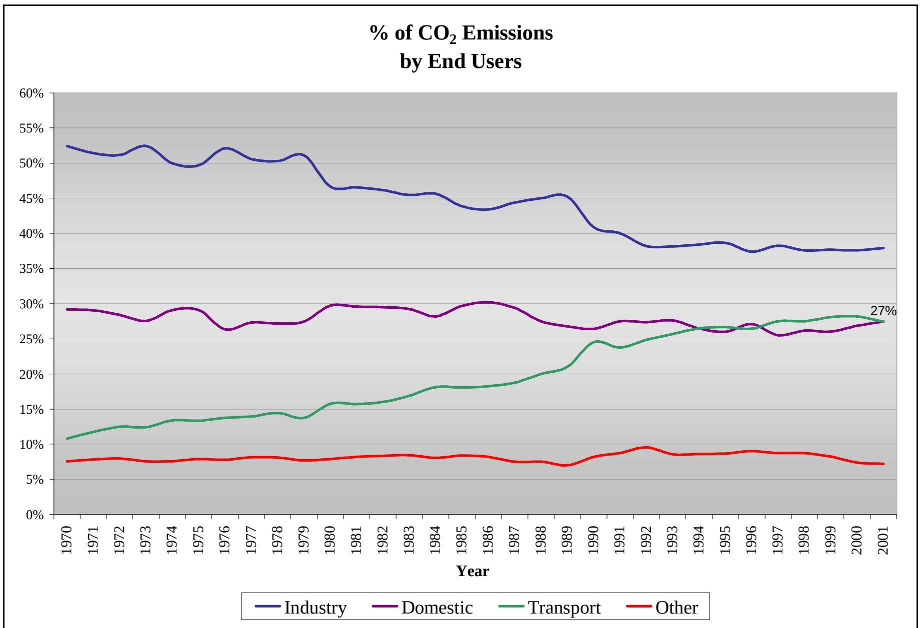


Figure 3.2: UK CO_2 emissions by End User [10]

3.1 Domestic Energy Efficiency Solutions

Since 1990 domestic energy consumption has increased, the number of households has increased by more than 10%, population has increased by 4% and household disposable income has increased by 30%.[16] Despite energy efficiency solutions, such as insulation, double glazing, and energy efficient electrical appliances, domestic energy consumption has not increased at a greater rate.

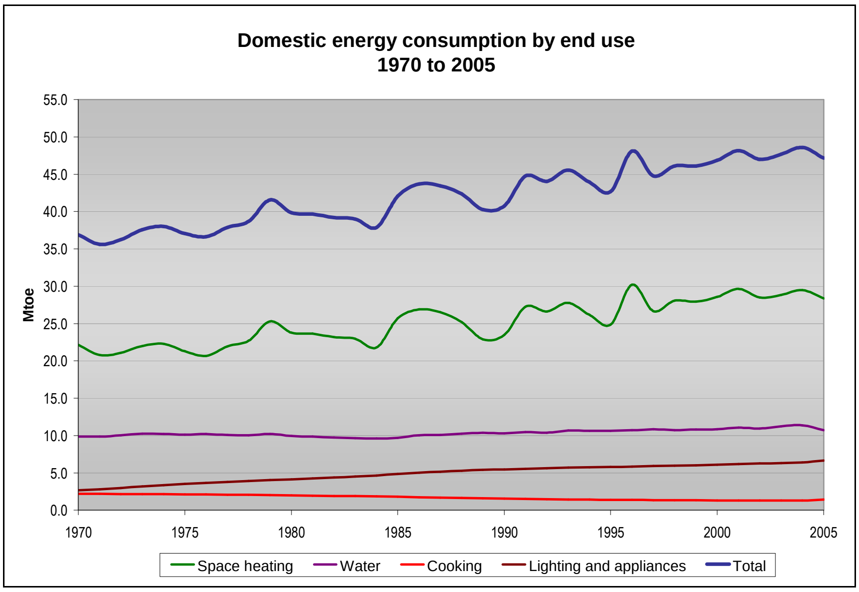


Figure 3.3: UK Domestic energy consumption by End Use, 1970 to 2005 [15]

As it can be seen in Figure 3.3, the majority of energy consumed in the domestic sector is for space heating, which accounted for 60% of all delivered energy consumed[16]. Space heating is dependent on outside temperatures, which explain the fluctuations between years; it is also dependent on the characteristics of the walls, floors, roofs, and windows. The heat loss of an average house is shown in Figure 3.4.

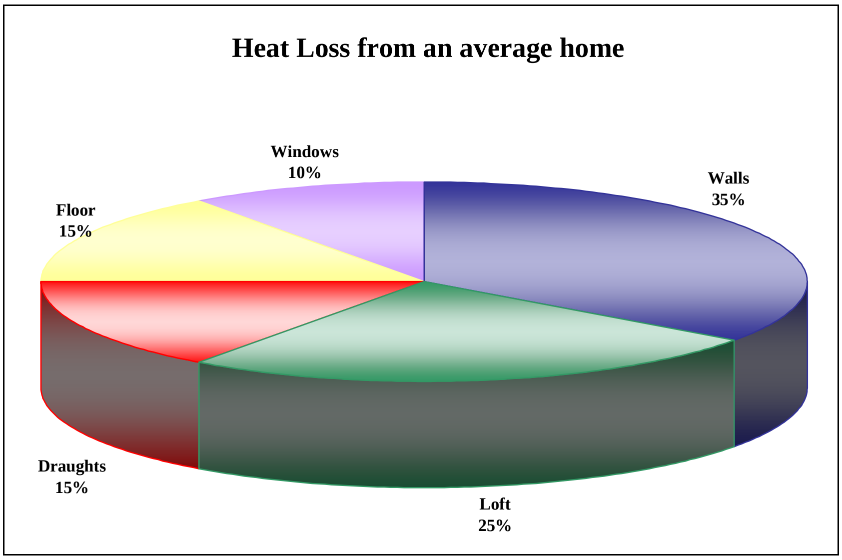


Figure 3.4: Heat loss from an average UK home [3]

Energy efficiency can be achieved either by meeting at least the minimum levels of performance set by the regulations or by applying energy efficiency solutions. In order for them to be efficient, they also should be cost effective and applicable to the household. The average household could save around two tonnes of CO_2 a year by making their home energy efficient.[20]

3.1.1 Common Solutions

Given that not all the solutions can be applied to a same household, it is important to choose the most suitable, and undertake the improvements considering their opportunities (i.e. when installing a new bathroom it would be good to take a look to other opportunities that will be more efficient once they are applied, such as wall, roof, and floor insulation). Table 3.1 gives an insight of these opportunities based on the approaches that can be done to a house or dwelling.

Measures to consider	Moving into a new existing homes	Extensions	Loft Conversion	Nursery	New kitchen	New bathroom	Adding a conservatory	Re-roofing	Re-plastering	Replacing windows	Re-wiring	Re-flooring	New heating system	Replacement boiler	Replacing hot water cylinder	Decorating	Re-render externally
Wall insulation	Good	Good	Good	Other	Other	Other	Good	Other	Good	Other	Other		Good	Other		Other	Good
Roof insulation	Good	Good	Good	Other		Other		Good	Other		Other		Good	Other			
Floor insulation	Other	Good		Other	Other	Other			Other		Other	Good	Good	Other			
Efficient heating and controls	Other	Other	Other	Other			Other						Good	Good	Other		
Efficient hot water system	Other	Other	Other	Other			Other						Good	Good	Good		
Draught-stripping	Other	Good	Good	Other	Other	Other	Other		Other	Good		Good	Good	Other		Good	Other
Ventilation	Other	Good	Good	Other	Good	Good	Good	Other	Other	Good		Good	Good	Other			Other
Windows	Other	Good	Good	Other	Other	Other	Good	Other		Good			Good	Other			Other
Energy efficient lighting	Good	Good	Good	Good	Good	Good	Good		Other		Good					Other	
Energy efficient appliances	Good	Good			Good	Good					Other						

■ Good opportunities for cost-effective energy efficiency improvements

■ Other opportunities that are well worth considering

Table 3.1: Opportunities for energy efficiency improvement [20]

Some of the factors that affect the amount of energy used and the impacts in emissions and costs are the type of dwelling, age, weather and location, number of occupants, activities of the occupants, etc. The more factors considered, the better the result.

The main types of insulation in the UK are loft insulation, cavity wall insulation, double glazing and hot water tank insulation.[16] In 2000, 72 % of all houses in the UK had loft insulation, 19% had some form of cavity wall insulation installed, 39% of houses had more than 80% of their windows treated with double glazing and most houses with hot water tanks have hot water tank insulation since it is a low cost, easy maintenance form of insulation[16]. The effects of some of these improvements are shown in Figure 3.4.

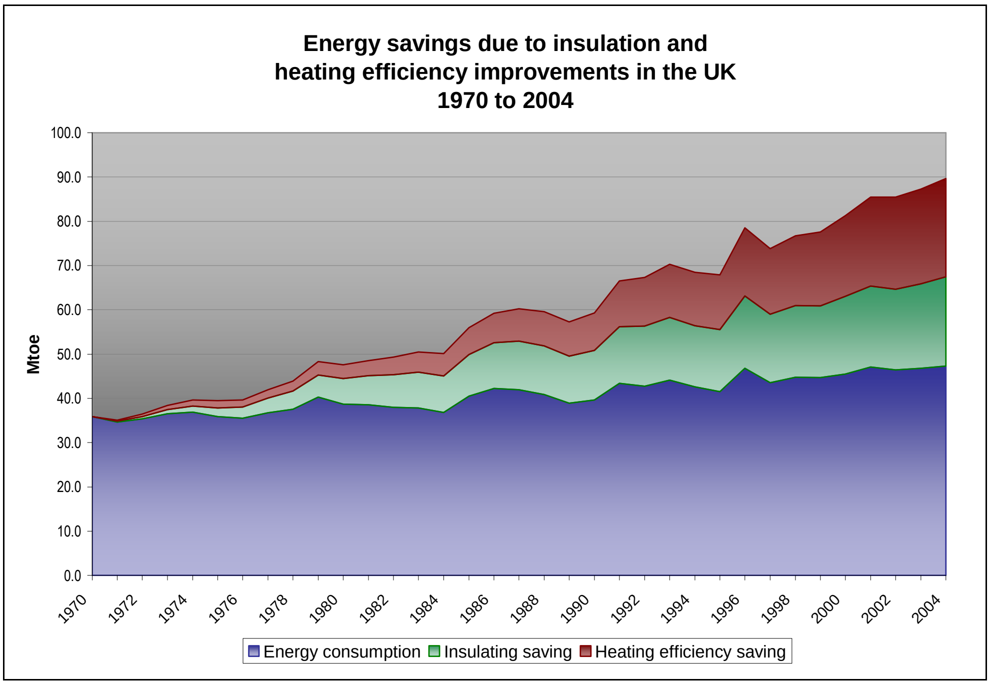


Figure 3.5: Energy savings due to home improvements in the UK, 1970 to 2004 [12]

The combined savings from insulation and heating efficiency improvements reduced domestic space heating energy consumption to about 48% of what it could otherwise have been in the absence of those improvements.[16]

The most common Energy Efficiency Solutions will be explained in the next section.

3.1.1.1 Insulation

Wall insulation can reduce heat loss considerably; therefore, it is one of the most important energy-saving measures to consider.

3.1.1.1.1 Cavity Wall

Cavity walls consists of two leaves of masonry, an outer leaf often of facing brickwork and an inner leaf of brickwork or blockwork separated by a nominal 50mm wide cavity. Cavity fill reduces the heat loss through the walls by up to 60%[20], thus giving significant savings in heating costs. Its installation is quite fast, and provides greater comfort. Cavity wall insulation cannot be installed in a solid-walled dwelling. Cavity fill is the most cost-effective single insulation measure after loft insulation.[19]

They are suitable in the majority of homes built after 1930, including semi-detached and terraced houses, and low-rise and high-rise flats.

The estimated costs and carbon savings for applying cavity wall insulation are as follow:

Property type	Wall area *m^2*	U value *W/m^2K*	Capital cost *£*	CO_2 *tonne/yr*	CO_2 saving *tonne/yr*	£ spent per *tonne of CO_2* saved
Semi-detached house	98	0.52	353.00	8.10	1.7	208.00
Low-rise purpose built flat	65.8	0.45	270.00	4.70	0.9	300.00
Modern mid-terrace	40.2	0.34	204.00	3.00	0.2	1,020.00
High-rise flats	64.1	0.22	7,102.00	5.00	3.1	2,291.00
Low-rise flats (traditional)	50.8	0.52	242.00	5.20	0.7	346.00
Low-rise flats (concrete panel)	50.8	0.23	5,730.00	5.00	1.1	5,209.00

Table 3.2: Estimated costs and carbon savings from cavity wall insulation [26]

As it can be seen in the tables in Appendix 2, a typical annual saving is around £130 and £160, the installed cost is around £260; therefore, the installed payback is less than 2 years.[20]

3.1.1.1.2 Solid wall

The heat lost through an uninsulated solid wall is typically more than double that of an uninsulated cavity wall[20]. A solid wall can be insulated either internally or externally – either option will greatly increase comfort, while also reducing running costs and associated environmental impact.

- Internal insulation typically consists of either dry lining in the form of a laminated insulating plasterboard (known as rigid insulation board), or a built-up system using insulation between a studwork frame. The estimated costs and carbon savings for applying internal insulation are as follow:

Property type	Wall area *m^2*	U value *W/m^2K*	Capital cost £	CO_2 *tonne/yr*	CO_2 saving *tonne/yr*	£ spent per *tonne of CO_2* saved
Medium-rise flats (pre-1919)	2.88	0.46	270.00	4.05	0.1	5,400.00
Victorian conversion	29.4	0.46	1,318.00	4.30	0.2	6,590.00
Low-rise 1970s flats	21.0	0.46	1,130.00	5.70	0.2	5,650.00

Table 3.3: Estimated costs and carbon savings from internal wall insulation [26]

- External insulation systems are made up of an insulation layer fixed to the existing wall (using a combination of mechanical fixings and adhesive, depending on the insulation material used) and a protective render or cladding finish. Not suitable for listed, historic or properties with fine architectural detailing. The estimated costs and carbon savings for applying external insulation are as follow:

Property type	Wall area *m^2*	U value *W/m^2K*	Capital cost £	CO_2 *tonne/yr*	CO_2 saving *tonne/yr*	£ spent per *tonne of CO_2* saved
Pre-1919 terrace	92.02	0.34	9,494.00	7.70	4.5	2,110.00
Victorian conversion	44.8	0.34	4,684.00	3.60	0.9	5,204.00
High-rise flats	64.1	0.22	7,102.00	5.00	3.1	2,291.00

Table 3.4: Estimated costs and carbon savings from external wall insulation [26]

As it can be seen in the tables in Appendix 2, a typical annual saving for the internal insulation is between £270 and £340. The installed cost varies from £40/m^2; whereas for the external the annual saving is around £290 and £350, the installed cost is from £1800 (marginal cost), therefore the installed payback about 5 to 6 years. It can have long payback times, unless installed in conjunction with other remedial work and refurbishment works.[20]

3.1.1.1.3 Other wall types

A variety of other common wall constructions can also benefit from additional wall insulation; however, each dwelling would have to be treated on a case-by-case basis.

- Timber-framed dwellings
- Non-traditional methods of construction

3.1.1.1.4 Roofs

Roof insulation can reduce heating costs in most house types by up to 20 per cent – more so, if there is no existing insulation.[20]

Lofts are the easiest to insulate – either insulating between the joists, or at roof level in the rafters. Attic rooms and flat roofs can be insulated, but the work is best done during a conversion or major renovation. The estimated costs and carbon savings for applying loft insulation are as follow:

Property type	Thickness of insulation *mm*	Area m^2	U value W/m^2K	Capital cost £	CO_2 *tonne/yr*	CO_2 saving *tonne/yr*	£ spent per *tonne of CO_2* saved
Pre-1919 end terrace	300	32.8	0.13	314	11.9	0.3	1,047
Medium-rise flats	200	63.4	0.13	434	3.8	0.3	1,447
Semi-detached house	Main: 200	44.6	0.13	306	9.5	0.4	874
	Bay: 200	1.6	1.18	140	9.7	0.1	1,400
Low-rise flats	200	57.9	0.13	397	5	0.6	662
	120 (polyurethane 0.02)	56.9	0.15	6,054	4.9	1.1	5,504
Modern mid-terrace house	200	30.4	0.13	209	3.1	0.1	2,090

Table 3.5: Estimated costs and carbon savings from loft insulation [26]

A typical annual saving varies according to the depth £220 to as low as £50, and the payback from about 1 to 5 years (depth 0mm and 50mm respectively).[20]

The optimum depth for loft insulation is 200-300mm; anything less than this should be topped up.

3.1.1.1.5 Floor insulation

Ground floor insulation is most effective for detached houses because most heat is lost along the perimeter of the floor.

- Heat loss through floors can be reduced by up to 60 per cent by insulation. The estimated costs and carbon savings for applying timber floor insulation are as follow:

Property type	Area *m^2*	U value *W/m^2K*	Capital cost £	CO_2 *tonne/yr*	CO_2 saving *tonne/yr*	£ spent per *tonne of* CO_2 saved
Pre-1919 end terrace	32.8	0.16	1,566	11.3	0.9	1,740
Victorian conversion	34.8	0.16	1,655	4.2	0.3	5,517

Table 3.6: Estimated costs and carbon savings from floor insulation [26]

The typical annual saving of timber floors is between £40 and £50. The installed cost from £100 for materials, therefore the installed payback is less than 3 years. [20]

3.1.1.2 Windows and doors

A major source of energy loss is through windows and doors. Regulations require windows, doors and roof-lights to achieve a U value of 2.0 W/m^2K (as an area-weighted average).[36]

Energy-efficient windows, when correctly selected and installed, will help to minimise the heating costs and will also increase comfort. Although savings from installing new windows are not as high as other measures (e.g. cavity wall insulation), it is important to recognise that windows are replaced very infrequently so another opportunity to install high-performance glazing may not arise for a number of years.

Secondary glazing is a good option where thermal performance needs to be improved and the existing character of the dwelling needs to be maintained. The estimated costs and carbon savings for applying double glazing (low-e) are as follow:

Property type	Area m^2	U value W/m^2K	Capital cost £	CO_2 *tonne/yr*	CO_2 saving *tonne/yr*	£ spent per *tonne of CO_2* saved
Period terrace house	7.6	2	2,801	11.4	0.8	3,501
Period conversion	8.8	2	3,228	4.2	0.3	10,760
Tenement flats	8.1	2	2,979	3.8	0.3	9,930
Semi-detached house	20.9	2	7,146	8.2	1.6	4,466
Low-rise flat	8.2	2	3,014	4.9	0.7	4,306
Modern terrace	8.2	2	3,014	2.7	0.5	6,028
High-rise flats	11.5	2	4,187	6.4	1.7	2,463
Low-rise flats (brick and block)	10.7	2	3,903	5.4	0.5	7,806
Low-rise flats (panel)	10.7	2	3,903	5.7	0.4	9,758

Table 3.7: Estimated costs and carbon savings from window glazing [26]

Solid timber doors typically have a U value of 3.0 W/m2K. Insulated doors that achieve a U value of 1.0 W/m2K or better are readily available as replacements for these, and will improve energy efficiency in the home. The estimated costs and carbon savings for applying insulation to doors are as follow:

Property type	Area m^2	U value W/m^2K	Capital cost £	CO_2 *tonne/yr*	CO_2 saving *tonne/yr*	£ spent per *tonne of CO_2* saved
Pre-1919 end terrace	3.8	0.7	1,100	11.8	0.4	2,750
Victorian conversion	1.9	0.7	550	4.5	0	
Medium-rise flats - top floor	1.9	0.38	550	4,05	0	11,000
Semi-detached house	3.8	0.7	1,100	9.7	0.1	11,000
Low-rise flats - top floor	1.9	0.7	550	5.5	0.1	5,500
Modern mid-terrace house	1.9	0.7	550	3.05	0.2	3,667
High-rise flats - mid floor	1.9	0.7	550	7.9	0.2	2,750
Low-rise flats - top floor	1.9	0.7	550	5.8	0.1	5,500
Low-rise flats - concrete panel	1.9	0.7	550	6	0.1	5,500

Table 3.8: Estimated costs and carbon savings from insulated doors [26]

Draught-stripping of existing badly fitting windows and doors is inexpensive and simple to install. It can greatly improve comfort as well as reducing heat loss.

3.1.1.3 Ventilation

In a typical house, at least 15% of the total heat loss is through uncontrolled ventilation. As well as wasting heat, all dwellings require ventilation for a number of reasons:

- For the health and comfort of occupants.
- To ensure safe and efficient operation of combustion appliances (e.g. gas boilers) which draw combustion air from within the dwelling.
- To control condensation by the removal of moisture vapour.
- To remove other pollutants and odours.

Average natural ventilation rates of between 0.5 and 1.0 air changes per hour are recommended for the whole home. This rate keeps humidity below 70%, which minimises the risk of condensation.

Controlled ventilation can be achieved using:

- Local background ventilation (e.g. trickle ventilators) to provide a steady flow of fresh air without draughts.
- Local rapid ventilation (e.g. extract fans or passive stack ventilation) to remove stale air and moisture, and draw in fresh air from other rooms or outside through trickle vents; possibly with heat recovery.
- Whole-house mechanical ventilation, usually with heat recovery (MVHR).

The estimated costs and carbon savings for sealing chimneys, windows and doors, loft hatch and installing extract fans are as follow:

Property type	Capital cost £	CO_2 *tonne/yr*	CO_2 saving *tonne/yr*	£ spent per *tonne of* *CO_2* saved
Pre-1919 end terrace	599	11.7	0.5	1,198
Victorian conversion	465	4.6	-0.1	-4,650
Medium-rise flats - top floor	465	3.9	0.2	2,325
Semi-detached house	520	8.9	0.9	578
Low-rise flats - top floor	415	5.6	0	-
Modern mid - terrace house	430	3.2	0	-
High-rise flats - mid floor	415	8.1	0	-
Low-rise flats - top floor	415	5.9	0	-
Low-rise flats - concrete panel	415	6.1	0	-

Table 3.9: Estimated costs and carbon savings from ventilation measures [26]

- Whole house ducted systems based on either passive stack ventilation or mechanical ventilation with heat recovery. [20]

The estimated costs and carbon savings for HMVR are as follow:

Property type	Capital cost £	CO_2 *tonne/yr*	CO_2 saving *tonne/yr*	£ spent per *tonne of* *CO_2* saved
Pre-1919 end terrace	1,999	11	1.2	1,666
Victorian conversion	1,865	4.4	0.1	18,650
Medium-rise flats - top floor	1,865	3.7	0.4	4,663
Semi-detached house	1,920	8.7	1.1	1,745
Low-rise flats - top floor	1,815	5.1	0.5	3,630
Modern mid - terrace house	1,830	2.9	0.3	6,100
High-rise flats - mid floor	1,815	7.4	0.7	2,593
Low-rise flats - top floor	1,815	5.7	0.2	9,075
Low-rise flats - concrete panel	1,815	5.9	0.2	9,075

Table 3.10: Estimated costs and carbon savings from HMVR [26]

3.1.1.4 Lighting

Low-energy lighting, using compact fluorescent lamps (CFLs), can be fitted at any time. Low-energy lighting is most cost-effective when fitted in rooms that are most often used e.g. living room, kitchen and hallway.

The estimated costs and carbon savings associated with low-energy lighting are as follow:

Property type	Capital cost £	CO_2 *tonne/yr*	CO_2 saving *tonne/yr*	£ spent per *tonne of* CO_2 saved
Pre-1919 end terrace	120	12.1	0.1	1,200
Victorian conversion	90	4.4	0.1	900
Medium-rise flats - top floor	150	4	0.1	1,500
Semi-detached house	165	9.7	0.1	1,650
Low-rise flats - top floor	120	5.5	0.1	1,200
Modern mid - terrace house	135	3.1	0.1	1,350
High-rise flats - mid floor	90	8	1	900
Low-rise flats - top floor	105	5.8	0.1	1.05
Low-rise flats - concrete panel	105	6	0.1	1,050

Table 3.11: Estimated costs and carbon savings from low-energy lighting [26]

In most homes, lighting accounts for 15-20 per cent of the electricity bill. [20]

3.1.1.5 Appliances

Energy-efficient appliances use less electricity and therefore cost less to run. There is ample evidence that energy-efficient appliances are often no more expensive to buy than equivalent appliances that are much less efficient. When buying an appliance, it is necessary to look for the EU energy labels, where label A is the most efficient and G the least. [17]

3.1.2 Cost-effectiveness

A simple estimate of payback can be calculated by dividing the capital cost of the improvement measure by the estimated annual saving:

$$Payback(years) = \frac{CapitalCost}{AnnualSaving}$$

Based on this equation, Table 3.12 establishes the general range of cost-effectiveness for different improvement measures. This table should be used only as a quick reference, since there are many other factors that can influence the payback time. These values are estimated from a range of standard house types with gas central heating and standard occupancy.

	Typical payback (years)									
	Low cost improvements					Higher cost measures which will further reduce household bills and environmental impact				
	<1	2	3	4	5	6	7	8	9	>10
Insulation										
Roof insulation (new installation)	■									
Roof insulation (top up)			■	■						
Cavity wall insulation (CWI)	■	■	■							
Ground floor insulation (solid floor)								■	■	■
Ground Floor insulation (timber floor)			■	■	■					
Internal wall insulation							■	■	■	■
External wall insulation							■	■	■	■
Windows and doors										
Windows achieving a BRFC rating in band C or above					■	■				
Secondary glazing								■	■	■
Insulated doors										■
Heating and hot water										
A-rated condensing boiler	■									
Upgrade cylinder insulation	■	■								
Replace hot water cylinder with high performance model			■	■	■					
Full heating controls package				■	■	■				
Ventilation										
Seal any disused fireplaces	■									
Draught-stripping and sealing						■	■			
Lights and appliances										
Energy efficient lighting	■	■	■							
A-rated white goods	■	■	■							

Table 3.12: Payback time of common measures [20]

The costs and savings figures will vary according to the size of the dwelling, its location, the measures (if appropriate), fuel, heating system and the materials used.

Energy savings are estimated from a range of standard house types with gas central heating and standard occupancy. Actual savings depend on individual circumstances. Remember that some of the benefit may be taken in improved comfort.

In order to have a deeper analysis and more precise figures, a cost benefit analysis can be done taking into account further data related to the dwelling, costs and savings figures will vary according to the size of the house, its location, the measure, occupancy, fuel, heating system and the materials used. (See Appendix 2)

3.2 Renewable Generation for Domestic Use

Renewable Energy Generation Technologies, sometimes called microgeneration, is the small-scale production of heat and/or electricity from a low carbon source.[9]

The technologies included in this definition are solar photovoltaics to provide electricity and thermal to provide hot water, micro-wind (including the new rooftop mounted turbines), micro-hydro, heat pumps, biomass, micro combined heat and power (mCHP) and small-scale fuel cells.

The constraints currently preventing wide-spread uptake of microgeneration technologies

- Cost: relatively high upfront costs constrain demand; demand needs to be stimulated to allow the industry to exploit scale economies and learning effects in production and installation.

- Information: inadequate promotion and poor information regarding the costs, benefits and performance of the various technologies can hinder growth in demand and can also make it difficult to interest the construction industry and building designers in using these technologies.

- Technical: including metering, connection to the distribution network and balancing and settlement arrangements

- Regulatory: the regulations governing planning requirements for new build, planning permission for microgeneration installations on existing build and the Building Regulations can provide opportunities for the microgeneration industry.

The household microgeneration sector is still relatively small with less than 100,000 installations in total to date in the UK. Most of these installations were derived from early solar hot water heating installations.[9]

Figure 3.6 shows the cumulative installations for each technology.

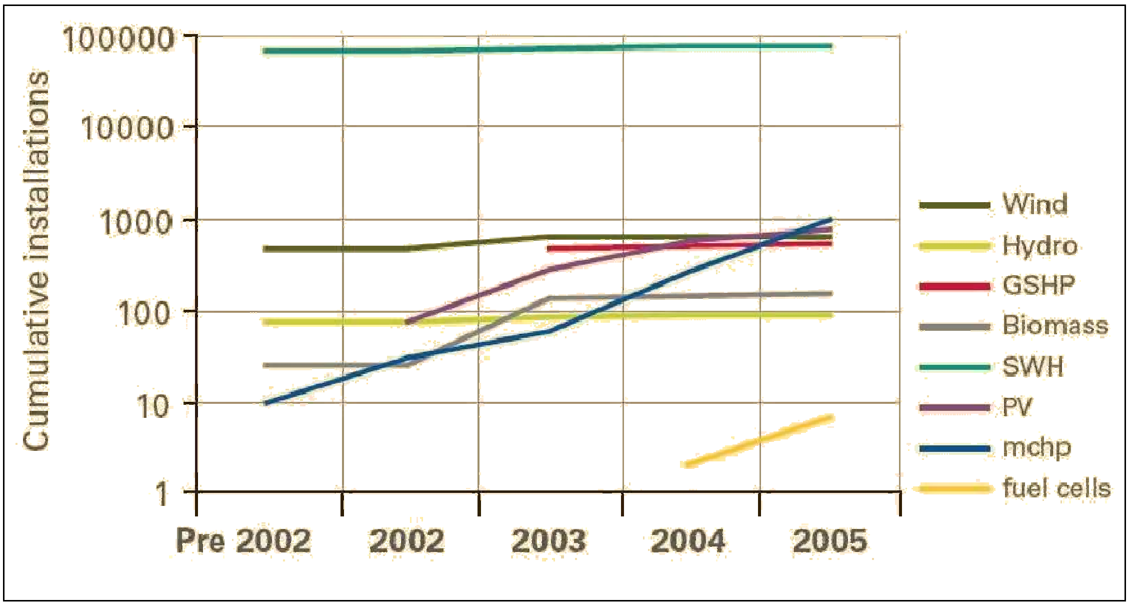


Figure 3.6: Installation of each microgeneration technology in the UK 2002 - 2005 [9]

It can be seen that in most technologies the installation rate has flattened, except for mCHP, a technology that has increase from 10 in 2002 to about 1,000 in 2005.

3.2.1 Electricity Generation Technologies

3.2.1.1 Solar photovoltaics (PV)

PV systems consist of semi-conductor cells that are linked and encapsulated into modular panels - often a rectangular shape about a metre long. These are then interconnected to provide electrical power, which can be harmonised with grid electricity and fed back into the network. For grid-connected installations an inverter is required to turn the electricity generated from direct current (DC) to alternating current (AC) and for off-grid installations, a storage mechanism and control system are generally needed. A typical household system of 2kWp could provide an average of between 40-50% of total annual electricity needs. The cost of installing a PV system varies depending on whether it is a standard bolt on system or a more integrated system, but the average cost is around £6,300 per kWp.[14]

There is a small but growing market for PV in the UK. The cumulative installation of PV has grown substantially over the last years:

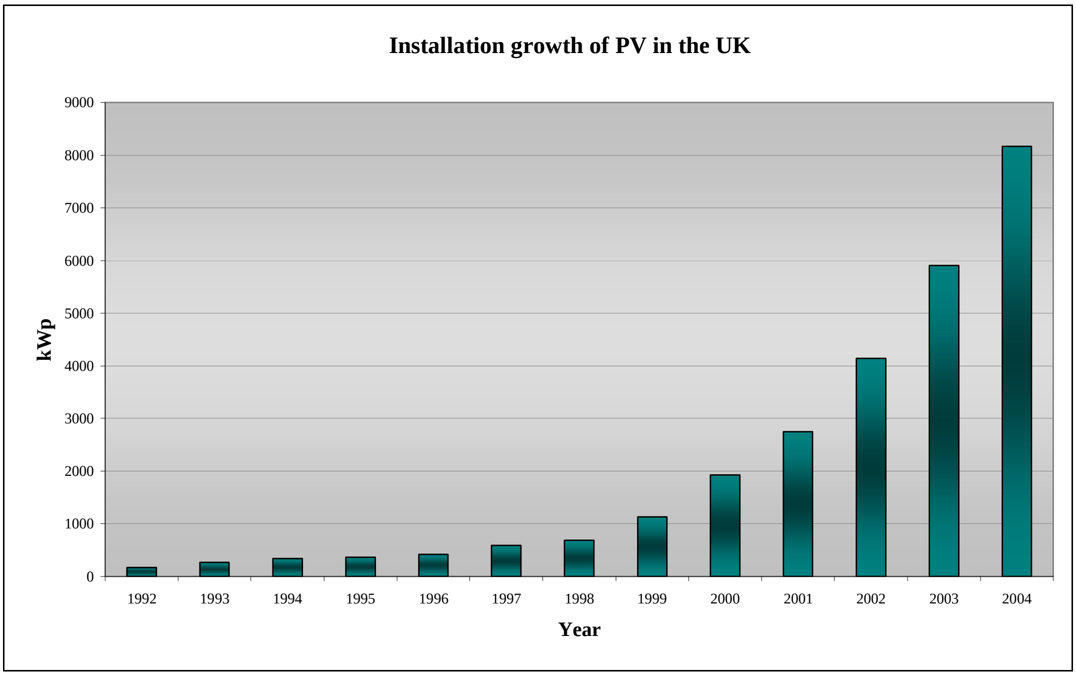


Figure 3.7: Installation growth of PV in the UK[9]

In addition the information related to the Renewables Innovation Review[6] estimated that PV could contribute 6-8% of overall electricity supply by 2050 and lead to a 3 million tonnes of carbon reduction in carbon emissions.

3.2.1.2 Wind Turbines

There are a number of established wind developers and installers both at the small (household) level and at the large (commercial) scale. It is estimated that there are around 650 – 700 small scale installations in the UK.[14] Current small scale installations are not generally mounted directly onto buildings, but small building mounted machines are under development and becoming more widely available.

A wind turbine converts wind to electricity. The most common design is for three blades mounted on a horizontal axis. The blades drive a generator either directly or via gearbox to produce electricity. The electricity can either link to the grid or charge batteries. Small wind turbines (less than 20 kW) produce AC (variable voltage and frequency) current which is converted to DC via a system controller. This DC is then converted to normal AC current (240V 50Hz) by inverters as with PV. Modern designs tend to be very near silent in operation.

A typical small scale system costs between £2,500 and £5,000 per kWe installed. A small wind turbine of 6kW capacity (sufficient for all of the electricity requirements of two or three typical UK households), costing about £20,000 to install, will generate about 10,000 kWh per year. This might amount to financial savings of around £700 per year and would equate to carbon saving of 4.3 tCO_2/year. The pay back time on an average 6kWp system would therefore be around 29 years (based on 2006 electricity prices).[14]

3.2.1.3 Small Hydro

There is a small, limited market for small and micro-hydro in the UK. A total installed capacity of around 100 MW is currently operating at about 120 small hydro sites, each with installed capacity of less than 5MW. In addition there are an unknown number of operational micro-hydro sites, with installed capacities of less than 20MW. Growth is estimated to at about 10MW per year. There are a number of small but established companies currently operating in the UK that specialise in micro-hydro installations.[14]

Water is used by "hydro turbines" to generate electricity. Water flowing down rivers, for example, turns the turbine round; this movement is used to produce power. Most hydro power is produced in hilly or mountainous areas, or in river valleys. The amount of electricity that can be produced is determined by how much water is available and how fast it flows. Additionally of all renewable energy technologies, it is the most consistent at providing electricity.

Costs for hydro projects depend greatly on the site and vary considerably, but can cost anything between £1,000 and £3,000 per installed kW.[14]

3.2.2 Heat Generation Technologies

3.2.2.1 Solar Thermal Hot Water

There is a small but established market in the UK for solar water heating systems. Estimates put the total number of existing installed domestic systems in the UK at over 70,000 [10], with about 5,000 new domestic systems installed each year. The main potential for this technology is in the domestic market. It is estimated that there is the potential for the number of retrofit installations to increase from this relatively low base (under favourable market conditions) to 50,000 new units installed per year by 2010, 300,000 by 2015 and 800,000 by 2020.[7]

Systems comprise of solar collectors (evacuated tubes or flat plates), a heat transfer system (a fluid in pipes) and a hot water store (e.g. domestic hot water cylinder). A 3m^2 collection area will provide between 50 – 70% of a typical home's annual hot water requirement. The cost of a professionally installed solar system for heating hot water can vary significantly, but a household system (4m^2) could cost £2,000 for a new build and £2,800 for a retrofit installation.[14]

System savings range from around 454 kilowatt hours (kWh)/year/m^2 of flat plate collector – 582kWh/year/m^2 for an evacuated tube system. This might amount to a saving of around £120 - £150 per year for electrically heated property or be as low as £36 - £46 for a gas-heated property. The pay back time on an average $3m^2$ household system would therefore be around 24 years for an electrically heated property and 80 years for a gas-heated property (based on current energy prices).[14]

3.2.2.2 Ground Source Heat Pumps (GSHP)

The market for ground source heat pumps is currently small but growing. The total number of existing installation in the UK is estimated to be 600 - 700 units.[7] The principal market for GSHP are domestic housing, commercial properties not connected to the natural gas network and commercial industrial properties with stable heat demand. It is estimated that there is the potential for the number of installations to increase from this low base to 10,000 units installed by 2010, 35,000 by 2015 and 55,000 by 2020.[14]

Systems operate by circulating water (or another fluid) through pipes buried in the ground in trenches or in vertical boreholes. The pipes extract heat from the ground and a heat exchanger within the heat pump extracts the heat from this fluid. The compression cycle is employed (also used in refrigerators) to then raise the temperature to supply hot water to the building. They require electricity to work, although this can be provided by complimentary renewable energy sources. The cost of a typical household system is £4 - 6,000. A typical system will provide 95 - 100% of a household's heating requirements.[30]

For a domestic system with a total annual heat load of 30,000 kWh heated by natural gas the annual carbon emissions would be in the region of 6.3 tCO_2/ year. Employing a 9 kW (peak heat output) ground source heat pump with a coefficient of performance (CoP) of 3.5 and costing around £9,000 would require 8,570 kWh of electricity to operate the pump. Assuming a normal electricity tariff, the carbon dioxide emissions would equate to 3.7 tCO_2/ year equivalent to a net saving of 2.6 tCO_2/ year.[14]

GSHP is most likely to be an option where there is no access to natural gas and so the alternative may be oil or direct electric heating (storage heaters). In the case of the latter, financial savings could amount to around £640 per annum (assuming off-peak electricity). In the case of oil fired heating, the likely running and installation costs would be comparable.[14]

3.2.2.3 Air Source Heat Pumps

These systems have yet to become widely available for the domestic market and continue to undergo minor development work. However they are likely to become commercially viable in the very near future.

They work in the same way as GSHP except that the source of the heat is the external ambient air. As external temperature is more variable than in the ground, coefficients of performance are likely to be lower, but so too are installation costs as no trenching or ground drilling is required.

Systems are often installed on an external wall, and may give rise to noise issues in high-density housing developments.

3.2.2.4 Bio-Energy

There are a range of small-scale biomass heating systems commercially available in the UK across a wide range of sizes, combustion technologies and fuel sources. These range from single room heaters hand fed with logs, through to large scale industrial units with fully automated fuel handling systems using wood chips for large scale steam or Combined Heat & Power (CHP) operation. It is estimated that the existing number of domestic wood burning installations produce around 2.38 TWh/year. The principal market for domestic scale biomass heating will be in more rural locations where there is the space to accommodate the boilers and access to fuel is easier. The potential market size is 1.1M houses with an energy potential of 19.6 TWh/year.[14]

The cost of a typical household system is between £2,400 - £2,600 for a single room heater or £200 - £600 per kilowatt thermal (kWth) installed for a boiler system, with fuel costs of around £15 – 30/MWh for wood pellets.[14]

For a typical domestic system with a total annual heat load of 30,000 kWh, a 9kW biomass system could deliver the heat required. In addition to the initial capital outlay, there would be an annual cost for fuel and maintenance. Overall the running costs would be comparable to gas or oil heated properties. But there would be net carbon savings of around 6.3 tCO_2/year for a gas heated property and 8.7 tCO_2/year for an oil heated property.[14]

3.3 UK Energy Approach to Fuel Poverty

Section 95 of the Housing (Scotland) Act 2001 defines Fuel Poverty as being a household living in a home which cannot be kept warm at reasonable cost[39]. However, the general definition of fuel poverty in Scotland is:

“A household is in fuel poverty if, in order to maintain a satisfactory heating regime, it would be required to spend more than 10% of its income (including Housing Benefit or Income Support for Mortgage Interest) on all household fuel use”. [37]

The definition of a 'satisfactory heating regime' would use the levels recommended by the World Health Organization. For elderly and infirm households, this is 23° C in the living room and 18° C in other rooms, to be achieved for 16 hours in every 24. For other households, this is 21° C in the living room and 18° C in other rooms. The period during weekdays is 9 hours in every 24; with two hours being in the morning and seven hours in the evening.[37]

Fuel poverty - not being able to heat a home to an acceptable standard at a reasonable cost - is caused by a combination of factors. Three of the most significant are household income, the cost of fuel, and energy efficiency of the home:[37]

- Low household income is the first major factor that can contribute to fuel poverty. The costs of heating a property form a greater proportion of total income for those on low incomes.

- Fuel costs are the second major factor that can affect the numbers of people suffering from fuel poverty. Higher prices reduce the affordability of fuel. Prices of different types of fuels can vary considerably, and the availability of different fuels in different areas, and of different types of heating systems, can affect the ability of consumers to exercise choice.

- The energy efficiency of the home is the third major factor that can result in fuel poverty. The thermal quality of the building and the efficiency of the heating source determine the amount of energy that must be purchased to heat the home adequately.

Fuel poverty has a negative impact on individuals, households, and communities. For individuals and households, the main negative impact of fuel poverty is its damaging effects on quality of life and health.

3.4 Software

3.4.1 HOMER

HOMER is a computer model, developed by the National Renewable Energy Laboratory from the U.S. Department of Energy, that simplifies the task of evaluating design options for both off-grid and grid-connected power systems for remote, stand-alone, and distributed generation (DG) applications. HOMER's optimization and sensitivity analysis algorithms allow you to evaluate the economic and technical feasibility of a large number of technology options and to account for variation in technology costs and energy resource availability. HOMER models both conventional and renewable energy technologies:[27]

Power sources:

- solar photovoltaic (PV)
- wind turbine
- run-of-river hydro power
- generator: diesel, gasoline, biogas, alternative and custom fuels, cofired
- electric utility grid
- microturbine
- fuel cell

Storage:

- battery bank
- hydrogen

Loads:

- daily profiles with seasonal variation
- deferrable (water pumping, refrigeration)
- thermal (space heating, crop drying)
- efficiency measures

3.4.2 NHER Auto Evaluator

Since 1990, the National Home Energy Rating (NHER) scheme has developed software solutions like the NHER Auto Evaluator, which is used for analysing existing dwellings and is unique in that it is the only software that can be used to issue authorised energy ratings on existing dwellings.[30]

3.4.2.1 Levels of Analysis

The NHER scheme has four levels of analysis. The characteristics of each level are explained in Table 3.13.

Level	Number of Data Items (Questions)	Accuracy	Other Properties
0	10-15	Stock Analysis only	Minimum data set that can be used as basis for an energy rating. Use of statistical relationships to establish dimensional data. Energy certificates cannot be issued at this level.
1	50-100	Fast audits	Fast surveys. It records wall constructions, floor areas, perimeters, heights, heating systems specifications. Assessment of the U-values. Lowest level at which a certificate of the NHER and SAP can be issued.
2	200	Full SAP Standard occupancy	All dimensional information on a dwelling must be assessed and U-values must be calculated from the detailed construction of all elements.
3	250	Accurate running costs	It includes details of how the occupants use the dwelling. It can match exactly the energy bill. Risk of surface condensation can be analyzed.

Table 3.13: Levels of Analysis – NHER [30]

3.4.2.2 Energy Ratings

Energy Ratings are designed to be a measure of the fuel cost of the property. The software takes into account two ratings:

- NHER Rating: This rating is calculated by estimating the total annual fuel costs for the property dividing by the floor area, and adjusting to fit on a 0 to 10 scale (0 being very energy inefficient, and 10 very energy efficient). The estimation of running costs uses a UK government developed calculation procedure called BREDEM.[30]

- SAP Rating: The Standard Assessment Procedure rating (SAP) only uses the space and water heating part of the calculations. The scale is from 1 to 100, and it is about 10 times more than the NHER Rating.

Apart from the scales, one of the differences between both ratings is the fact that the SAP rating is the same all over the country, whereas the NHER varies because it considers the running costs that vary according the location.

4. CASE STUDY AND STUDY SCENARIOS

4.1 Data Collection

The communities of Dailly, Barr, Pinwherry and Pinmore (see Figure 4.1) have received an amount of £300,000 from the Scottish and Southern Energy in connection with their Hadyard Hill Wind Farm, a windfarm that started to generate electricity in April 2006. Scottish and Southern Energy specified that this fund should be used improving the households in the community: applying energy efficiency solutions (EES) and, if possible, renewable electricity generation (REG).

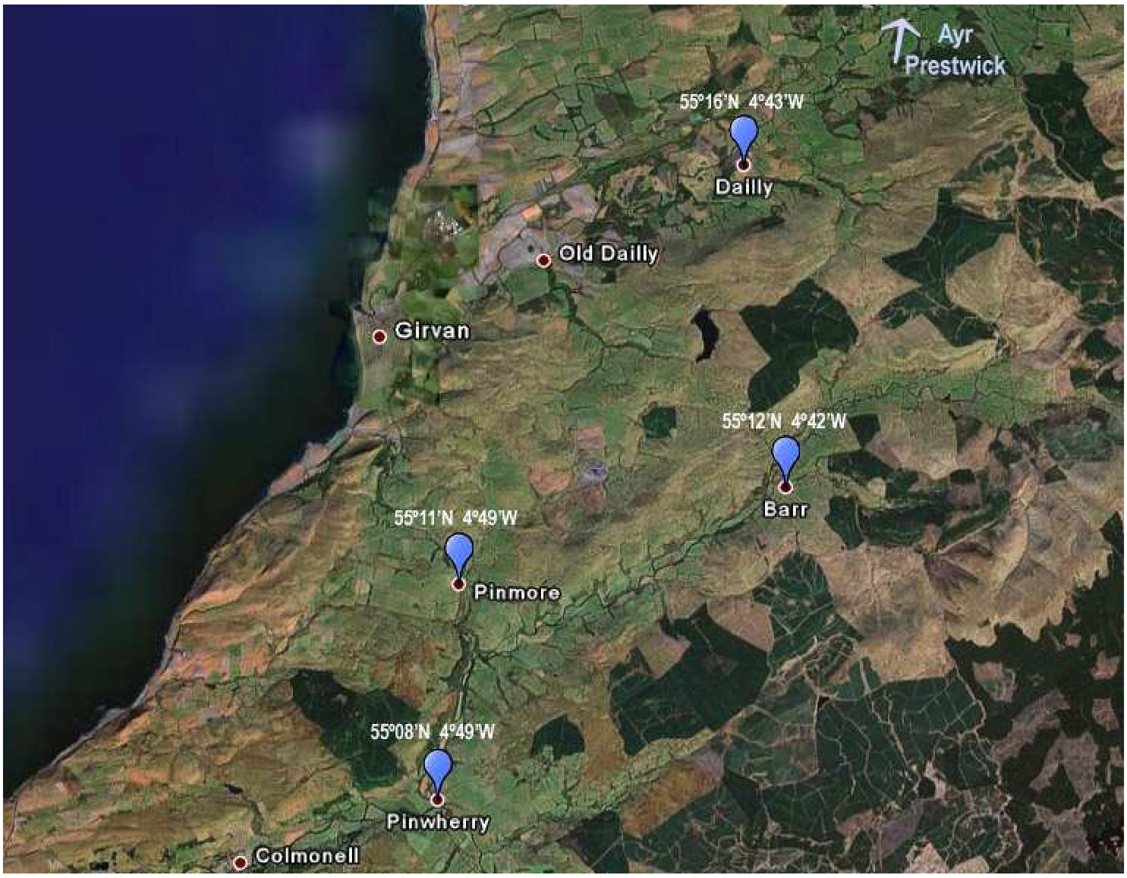


Figure 4.1: Location of the communities where the study has been carried out

In order to apply EES and REG, South Ayrshire council has given the management of the project to the Energy Agency. The Community Energy Project was launched in December 2006.

The Project followed an approach considering initiatives that aim to achieve a full assessment of all housing stock, like the Warm Zones in England, and considering lessons learned from other communities or council projects, such as the Dundee Community Energy Partnership.

Starting in March of 2007, a survey to each household was carried out in the communities. The data obtained from the survey was the main input to the present case study. The result of the survey was considered successful. Currently, the survey has reached 749 households of the existing 815; however, the data analysed in this case study will be of 650 households, since the remaining 99 surveys were carried out later, when the present study was already in progress.

The survey was based in the NHER scheme – Level 0 (see 3.4.1). It was considered appropriate to add some questions to the survey from Level 1 scheme in order to have some accurate and extra information that can be used in further studies and projects.

The items included in the survey are listed in the table below. Nevertheless, the complete survey can be found in Appendix 1.

Tenure	Wall Type	HLA Roof
Degree Day Region	Wall Insulation (mm)	Loft Insulation Depth Required
Built Form	Floor Insulation (mm)	No of Occupants
Age Band	Prim Heat Fuel	Over 60s
Suitable for Solar	Prim Heat System	No Retired
No of Storeys	Prim. Heat Code	No Working >16hrs
No of Bedrooms	Heating System Age	No Working <16hrs
No of Other Rooms	L1 Prim Heat Controls	No Full Time Carer
No of Rooms	Sec Heat Sys	No Unemployed
Roof Rooms	Hot Water Fuel	No in Full Time Education
Flat Type	Hot Water Sys	No Ill Health
Flat Roof Exposure	Cylinder Thermostat	No Children Not in Education
Flat Wall Exposure	Cylinder Insulation	Any Benefits
Flat Floor Exposure	Low Energy Bulbs	Income Band
Window Proofing	Draft Proofing Required	Energy Fuel Spend Last Yr
Door Proofing	Cylinder Insulation Required	Mileage Band
Window Type	Cavity Wall Insulation Required	No of Return Flights
Window Glazing	HLA Exposed Wall	Comments
Roof Type	Loft Insulation Required	Measures Required
Loft Insulation (mm)		

Table 4.1: NHER scheme data items included in the survey

4.1.1 Results of the Survey

Because of the time constraint, from all the data gathered, only the most relevant will be used in order to determine the most suitable and cost effective EES and REG.

4.1.1.1 Degree Days

All the houses are located in the same Degree Day Region, which is Southwest Scotland.

4.1.1.2 Built form

The survey showed that most of the dwellings are detached, followed by semidetached dwellings.

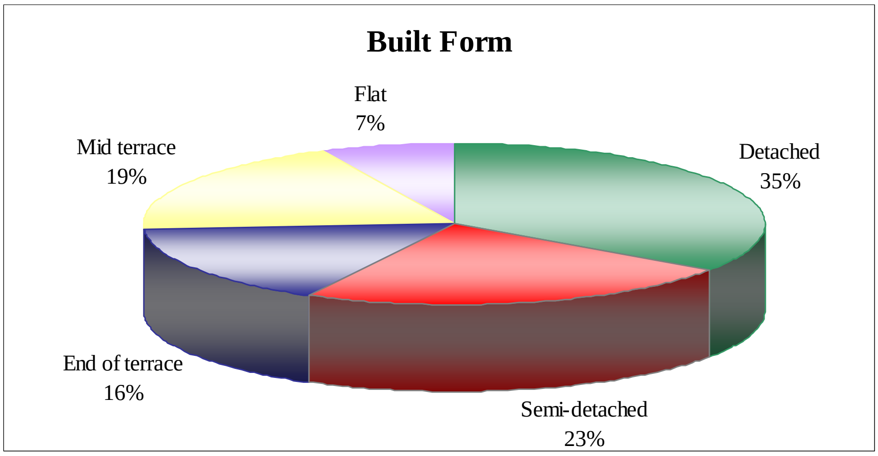


Figure 4.2: Distribution of households by Built Form

4.1.1.3 Age Band

The home age is required for the calculation to select the default U values for the wall, roof and floor. The results of the survey show that 35% of the houses were built before 1918, 21% during the 1930's and 1940's.

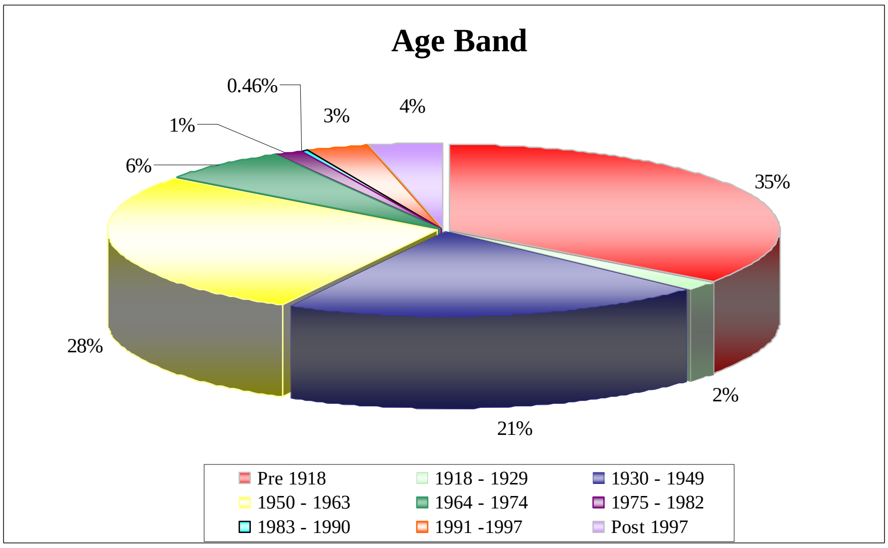


Figure 4.3: Distribution of households by Age Band

4.1.1.4 Suitable for solar

595 out of 650 are suitable for solar, meaning that almost 92% of the dwellings in the area have a roof that is roughly between South East and South West facing and not significantly in shadow.

4.1.1.5 Wall, glazing, roof, and door

Identifying insulation levels and constructions is also important in order to assume U-values.

Wall Type	No of Houses
Cavity	368
Stone	160
Solid	81
Timber frame	41
Window Glazing	**No of Houses**
Double	516
Single	134
Roof Type	**No of Houses**
Pitched	618
Mixture (of flat and pitched)	9
Flat	3
No data	20
Door Proofing	**No of Houses**
Well Sealed	379
Minimal	254
None	17

Table 4.2: Wall, glazing, roof, and door proofing survey results

4.1.1.6 Occupancy data

The survey showed that the majority of the dwellings (39%) are occupied by two persons.

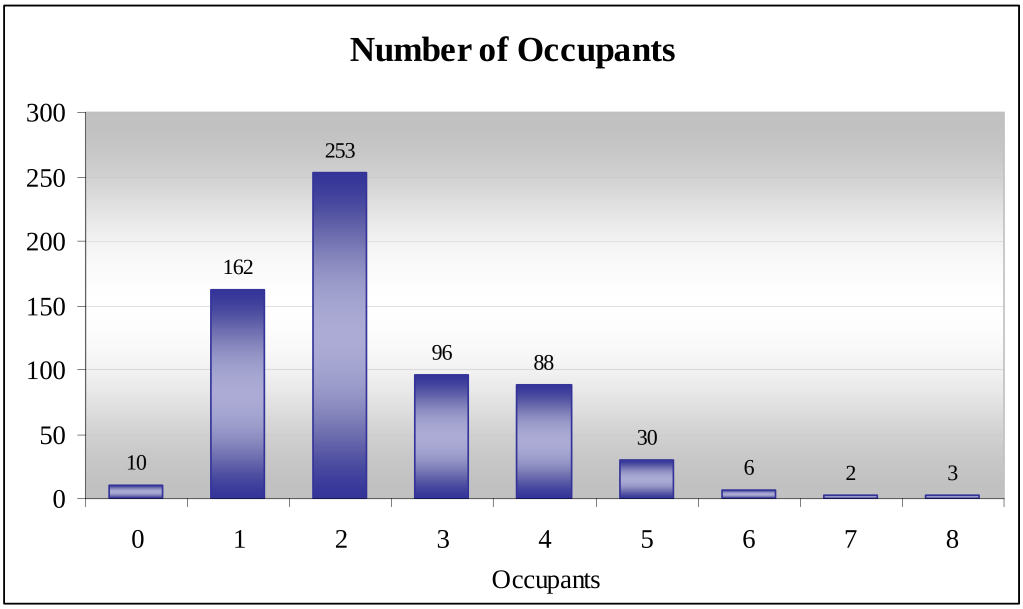


Figure 4.4: Number of Occupants per household

4.1.1.7 Heating System

As it can be seen in the table, most of the heating systems in the households depend on electricity as a fuel, making it very inefficient.

Primary Heating System	
Boiler system (oil)	216
Boiler system (solid)	150
Storage heaters	143
Boiler system (elec)	79
Boiler system (gas)	40
Room Heaters (solid)	14
Room Heaters (elec)	4
Heat Pump on-peak(elect)	1
Warm air system (elec)	1
Warm air system (oil)	1
No Data	1

Table 4.3: Primary Heating System

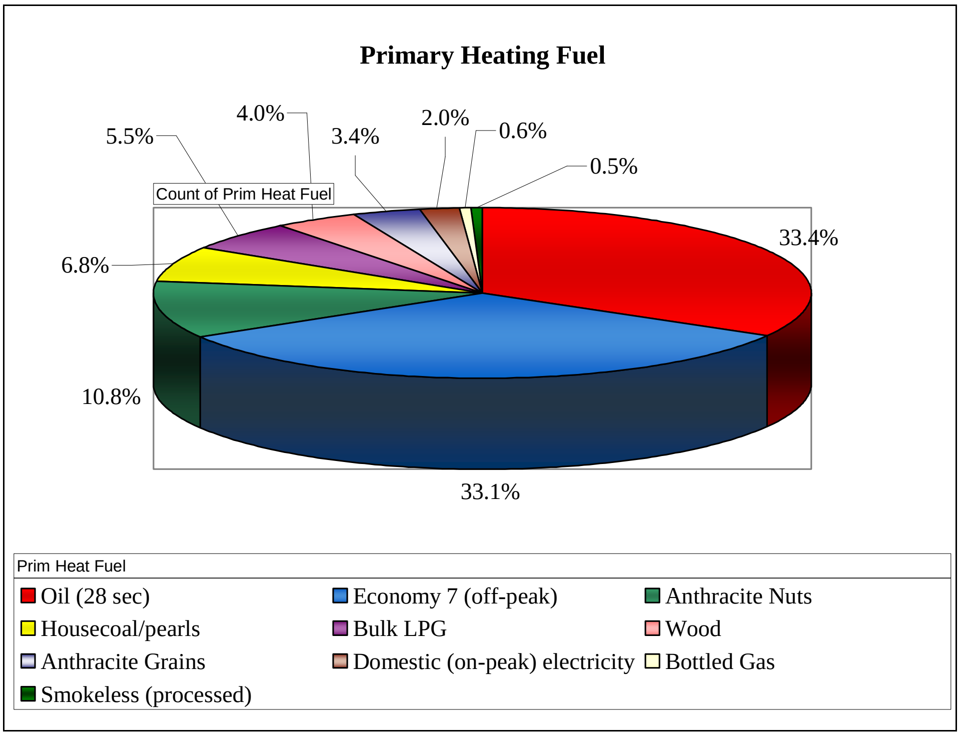


Figure 4.5: Primary Heating Fuel

Electricity accounts for almost 35% of the fuels in the survey (Economy 7 and Domestic electricity). Electricity used for heating purposes becomes environmentally inefficient considering the amount of households using this as a fuel.

4.1.1.8 Income Band

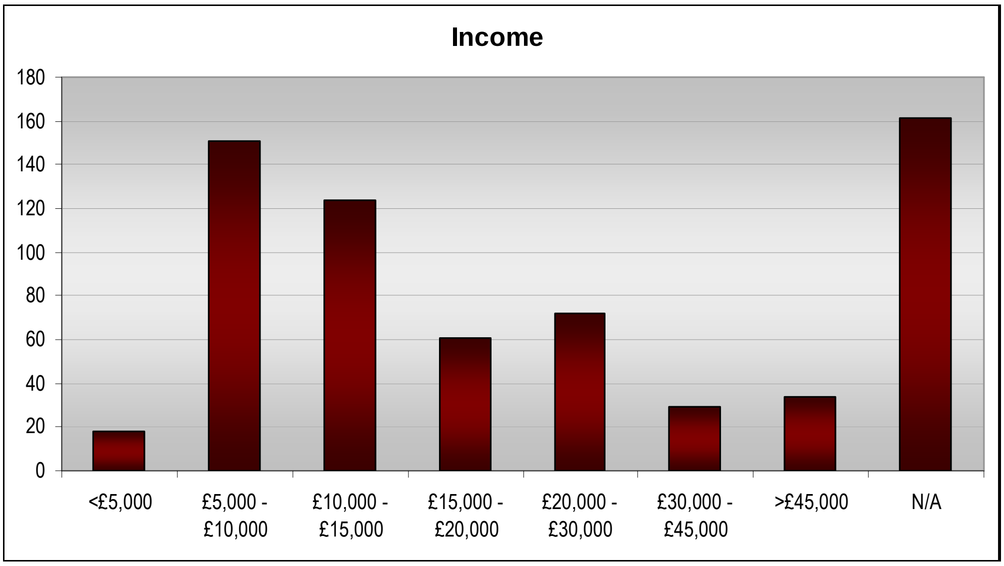


Figure 4.6: Income Band per number of households

Most of the residents have an annual income between £5,000 and £15,000. Nevertheless, information related to income was missing for 161 of the dwellings, either because it was unknown or because people refused to answer.

4.2 Scenarios

4.2.1 Arguments

After discussing with the Energy Agency, considering the big amount of data from the survey varies from one household to another and the time constraint for the present analysis, three study scenarios will be built in order to assess them in a proper way. These scenarios are expected to represent the majority of the dwellings in the communities. In order to achieve these, the following arguments were considered:

- One of the main concerns of the communities is to alleviate fuel poverty. As it was mentioned in section 3.3, the factors linked to fuel poverty are: low income, fuel used, and energy efficiency of the house.

  The survey showed information related to income (Figure 4.4) and fuel used for heating systems (Table 4.3), whereas energy efficiency will be evaluated considering the following data:

- Age Band (Figure 4.3) and Built Form (Figure 4.2): In general, U-values can be determined by age and style of construction).

- Occupancy (Figure 4.4): One of the dominant factors influencing the electricity demand profile is occupancy (i.e. number of people present in the household)[33].

4.2.2 Definition of the Scenarios

As a first step, the dwellings that used electricity as a primary heating system fuel were not considered as part of the study, since the use of electricity as a fuel is not energy efficient, therefore the demand profile is different to the ones that are most commonly found in the survey. Nevertheless, all the EES that will be recommended can be applied once the dwellings change electricity for another type of heating fuel, such as a gas boiler.

Taken all these into account and due to the large amount of data, the rest of the scenarios will be defined in two different graphs that will combine occupancy, age band, and built form:

Figure 4.7 shows data from the survey for occupancy and age band.

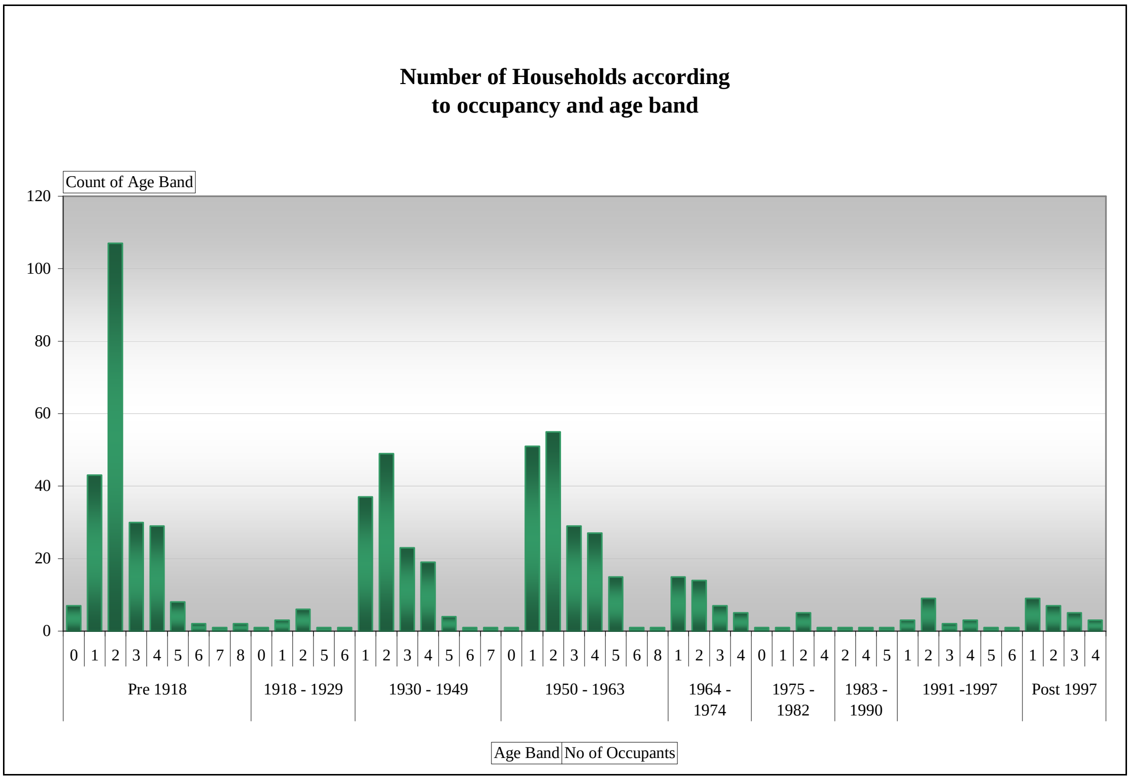


Figure 4.7: Households according to age band and occupancy

As mentioned in section 4.1.1.6, the majority of the households have two occupants. Therefore, from the graph, three options could be considered:

- Pre 1918 with 2 occupants,
- 1930 to 1949 with 2 occupants, and
- 1950 to 1963 with 2 occupants.

A second graph was plotted based on the three groups described in the last paragraph, adding the built form. The result can be seen in Figure 4.8.

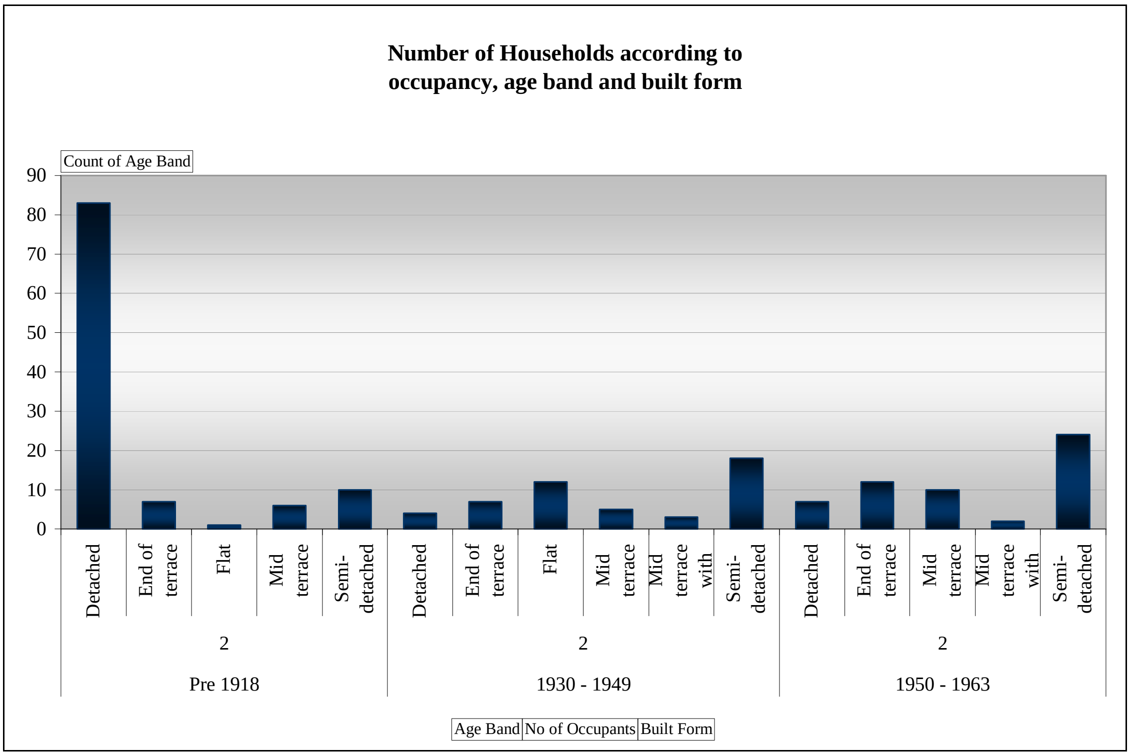


Figure 4.8: Households according to age band, occupancy, and built form

It can be seen that the buildings that are more representative of the area, which are going to be the three scenarios to be assessed EES and RG, are:

- Pre 1918 Detached dwelling with two occupants.
- 1930-1949 Semi-detached dwelling with two occupants, and
- 1950-1963 Semi-detached dwelling with two occupants.

This also coincides with the scenarios that the Energy Agency considered to represent the majority of the households in the communities.

4.2.3 Description of the scenarios

These three scenarios were analysed separately from the spreadsheet with data from the survey. (Note: The spreadsheet has an enormous amount of data that is not displayed in this work due to space constraints). The most common characteristics for each scenario are shown in Table 4.4.

	Scenario I	Scenario II	Scenario III
Degree Day Region	South West Scotland	South West Scotland	South West Scotland
Built Form	Detached	Semi-detached	Semi-detached
Age Band	Pre 1918	1930 - 1949	1950 - 1963
No of Occupants	2	2	2
Suitable for Solar	Yes	Yes	Yes
No of Storeys	2	2	2
No of Bedrooms	3	2	3
No of Other Rooms	5	4	4
No of Rooms	8	6	7
Roof Rooms	Yes	No	No
Window Proofing	Minimal	Well sealed	Well sealed
Door Proofing	Minimal	Well Sealed	Minimal
Window Type	Sash	UPVC	UPVC
Window Glazing	Single	Double	Double
Roof Type	Pitched	Pitched	Pitched
Loft Insulation (mm)	0	150	150
Wall Type	Stone	Cavity	Cavity
Wall Insulation (mm)	0	0	0
Floor Insulation (mm)	0	0	0
Cylinder Insulation required	No	No	No
Prim Heat Fuel	Oil (28 sec)	Anthracite Nuts	Anthracite Nuts
Prim Heat Sys	Boiler system (oil)	Boiler system (solid)	Boiler system (solid)
Heating System Age	More Than 15 Years	More Than 15 Years	8 - 15 Year
Sec Heat Sys	Electric	None	Closed Fire
Hot Water Fuel	Oil (28 sec)	Anthracite Nuts	Anthracite Nuts
Hot Water Sys	From boiler	Coal fired kitchen range	From boiler
Low energy bulbs	None	None	25%
Income Band	£10,000 - £15,000	£20,000 - £30,000	£10,000 - £15,000
Energy Fuel Spend	£1,900	£1,360	£1,670

Table 4.4: Characteristics of each scenario obtained from the survey

4.2.3.1 Scenario I: Pre 1918 detached dwelling with two occupants

Figure 4.9: Pre 1918 detached dwelling [30]

This scenario has the following characteristics:

- Walls: For dwellings of this period the walls are traditional sandstone (or granite) dwellings with solid walls, stone thickness typically 600mm with internal lath and plaster finish.[33]

- Roofs: According to the survey, most of the dwellings have pitched roofs. Some have insulation, but since one of the aims of the project is to tackle fuel poverty, the worse case, which is with no insulation, will be considered.

- Floors: Since the dwelling is detached, the U-value tends to be higher in detached dwellings.[33]

- Windows: From the survey, it can be seen that for this scenario the windows are predominantly single glazing.

	U-value (W/m^2K)
Walls	1.7
Roofs	1.6
Floors	0.8
Windows	4.8

Table 4.5: U-values for Scenario I [21]

4.2.3.2 Scenario II: 1930-1949 semi-detached dwelling with two occupants

Figure 4.10: 1930-1949 semi-detached dwelling [30]

This scenario has the following characteristics:

- Walls: For dwellings of this period the walls are cavity walls involving bricks and blocks with external render, but predominantly they are made of timber or concrete based, with smaller numbers of metal-framed dwellings.[33] However, the houses from this group where the survey was carried are all, except for one, cavity walls.

- Roofs: According to the survey, all the dwellings from this group where the data is available have pitched roofs. Some have insulation, but since we are aiming to tackle fuel poverty, the worse case, which is with no insulation, will be considered.

- Floors: Since the dwelling is semi-detached, the U-value is less than detached dwellings. [33]

- Windows: From the survey, it can be seen that for this scenario the windows are predominantly double glazing.

	U-value (W/m^2K)
Walls	1.7
Roofs	1.6
Floors	0.6
Windows	3.1

Table 4.6: U-values for Scenario II [21]

4.2.3.3 Scenario III: 1950-1963 semi-detached dwelling with two occupants

Figure 4.11: 1950-1963 semi-detached dwelling [30]

This scenario has the following characteristics:

- Walls: For dwellings of this period the walls are no-fines concrete or cavity walls. But predominantly tower blocks typically 25mm EPS between system build double concrete panels involving bricks and blocks with external render.[33] However, the houses from this group where the survey was carried are all, except for two, cavity walls.

- Roofs: According to the survey, all the dwellings from these scenarios where the data is available have pitched roofs. For this period, the thickness of the roof had to me at least 12mm.[21]

- Floors: Since the dwelling is semi-detached, the U-value is less than detached dwellings.[21]

- Windows: From the survey, it can be seen that for these scenarios the windows are predominantly double glazing.

	U-value (W/m^2K)
Walls	1.7
Roofs	1.1
Floors	0.6
Windows	3.1

Table 4.7: U-values for Scenario III [21]

5. ASSESSMENT OF ENERGY EFFICIENCY SOLUTIONS

5.1 Methodology

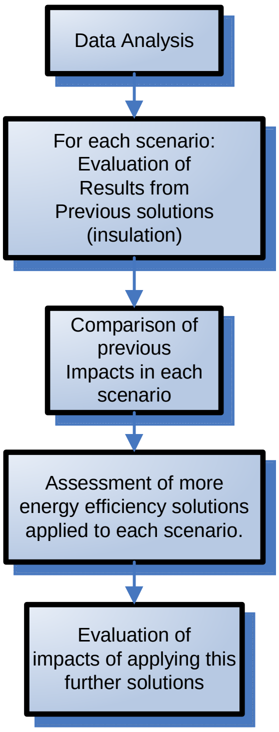


Figure 5.1: Methodology for EES

The data was assessed through a software that was explained previously: NHER Site Assessor (done by a subcontractor) and through calculations based on energy assumptions which will be explained in the next section.

5.2 Algorithm

Initially the software NHER Auto Evaluator was used in order to recommend some basic EES. Nevertheless, since this software is not available for free use and because the output was limited to insulation parameters, some further assessment will be carried out by information gathered from different best practice guides available on the internet. It is important to note that the software is not restricted to these results, but the level 0 scheme limited the questions and the output.

Information regarding CO_2 emissions, costs of EES and energy savings will be calculated combining information from the survey as well as benchmarks.

The analysis is done in a simple spreadsheet with the values displayed in the tables in section 3.1 and Appendix 2.

The equations and calculations used to find the results are explained in the following paragraphs:

Current energy use (data from survey)

$$Q_1 = U_1 A \Delta T \qquad (1)$$

New energy use

$$Q_2 = U_2 A \Delta T \qquad (2)$$

Where U_1= existing U value, and U_2=improved U value

Since it is the same room, the area and the difference of temperature will not change, from (1) and (2) the energy use considering the improvement will be:

$$Q_2 = Q_1 \frac{U_2}{U_1}$$

Annual energy saving = $Q_1 - Q_2$ [kWh]

The values for U depend on the Age Band[21] due to the building regulations, some values that were used for the calculation of the improvements are showed in the next table, and are based on tables in section 3.1.1. and section 4.2.3[36]:

Existing U value U_1 W/m^{2}K (common values according to age band)[36]			EES		Improved U value U_2 W/m^{2}K (current regulation)[36]
Scenario I	Scenario II	Scenario III			For all scenarios
-	1.7	1.7	Walls	Cavity wall insulation	0.3
1.7	-	-		Internal wall insulation	
0.8	0.6	0.6	Floor	Floor insulation	0.25
1.6	1.6	1.1	Roofs	Roof insulation	0.25
4.8	3.1	3.1	Windows	Windows, doors and roof lights	2.2

The capital costs for each EES and the CO_2 savings are showed in tables in section 3.1.1 and Appendix 2 according to the type of dwelling, and built form.

The cost saving is the annual energy saving times the cost of electricity. Assuming that the electricity cost is 0.02 £/kWh (data from the dti)[11]

$$\text{Annual cost saving} = (Q_1 - Q_2)\ 0.02 \quad [£]$$

The payback period was explained in section 3.1.2.

$$Payback = \frac{CapitalCost}{AnnualSaving} \quad \text{[years]}$$

The amount of money spent for tonnes of CO_2 saved is simply the relationship between capital cost and CO_2 savings:

$$£spent / tonnesCO2_2\, saved = \frac{CapitalCost}{CO_2 savings}$$

5.3 Evaluation

The data collected from the survey was evaluated by a subcontractor through the NHER Auto Evaluator software Level 0. The software processes the data gathered in order to get some basic information related to energy demand of the dwelling. The information obtained is shown in Table 5.1.

	Scenario I	Scenario II	Scenario III
Energy Rating	2.09	3.39	3.31
CO_2 Tonnes per year	22.23	9.57	10.18
Running Cost £	1,619	687	748
Total Energy Use kWh	76,505.56	29,272.22	31,266.67
Primary Heating Use kWh	57,869.44	22,361.11	19,655.56
Hot Water Energy Use kWh	7,213.89	3,888.89	5,922.22
Lights and Appliance Energy Use kWh	7,563.89	3,022.22	3,686.11
Primary Heating Cost £	2,060.15	491.94	432.42
Hot Water Energy Cost £	256.81	85.56	130.29
Lights and Appliance Energy Cost £	822.28	354.49	422.87
Total Energy Cost £	3,536.66	931.99	1,028.64

Table 5.1: Energy data of the dwelling from the simulation

As it can be seen, the dwellings from the three scenarios have a low NHER rating, between 2.09 and 3.39, which means they are energy inefficient households.

Currently, some measures have been already applied to the dwelling in the communities. These measures include wall and loft insulation due to the cost effectiveness of the solutions (see Section 3.1.1.1). The walls have been filled with glasswool, also known as Supafil, whereas the loft insulation is superglass mineral wool.

In the case of the Scenarios studied in this project, the EES already applied are:

Scenario I: Loft insulation

Scenario II: Cavity wall insulation

Scenario III: Cavity wall insulation and Loft insulation

The NHER Auto Evaluator also gives the same information for energy use in order to after cavity wall and/or loft insulation were applied. These new figures are shown in Table 5.2.

All these values were automatically generated by the software, no further calculations were done.

	Scenario I	Scenario II	Scenario III
New Energy Rating	3.06	5.94	5.55
New CO_2 Tonnes per year	17.68	6.12	6.79
New Running Cost £	1,360	498	571
New Fuel Saving	259	189	177
New Carbon Saving	4.55	3.45	3.39
New % Cost Saving	0.16	0.28	0.24
New Total Energy Use kWh	60,208.33	18,144.44	20,636.11
New Primary Heating Use kWh	42,605.56	11,252.78	10,025.00
New Hot Water Energy Use kWh	7,213.89	3,888.89	5,922.22
New Lights and Appliance Energy Use kWh	7,547.22	3,002.78	3,666.67
New Primary Heating Cost £	1,516.76	247.56	220.55
New Hot Water Energy Cost £	256.81	85.56	130.29
New Lights and Appliance Energy Cost £	820.56	352.49	420.87
New Total Energy Cost £	2,886.83	685.60	793.68
Total Saving £	649.83	246.39	234.96

Table 5.2: Energy data of the dwelling from the simulation after EES

Only with those two EES, the energy rating has improved for all the scenarios, improving the NHER rating from about 3.06 – 5.94, values that are between the averages households, according to the NHER scale. The carbon savings is also significant: around 3.5 tonnes per year.

From these figures, some comparisons between scenarios can be done graphically.

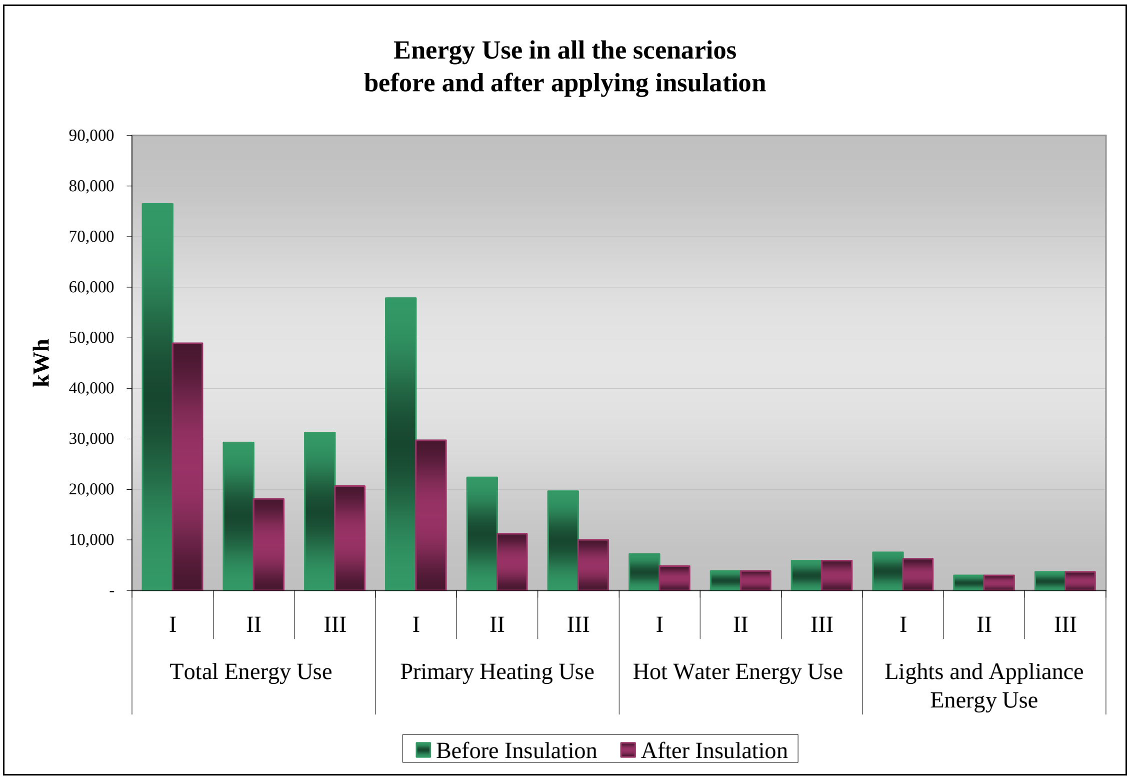


Figure 5.2: Comparison of energy use before and after initial measures were taken

As it can be seen in the graph, there has been a considerable saving after applying cavity and loft insulation to the dwellings in all the scenarios, in some cases, the energy use has decreased by 50%. Only the Hot Water Energy Use did not show an improvement after the measures, due to the fact that the software assumes that hot water is independent of cavity wall or loft insulation.

The following graph shows the cost effects of the insulation measures that have already been applied in the communities for each scenario.

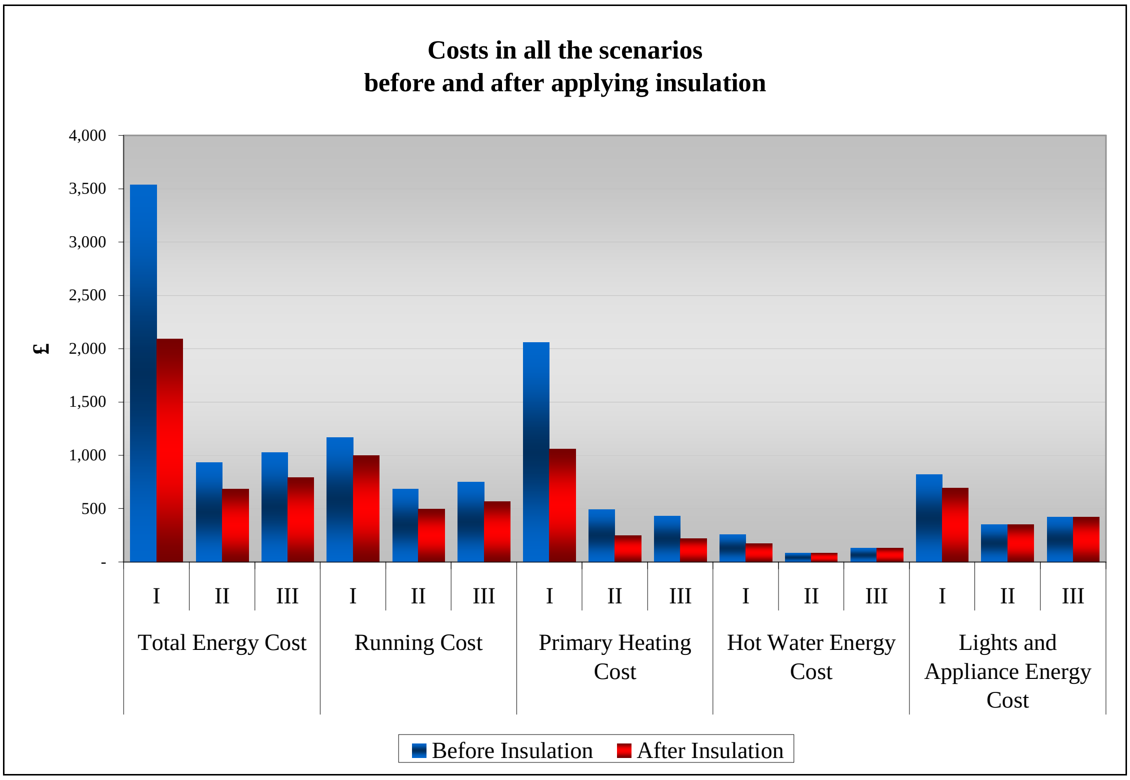


Figure 5.3: Comparison of costs before and after initial measures were taken

As it can be seen, the same effect in costs as in energy use is shown: there are significant cost savings related to primary heating costs, total energy costs, running costs, and in a smaller scale in lights and appliances costs, by applying cavity and loft insulation to the dwellings in all the scenarios. Like it was mentioned in the last paragraph, hot water use does not depend on insulation; therefore, no cost savings are expected for this item.

Further EES can be applied considering each case scenario, measures that were not considered by the NHER Auto Evaluator – Level 0, but that can be assessed through benchmarks of each type of house and following best practice guides for Energy Efficient Households.

The following sections will consider the rest of the common EES described in section 3.1.1, since insulation was already assessed by the NHER scheme.

5.3.1.1 Scenario I

It is expected for buildings from this age band to have already loft insulation (50-80mm), the addition of a new boiler and radiators, full or partial double glazing, draught proofing, new appliances and some low energy lighting. These additions will reduce bills and CO_2 emissions but the energy efficiency would not be up to the current standards. Therefore, some appropriate improvements are: Specify a new condensing boiler, improve the heating and hot water controls, hot water cylinder is well insulated, add more insulation, install low energy lighting, use appliances with energy saving label.[20]

In Table 4.4 it can be seen that this scenario had most of the specifications mentioned in the last paragraph: a condensing oil boiler, heating controls, cylinder insulation, and wall insulation, including the loft insulation that was added after the survey. However, the dwelling does not have low energy lighting and there is no information about appliances.

In the following paragraphs, every common EES will be briefly mentioned, but the cost analysis and the environmental impact analysis will be done in Section 5.4.1:

5.3.1.1.1 Insulation

Wall: Cavity wall insulation could not be applied to this scenario, since the walls are solid stone walls. Therefore, the option is between applying external or internal wall insulation. As it was mentioned in section 3.1.1.1.2, the main advantage of external wall insulation is the reduction of running costs; it also improves the air tightness of the construction reducing draughts and minimizes heat loss. A disadvantage of having internal wall insulation is the reduction of space. Therefore, external wall insulation is recommended.

Roof: One of the measures already applied to this scenario was the roof insulation because its cost-effectiveness. The values for this were already added in the first part.

Floor: Ground floor insulation is most effective for detached houses because most heat is lost along the perimeter of the floor.[20] Therefore, this would decrease the energy use of the household while increasing the comfort of the occupants. Since there is no existing floor insulation at all, the effects are even bigger. Nevertheless, the cost for floor insulation is high and their effect will be shown in the results analysis section.

5.3.1.1.2 Windows

In this case, the solution to apply is obvious: double glazing. This option it is not as cost effective as insulation, since the energy savings are not as big, but it is a good option whenever other measures are being carried out. (See Table 3.1)

Since the survey showed that the draught stripping was minimal, so it should be consider since it is inexpensive and a good way to reduce heat loss.

5.3.1.1.3 Ventilation

Unfortunately, because it was a NHER level 0 assessment the survey did not include data for ventilation.

Providing controllable ventilation, via ventilation systems such as extract fans, is essential to maintain healthy living conditions. Depending on the type of dwelling, approximately 16 to 20 per cent of total heat loss is through uncontrolled ventilation like gaps and cracks in the building fabric and around poorly fitting service pipes. Any uncontrolled ventilation can be dealt with by carrying out draught-proofing, sealing unwanted gaps and cracks around services, and therefore reducing any unwanted air leakage.[20] Therefore, the EES mentioned in section 3.1.1.3 should be applied: sealing chimneys, windows and doors, loft hatch and installing extract fans: draught-stripping measures.

5.3.1.1.4 Lighting and Appliances

This scenario does not have any low-cost lighting, and the survey does not provide further information about appliances. Therefore, low-energy lighting and efficient appliances should be applied.

5.3.1.2 Scenario II

It is expected for buildings from this age band to have loft insulation, the addition of a new boiler and radiators, full or partial double glazing, draught proofing, new appliances and some low energy lighting. These additions will reduce bills and CO_2 emissions but the energy efficiency would not be up to the current standards. Therefore, some appropriate improvements are: add more insulation, install low energy lighting, use appliances with energy saving label.[20]

In Table 4.4 it can be seen that this scenario had most of the specifications mentioned in the last paragraph. However, the dwelling does not have low energy lighting and there is no information about appliances.

In the following paragraphs, some common EES will be briefly mentioned, and the cost analysis and the environmental impact analysis will be done in Section 5.4.2:

5.3.1.2.1 Insulation

Wall: Cavity wall insulation was already applied previously as part as the project.

Roof: This scenario considers the existence of loft insulation.

Floor: Ground floor decreases the energy use of the household while increasing the comfort of the occupants. Since there is no existing floor insulation at all, the effects are even bigger.

5.3.1.2.2 Windows

This scenario considers the existence of double glazing.

Draught stripping is inexpensive and a good way to reduce heat loss.

5.3.1.2.3 Ventilation

Unfortunately, because it was a NHER level 0 assessment the survey did not include data for ventilation.

Providing controllable ventilation, via ventilation systems such as extract fans, is essential to maintain healthy living conditions. Depending on the type of dwelling, approximately 16 to 20 per cent of total heat loss is through uncontrolled ventilation like gaps and cracks in the building fabric and around poorly fitting service pipes. Any uncontrolled ventilation can be dealt with by carrying out draught-proofing, sealing unwanted gaps and cracks around services, and therefore reducing any unwanted air leakage.[20] Therefore, the EES mentioned in section 3.1.1.3 should be applied: sealing chimneys, windows and doors, loft hatch and installing extract fans.

5.3.1.2.4 Lighting and Appliances

There are no lighting measures in this scenario, and the survey does not provide further information about appliances. Therefore, low-energy lighting and efficient appliances should be applied.

5.3.1.3 Scenario III

The original construction consists on cavity brick walls, waterproofing render timber roof, boards and felt under concrete tiles, metal window frames, and timber floors.

It is expected that this type of buildings have changed from the original in different ways: timber windows, single glazed, electric storage heaters, electric immersion heater (usually during the 1980’s) and roof insulation

In Table 4.4 it can be seen that this scenario had most of the specifications mentioned in the last paragraph. However, the dwelling only has about 25% of low energy lighting and there is no information about appliances.

In the following paragraphs, some common EES will be briefly mentioned, and the cost analysis and the environmental impact analysis will be done in Section 5.4.3:

5.3.1.3.1 Insulation

Wall: Cavity wall insulation was already applied previously as part as the project.

Roof: Loft insulation was already applied previously as part as the project.

Floor: Ground floor decreases the energy use of the household while increasing the comfort of the occupants. Since there is no existing floor insulation at all, the effects are even bigger.

5.3.1.3.2 Windows

This scenario considers the existence of double glazing.

Nevertheless, it shows a minimal draught stripping in doors. This is inexpensive and a good way to reduce heat loss.

5.3.1.3.3 Ventilation

Unfortunately, because it was a NHER level 0 assessment the survey did not include data for ventilation.

Providing controllable ventilation, via ventilation systems such as extract fans, is essential to maintain healthy living conditions. Depending on the type of dwelling, approximately 16 to 20 per cent of total heat loss is through uncontrolled ventilation like gaps and cracks in the building fabric and around poorly fitting service pipes. Any uncontrolled ventilation can be dealt with by carrying out draught-proofing, sealing unwanted gaps and cracks around services, and therefore reducing any unwanted air leakage.[20] Therefore, the EES mentioned in section 3.1.1.3 should be applied: sealing chimneys, windows and doors, loft hatch and installing extract fans.

5.3.1.3.4 Lighting and Appliances

Only 25% of the lighting is low-energy in this scenario, and the survey does not provide further information about appliances. Therefore, more low-energy lighting and efficient appliances should be applied.

5.4 Economical and Environmental Impacts

All the costs are taken from figures given by the Energy Saving Trust, the Department of Transport and from different sources that were already discussed in section 3. The tables take the capital costs for each EES applied alone, which is the worst case scenario; therefore, if many EES are taken at the same time together (See opportunities in Table 3.1) the costs would me less.

Applying the values discussed in section 3 and the cost effects found in Appendix 2, the EES described in section 5.3.1.1, and following the procedure explained in Section 5.2, the following tables were obtained:

EES	Capital cost £	Annual Energy Savings *kWh*	Cost savings *£/year*	Payback period *years*	CO_2 Savings *tonne/year*	£ spent for tonnes of CO_2 saved
Int. Wall insulation	2,300	10,625.00	212.50	10.82	4.50	2,110
Floor insulation	1,566	18,815.10	376.30	4.16	0.9	1,740
Double Glazing	3,052	27,595.48	551.91	5.53	0.3	10,760
Ventilation	599	9,031.25	180.62	3.32	0.5	1,198
Lighting (8 x lamps)	30	832.03	16.64	1.80	0.1	1,200

Table 5.3: EES Costs and CO_2 emissions for Scenario I

EES	Capital cost £	Annual Energy Savings *kWh*	Cost savings *£/year*	Payback period *years*	CO_2 Savings *tonne/year*	£ spent for tonnes of CO_2 saved
Floor insulation	1,566	5,670.14	113.40	13.81	0.9	1,740
Ventilation	599	2,721.67	54.43	11.00	0.5	1,198
Lighting (8 x lamps)	30	332.44	6.65	4.51	0.1	1,200

Table 5.4: EES Costs and CO_2 emissions for Scenario II

EES	Capital cost £	Annual Energy Savings *kWh*	Cost savings *£/year*	Payback period *years*	CO_2 Savings *tonne/year*	£ spent for tonnes of CO_2 saved
Floor insulation	1,566	6,448.78	128.98	12.14	0.9	1,740
Ventilation	599	3,095.42	61.91	9.68	0.5	1,198
Lighting (6 x lamps)	45	405.47	8.11	5.55	0.1	1,200

Table 5.5: EES Costs and CO_2 emissions for Scenario III

5.5 Results Analysis

The tables in section 5.4 are considering the improvements as independent measures, which mean that each of the EES is applied one at a time. If the EES are all applied at once, the total cost would be less than the sum of the EES all together because of the opportunities explained in Table 3.1. Similarly, the energy savings would be different to the sum of the independent EES. This is due to different factors, like the kind of dwelling. An explanation for this is that some solutions will not be suitable if other measures are carried out previously. The evaluation has been done in three stages:

- Information from the survey
- NHER Auto Evaluator analysis with EES already applied
- Analysis of further EES based on benchmarks and data gathered from the Best Practice guides

		Before any EES	After applying insulation (as part of project)	After EES recommended are applied
Energy Rating	Scenario I	2.09	3.06	N/A
	Scenario II	3.39	5.94	N/A
	Scenario III	3.31	5.55	N/A
Emissions CO_2 *tonnes per year*	Scenario I	22.23	17.68	11.38
	Scenario II	9.57	6.12	4.62
	Scenario III	10.18	6.79	5.29
Total Energy Use *kWh*	Scenario I	76,505.56	60,208.33	40,830.56
	Scenario II	29,272.22	18,144.44	15,332.08
	Scenario III	31,266.67	20,636.11	15,384.11
Total Costs £	Scenario I	3,536.66	2,886.83	2,135.23
	Scenario II	931.99	685.60	406.79
	Scenario III	1,028.64	793.68	476.03

Table 5.6: Summary of emissions, costs and energy use of each scenario

The first EES that have already been applied in the dwellings of the communities as part of the project show an increase of the energy rating:

The results showed that after those measures the energy rating increased; however, this is still far from being a very energy efficient house. Therefore, more EES can be applied, but this means that more money should be invested, but as any good investment it will give a return in energy savings and low carbon emissions, and it will take some period to pay back.

It can also clearly be seen that the second scenario is the most energy efficient, therefore the emissions are lower and the energy consumption less. Furthermore, the need of less EES to be applied lower the cost of maintenance to the dwelling.

Finally, the results show that the effect of basic EES in less efficient houses is greater than the houses that are more energy efficient; therefore, the more efficient the house the less impact of EES.

6. ASSESSMENT OF RENEWABLE ELECTRICITY GENERATION

Past experiences in Scotland have shown that community REG is not the best approach. Therefore, the Energy Agency has considered that the project should continue funding only households that want to apply to a REG, and not applying a single community project.

The next step for this project is to send a questionnaire explaining the approach for this new phase:

- Whoever wants to be part of this funding will have to be aware that it is not completely free.
- There will be an extra 10% funding in case the owner decides to apply to solar water heating program.

6.1 Methodology

When applying new and renewable energy technologies to existing dwellings it is important to reduce the energy demand. Older, not previously improved, dwellings rarely have adequate levels of insulation. Heating systems often have high output and poor efficiency. There will probably be conventional electric lighting (i.e. with tungsten lamps) and older electrical appliances. All of these factors can raise the electric power demand of older dwellings to levels that renewable energy systems may not be able to meet. Improving energy efficiency is therefore a strongly recommended precursor to the installation of renewable energy systems. Energy efficiency should be improved on a 'whole house' basis wherever possible, including:[22]

- Insulation.
- Reduced thermal bridging.
- Improved air-tightness.
- Controlled ventilation.
- Efficient lighting and appliances.

Once these measures have been already assessed (section 5) the demand load profile should be plotted. With this data, plus the weather data the simulation can be executed.

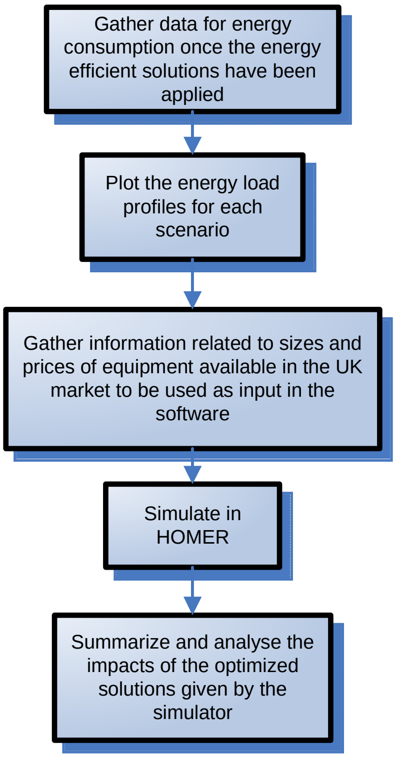


Figure 6.1: Methodology for REG

6.2 Algorithm

In order to assess the data, the software called HOMER (see section 3.4.1) will be used. This software simulates the best combination of wind and solar technologies. All data for these components is considered, including climate data. Therefore, the results will only include these two technologies. This specific combination of REG presents many benefits.. Moreover with the use of the appropriate auxiliary systems like batteries you can store energy which will be useful in compensating electrical demands used by the house for periods where there is no sun or wind. Finally, it is economically sound and advantageous to use non finite resources, i.e. solar and wind (hybrid).

- Photovoltaics are ideal for use in rural environments because electricity is generated at the point of use; energy loss and costs associated with transmission and distribution are avoided. The capital cost of installing these systems however, can be prohibitive.[24]

- The UK has the largest potential wind resource in northern Europe, with approximately 40 per cent of the total supply available. Nevertheless, wind data resource on site for each dwelling is impossible to get, since the area is wide and dispersed. For the particular case of this study, wind data from Prestwick is considered.

The main data input that for this software is:

- Demand Load Profile
- Climate Data: Solar and Wind resources)
- Components: PV, Wind Turbine, Generator, Battery, Converter
- Constraints

6.2.1 Demand Load Profile

The energy demand profile is vital in order to guarantee an accurate sizing in the demand supply balance analysis. Currently, the majority of REG schemes are based on the typical-national demand profile. This can produce different types of problems, such as over sizing, or insufficient supply to cover the load in the case of under sizing. Therefore, it is important to take into account different scenarios considering the difference in:

- House Stock
- Occupancy level
- Occupant behavior

Thus, the demand profile should reflect the energy load of the dwelling.

The energy demand plus the carbon emissions of a dwelling can be calculated in different ways, such as energy bills, national annual average consumption or by modelling tools:[25]

- Energy bills: Simply sum up all the monthly electricity and gas bills of the households.[25] This approach will not be possible, because not all the dwellings were able to give that information to the surveyors.

- National Annual Average Energy Consumption: In the absence of energy bills, a rough estimation of current demand and carbon emissions can be made using the national annual average energy consumption.[25]

  Total domestic energy consumption per household 27,630 kWh [11]

  Total domestic energy consumption per capita 11,410 kWh [36]

  This approach is inaccurate in the sense that it considers all the dwellings the same, and it is usually used when there is not any information available, which is not true in this case.

- Modelling the energy load profile: The data collected in the survey can be processed in different ways. There are some tools and software that give an accurate estimation of the energy demand. However, this software is not available for common users.

  One of the options explored was the use of a spreadsheet developed by the Demand Side Management group from the MSc Energy Systems and the Environment[25] based on a paper called "A method of formulating energy load profile for domestic buildings in the UK".[43] This method will be explained in the following sections, since it will be the one to be used.

<u>Method of generating domestic load profile</u>

The use pattern varies depending on the different factors, such as climate, household composition, family income, culture background, and human factor, etc. In order to produce a domestic load profile which takes into account various factors, a cluster analysis method has been applied. The energy demand can be categorized into two types of determinants: To model appliance energy-consumption profile for a typical household, the information of daily usage of each appliance is needed. That is daily energy-consumption for each appliance, ownership of each appliance, and occupied period. [16]

The calculation of daily energy-consumption of each appliance can use the following equation: [43]

$$E_a = N \times \sum A$$

Where E_a is the daily delivered appliances energy consumption of household, N number of occupants, and A the appliance.[43]

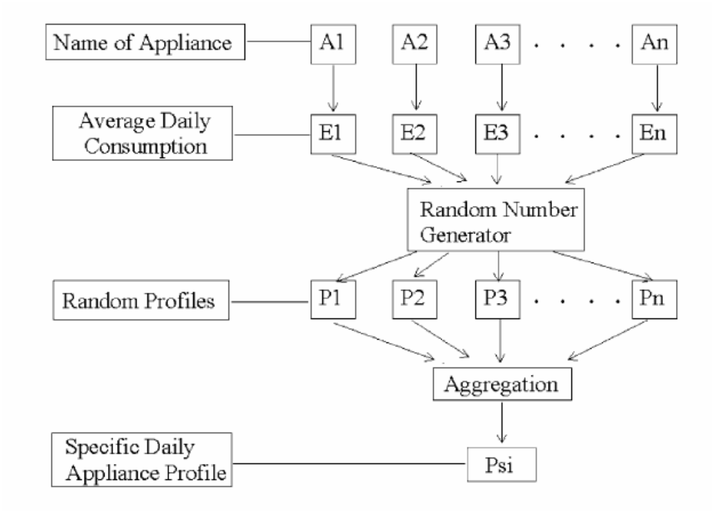


Figure 6.2: Framework of generating electrical load profile [43]

The aggregation of all appliances' random profiles will generate a daily electric appliances load profile for a stated scenario. This profile is called Specific Profile because it is relevant to a specific occupancy scenario. For each scenario, the daily load profile can be different from day to day and peaky.[43]

The framework showed in Figure 6.2 can be simulated in a spreadsheet. As it was mentioned before, the spreadsheet developed by the Demand Side Management group from the MSc Energy Systems and the Environment[25] will be used, assuming national data f since the survey does not include information about appliances for the dwellings in the community.

For the case of Heating Load, the framework used is the one showed in Figure 6.3.

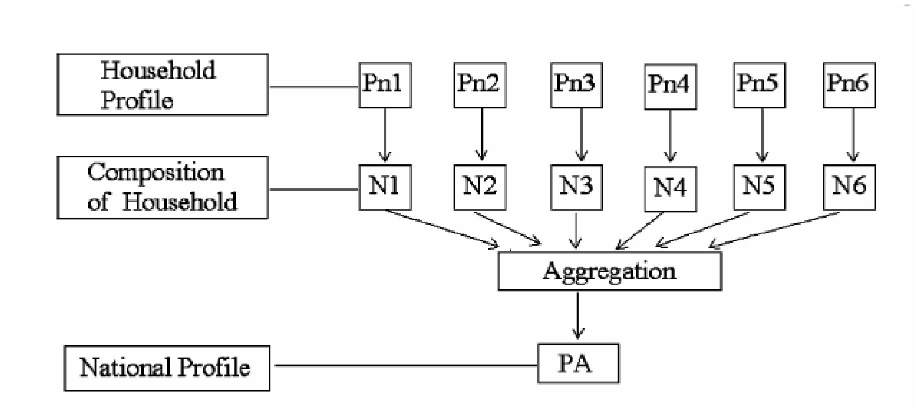


Figure 6.3: Framework of generating heating load profile [43]

Load profile for space heating depends on the building thermal characteristics, orientation, internal temperature, local climate, etc. The equation that illustrates the simulation is:

$$C\frac{dT}{dt} = \Phi_{heat/cool} + \Phi_{cond} + \Phi_{vent} + \Phi_{solar} + \Phi_{sp}$$

C is the thermal capacity of the stated node, $\Phi_{heat/cool}$ the auxiliary heating/cooling energy of the room, Φ_{cond} the conductive heat transfer through the building envelope (wall and window); Φ_{vent} the ventilation heat transfer through the building, Φ_{solar} the solar gain, Φ_{sp} the internal gain from electrical lighting, people and appliance. Most of these data has to be assumed considering the type of building and the age band of the building, the characteristics are part of the interactive tool [25] to be used.

6.2.1.1 Scenario I

Winter season was considered in order to obtain the energy load profile as the worst case scenario. Nevertheless, the data used to plot the graphs and data for the summer season is in Appendix 4.

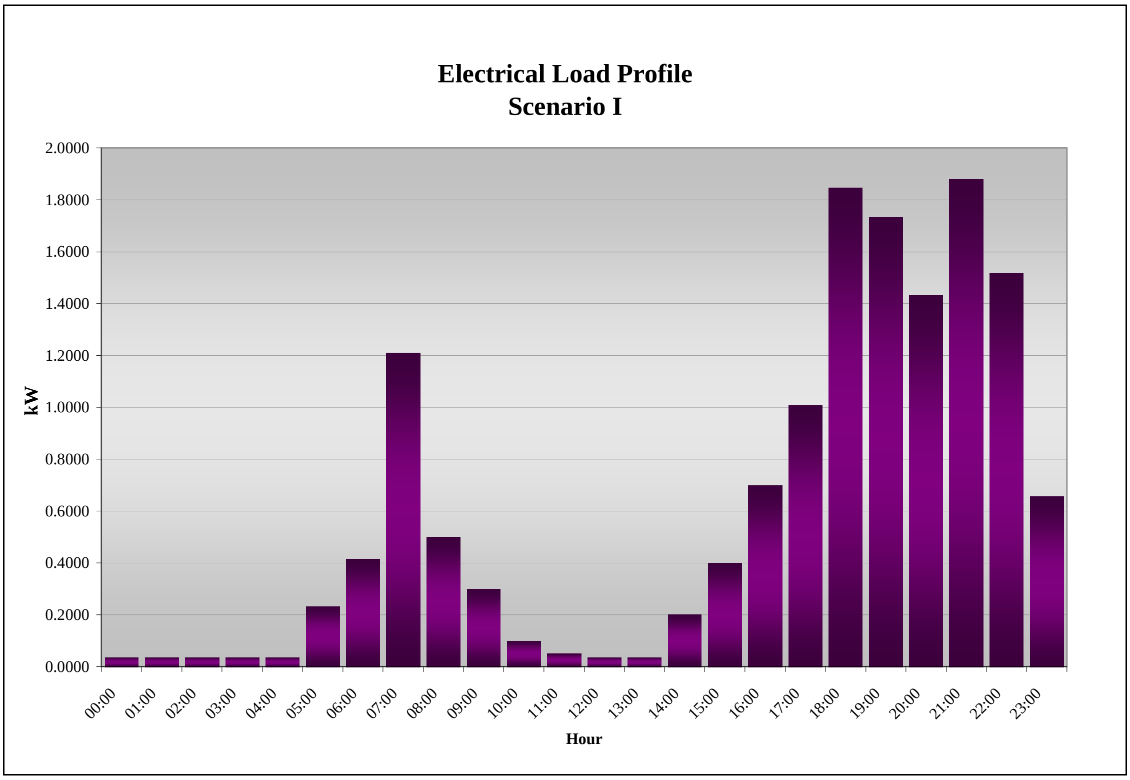


Figure 6.4: Electrical load profile Scenario I

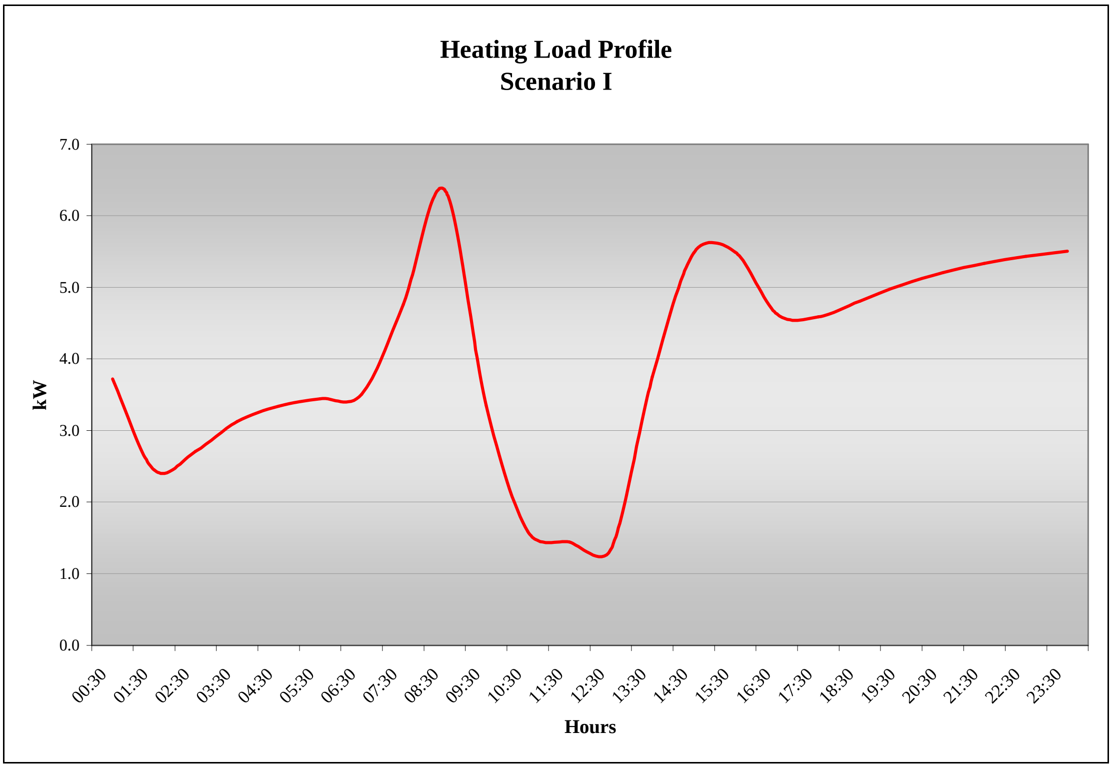


Figure 6.5: Heating load profile Scenario I

6.2.1.2 Scenario II

Winter season was considered in order to obtain the energy load profile as the worst case scenario. Nevertheless, the data used to plot the graphs and data for the summer season is in Appendix 4.

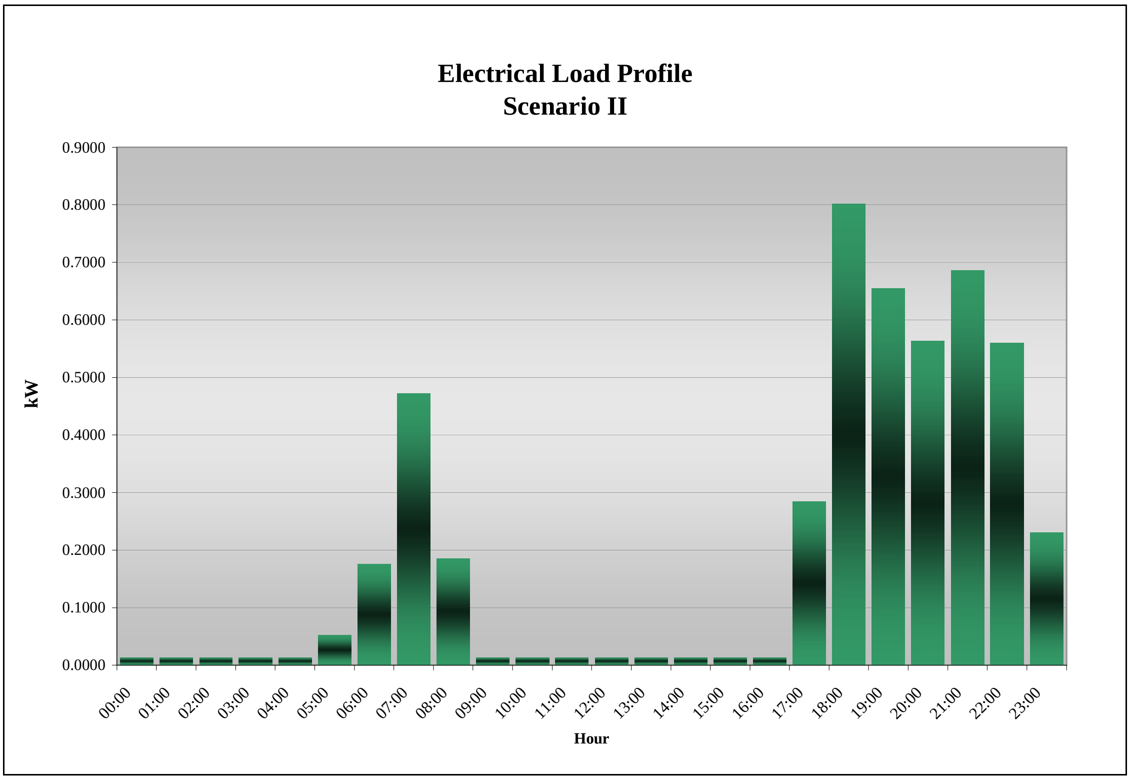


Figure 6.6: Electrical load profile Scenario II

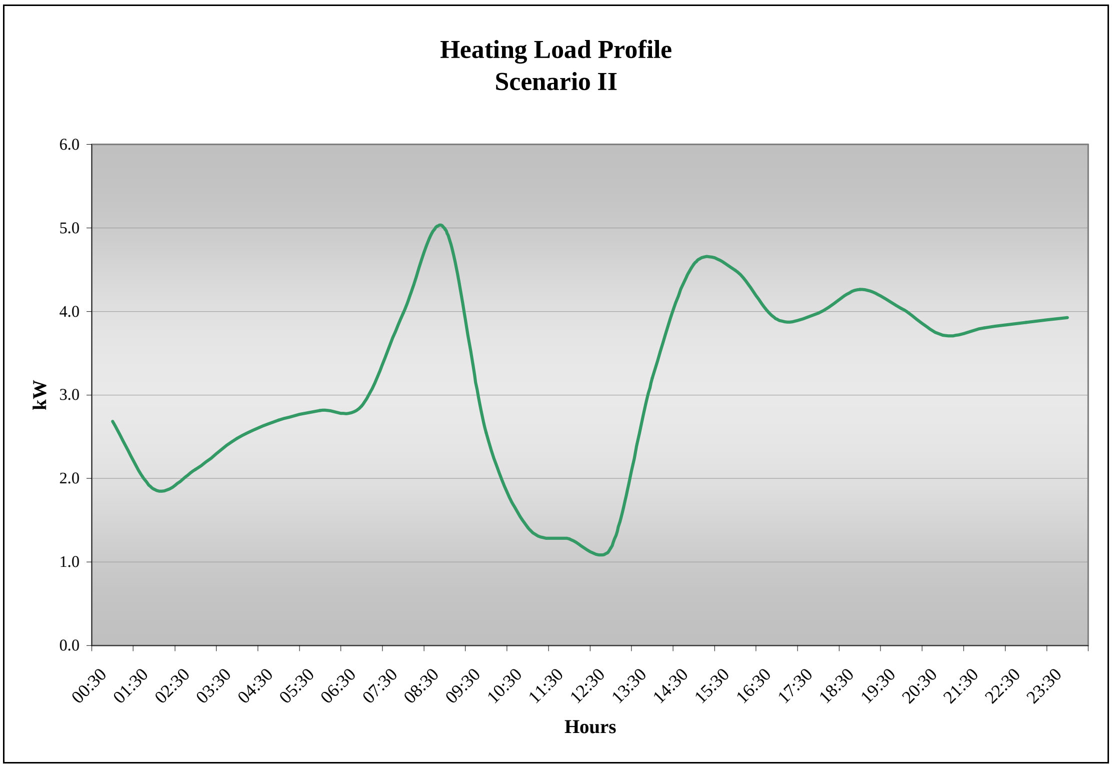


Figure 6.7: Heating load profile Scenario II

6.2.1.3 Scenario III

Winter season was considered in order to obtain the energy load profile as the worst case scenario. Nevertheless, the data used to plot the graphs and data for the summer season is in Appendix 4.

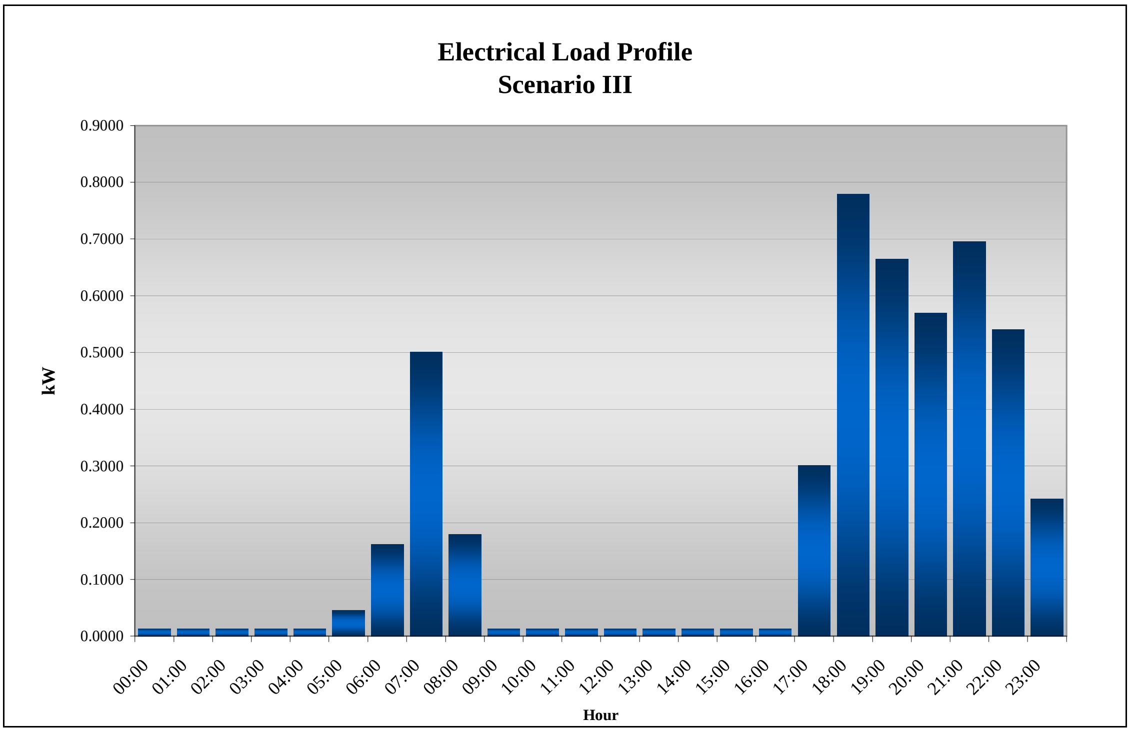


Figure 6.8: Electrical load profile Scenario III

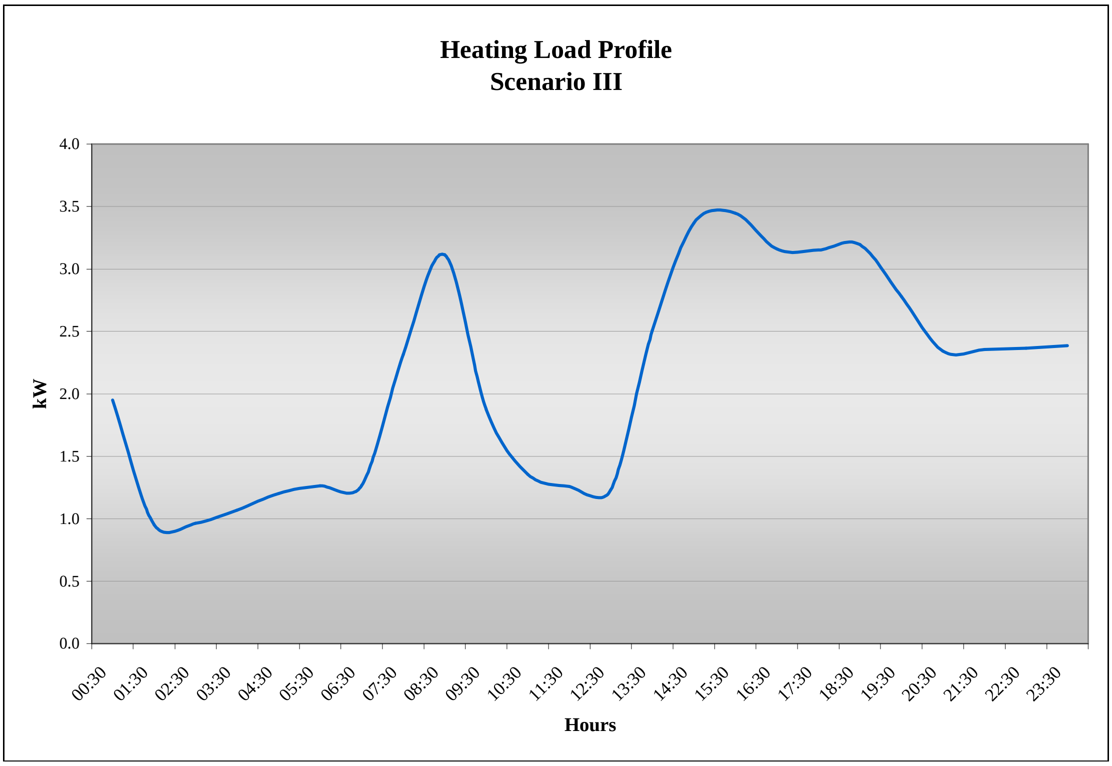


Figure 6.9: Heating load profile Scenario III

6.3 Simulation

As it was mentioned previously, before applying any REG the total energy requirements (for space heating, hot water and electricity) should always be reduced as much as possible. Therefore, for the simulations the total energy use after EES are taken is considered. This data is displayed in Section 5.5, Table 5.6.

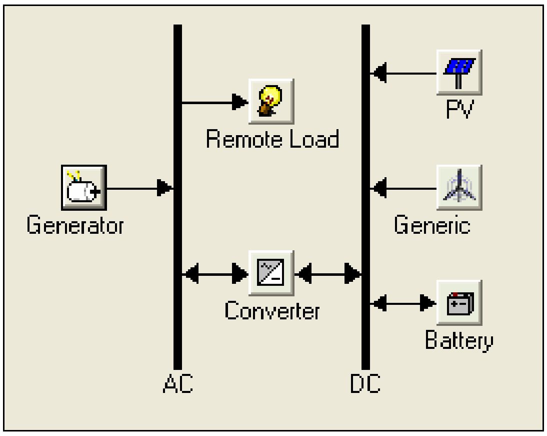


Figure 6.10: Homer model to be simulated

The model used for the simulations in HOMER is shown in Figure 6.10. It is fairly simple, and the components considered are: PV, small generic wind turbine, batteries, converters, and a generator. The generator has to be used due to the security the supply, since PV and wind energy depend on many factors that cannot be controlled. Therefore, a generator has to be added to the configuration, otherwise it will not run, unless all the demand is covered by REG, which is not the aim of the project.

The main data used to run the simulations and main assumptions for all the components are shown in the following table:

The option of adding noise to the simulations was added: the daily and hourly noise inputs allow adding randomness to the load data to make it more realistic. The software recommends a value of 20% daily and 15% hourly.

The costs for the equipment were obtained from different dealers in the UK in the internet.

Demand Load Profile	Electrical Demand profiles	The data is available in Appendix 4
Climate Data	Solar resource	The data is available in Appendix 3
	Wind resource	The data is available in Appendix 3
Components	PV	55W, 110W and 125W *
	Wind Turbine	1kW and 3kW*
	Generator	3.2 kW, 230V, Natural Fuel: Natural Gas (price 0.0313£/kWh)
	Battery	12v 110 Ah and 200 Ah
	Converter	4A, 1.2 kW

*Available in the UK market: www.energyenv.co.uk

Table 6.1: General data used for all the HOMER simulations

The generator that is part of this system can be considered as power generated by the grid, since it is going to give the electricity needed when the climate conditions are not given for the components to generate electricity.

6.3.1.1 Scenario I

The profile that is actually used for the simulation is the one shown in Figure 6.10, which is generated automatically by the software adding noise and making it more realistic.

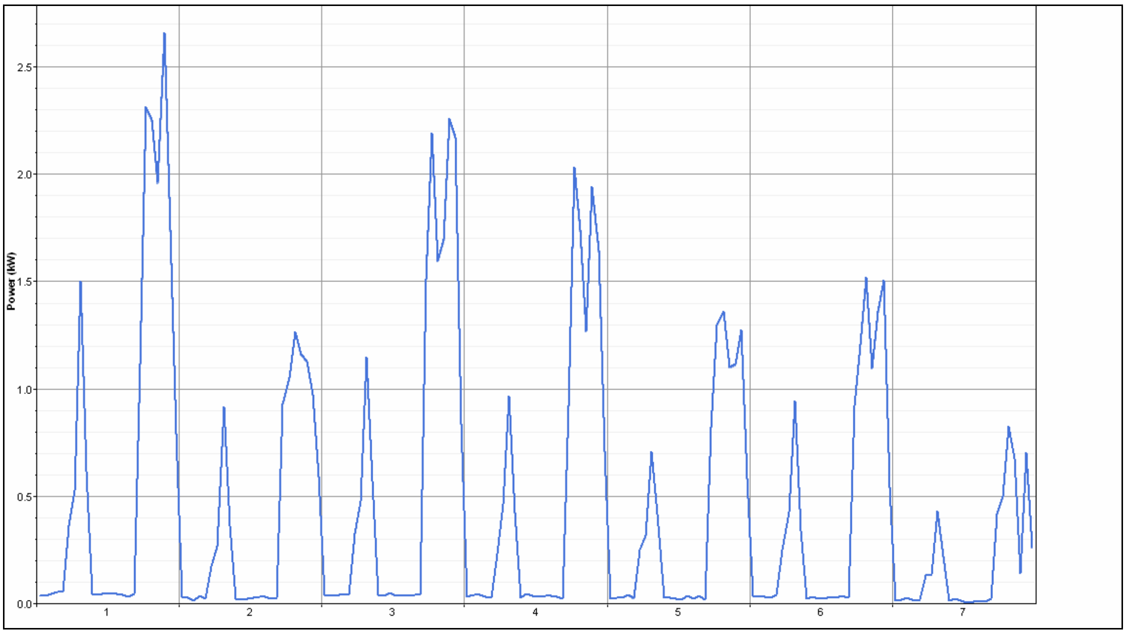
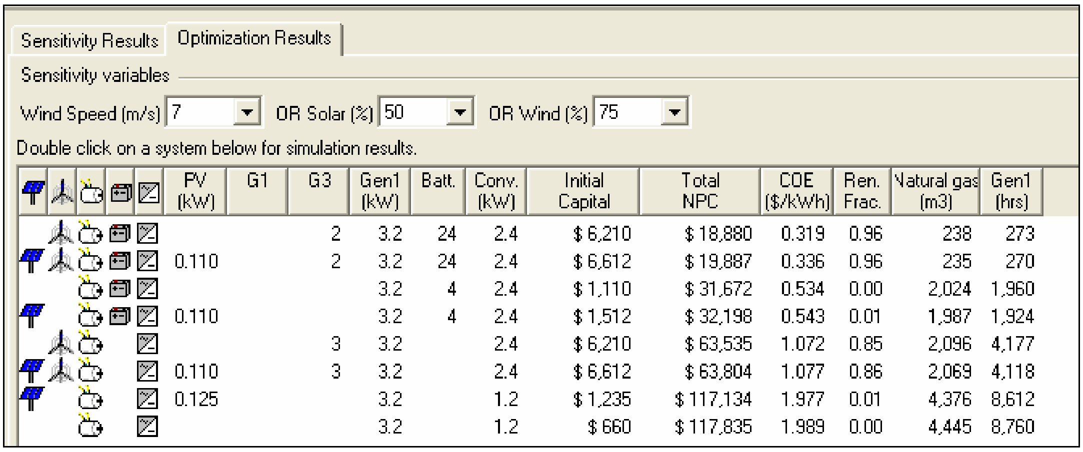


Figure 6.11: Demand Load Profile with noise Scenario I

For this scenario 630 simulations were done for 63 sensitivity cases. Once the simulation is done, the program gives a table of results. The results are displayed in the window like the one showed in Figure 6.12:



PV (kW)	G1	G3	Gen1 (kW)	Batt.	Conv. (kW)	Initial Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Natural gas (m3)	Gen1 (hrs)
		2	3.2	24	2.4	$ 6,210	$ 18,880	0.319	0.96	238	273
0.110		2	3.2	24	2.4	$ 6,612	$ 19,887	0.336	0.96	235	270
			3.2	4	2.4	$ 1,110	$ 31,672	0.534	0.00	2,024	1,960
0.110			3.2	4	2.4	$ 1,512	$ 32,198	0.543	0.01	1,987	1,924
		3	3.2		2.4	$ 6,210	$ 63,535	1.072	0.85	2,096	4,177
0.110		3	3.2		2.4	$ 6,612	$ 63,804	1.077	0.86	2,069	4,118
0.125			3.2		1.2	$ 1,235	$ 117,134	1.977	0.01	4,376	8,612
			3.2		1.2	$ 660	$ 117,835	1.989	0.00	4,445	8,760

Figure 6.12: Simulation output for 7 m/s for wind speed for Scenario I

Refer to Appendix 5 for all the sensitivity results from the simulations.

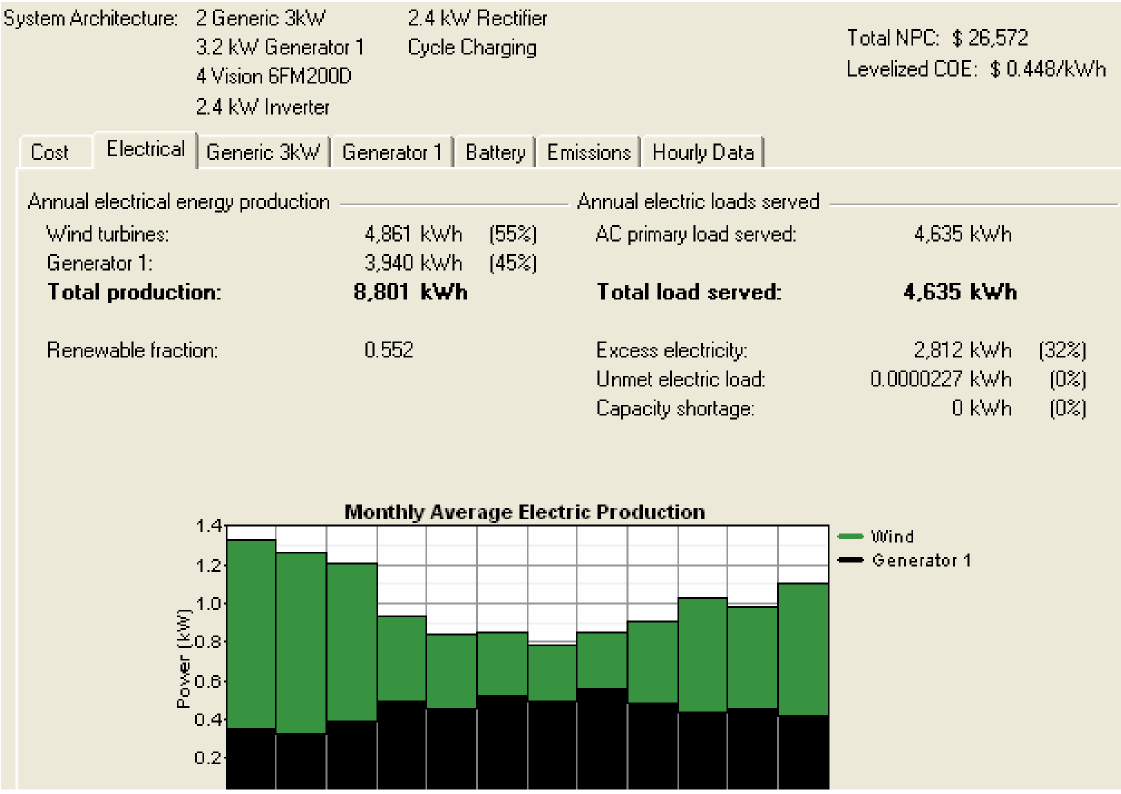


Figure 6.13: Simulation output for the electrical demand Scenario I

For the first scenario, it can be seen that the demand is met mainly by the wind turbine. 55% of this demand is covered by a renewable source. This is mainly because the simulation considers two wind turbines. Compared to the other two scenarios, this is the less efficient and with less renewable fraction.

6.3.1.2 Scenario II

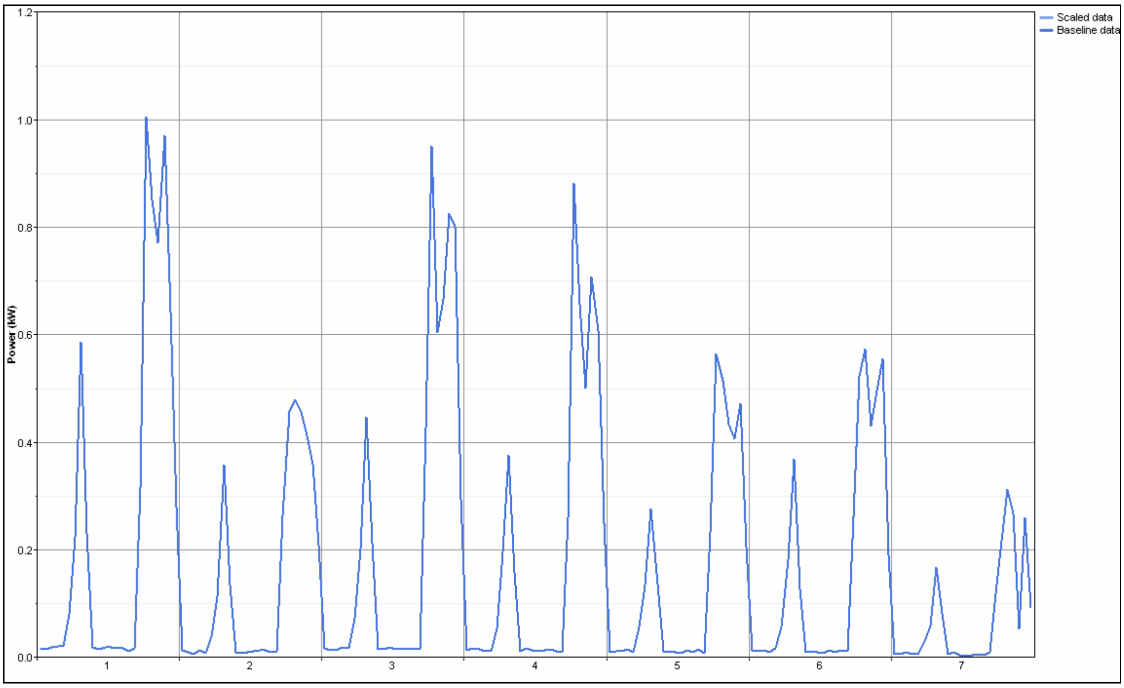


Figure 6.14: Demand Load Profile with noise Scenario II

For this scenario 630 simulations were done for 63 sensitivity cases. Once the simulation is done, the program gives a table of results. The results are displayed in the window like the one showed in Figure 6.15:

Sensitivity Results | Optimization Results

Sensitivity variables

Wind Speed (m/s) 7 | OR Solar (%) 50 | OR Wind (%) 75

Double click on a system below for simulation results.

PV (kW)	G1	G3	Gen1 (kW)	Batt.	Conv. (kW)	Initial Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Natural gas (m3)	Gen1 (hrs)
		1	3.2	4	2.4	$ 2,910	$ 14,847	0.336	0.81	616	623
0.110		1	3.2	4	2.4	$ 3,312	$ 15,890	0.359	0.82	615	623
			3.2	4	2.4	$ 1,110	$ 25,281	0.572	0.00	1,559	1,511
0.110			3.2	4	2.4	$ 1,512	$ 25,775	0.583	0.02	1,520	1,473
		3	3.2		1.2	$ 6,060	$ 57,450	1.299	0.87	1,854	3,782
0.110		3	3.2		1.2	$ 6,462	$ 57,584	1.302	0.87	1,823	3,713
0.125			3.2		1.2	$ 1,235	$ 112,740	2.549	0.01	4,052	8,287
			3.2		1.2	$ 660	$ 117,767	2.662	0.00	4,268	8,760

Figure 6.15: Simulation output for 7 m/s for wind speed for Scenario II

Refer to Appendix 5 for all the sensitivity results from the simulations.

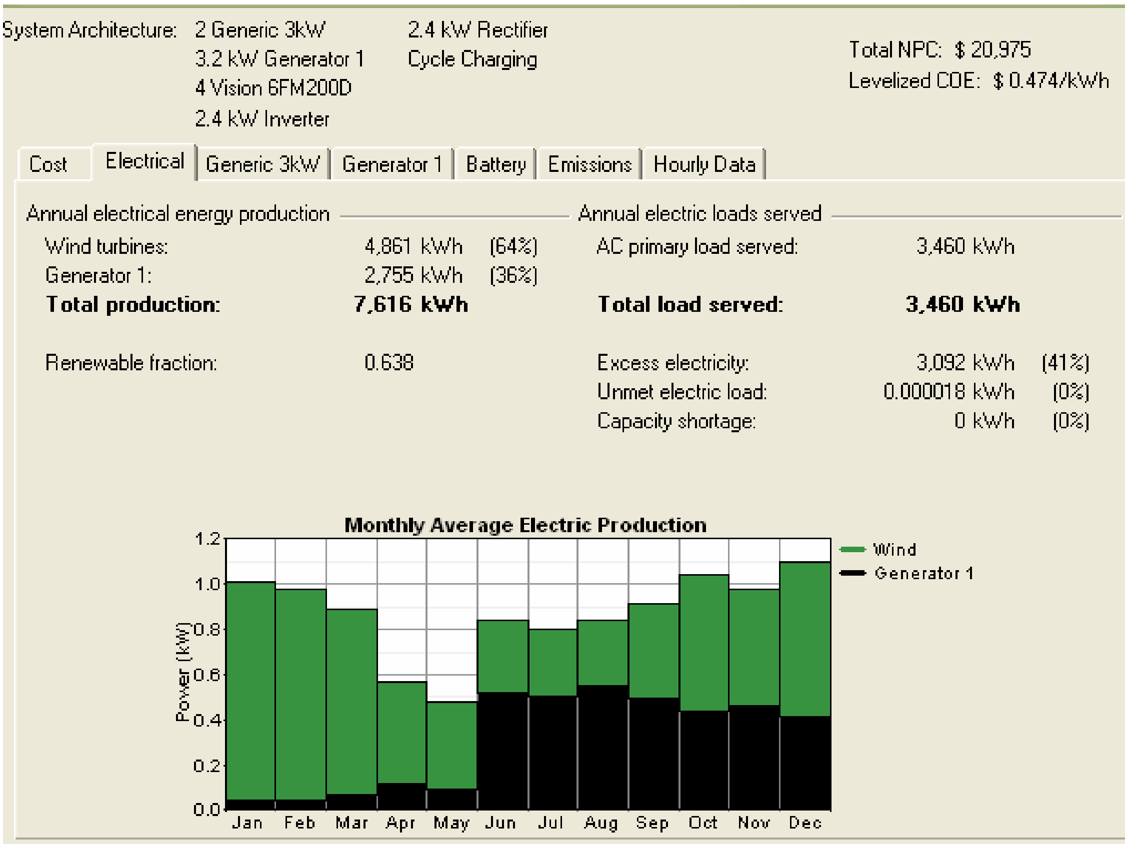


Figure 6.16: Simulation output for the electrical demand Scenario II

For the second scenario, it can be seen that the demand is met mainly by the wind turbine. Almost 64% of this demand is covered by a renewable source. This is mainly because this scenario considers two wind turbines.

6.3.1.3 Scenario III

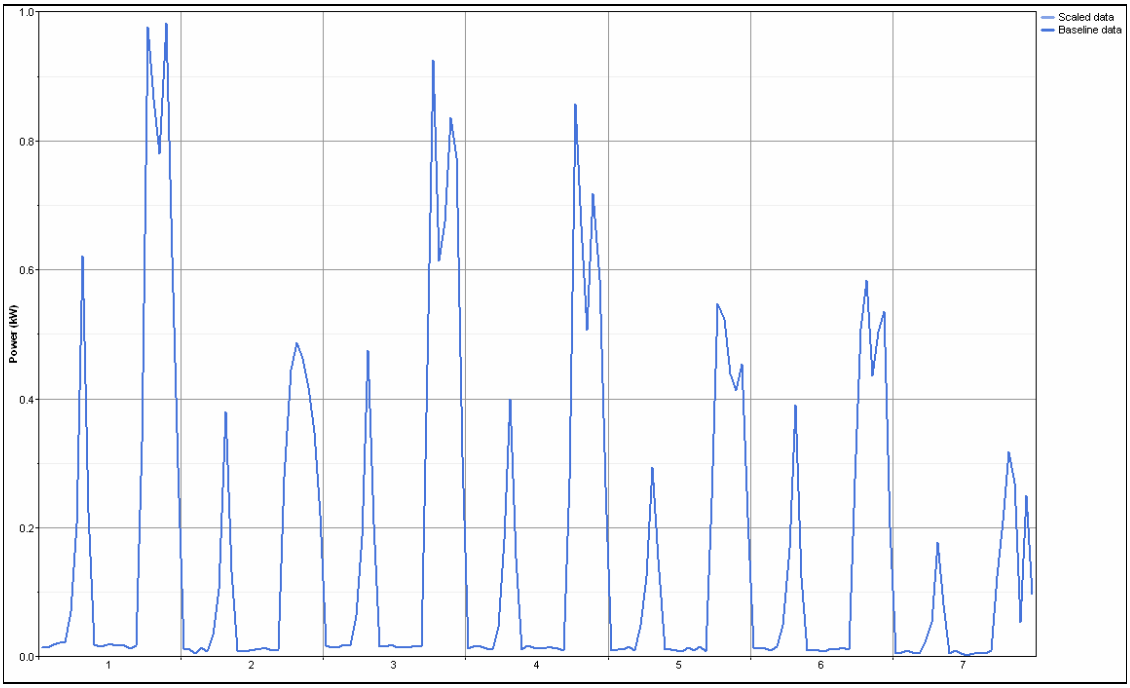
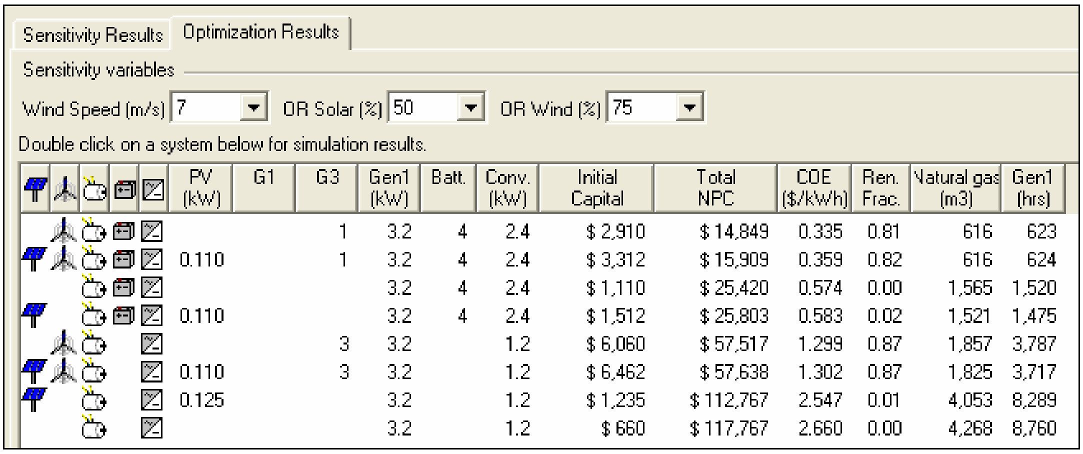


Figure 6.17: Demand Load Profile with noise Scenario III

For this scenario 630 simulations were done for 63 sensitivity cases. Once the simulation is done, the program gives a table of results. The results are displayed in the window like the one showed in Figure 6.18:



Sensitivity Results | Optimization Results

Sensitivity variables

Wind Speed (m/s) 7 | OR Solar (%) 50 | OR Wind (%) 75

Double click on a system below for simulation results.

PV (kW)	G1	G3	Gen1 (kW)	Batt.	Conv. (kW)	Initial Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Natural gas (m3)	Gen1 (hrs)
		1	3.2	4	2.4	$ 2,910	$ 14,849	0.335	0.81	616	623
0.110		1	3.2	4	2.4	$ 3,312	$ 15,909	0.359	0.82	616	624
			3.2	4	2.4	$ 1,110	$ 25,420	0.574	0.00	1,565	1,520
0.110			3.2	4	2.4	$ 1,512	$ 25,803	0.583	0.02	1,521	1,475
		3	3.2		1.2	$ 6,060	$ 57,517	1.299	0.87	1,857	3,787
0.110		3	3.2		1.2	$ 6,462	$ 57,638	1.302	0.87	1,825	3,717
0.125			3.2		1.2	$ 1,235	$ 112,767	2.547	0.01	4,053	8,289
			3.2		1.2	$ 660	$ 117,767	2.660	0.00	4,268	8,760

Figure 6.18: Simulation output for 7 m/s for wind speed for Scenario III

Refer to Appendix 5 for all the sensitivity results from the simulations.

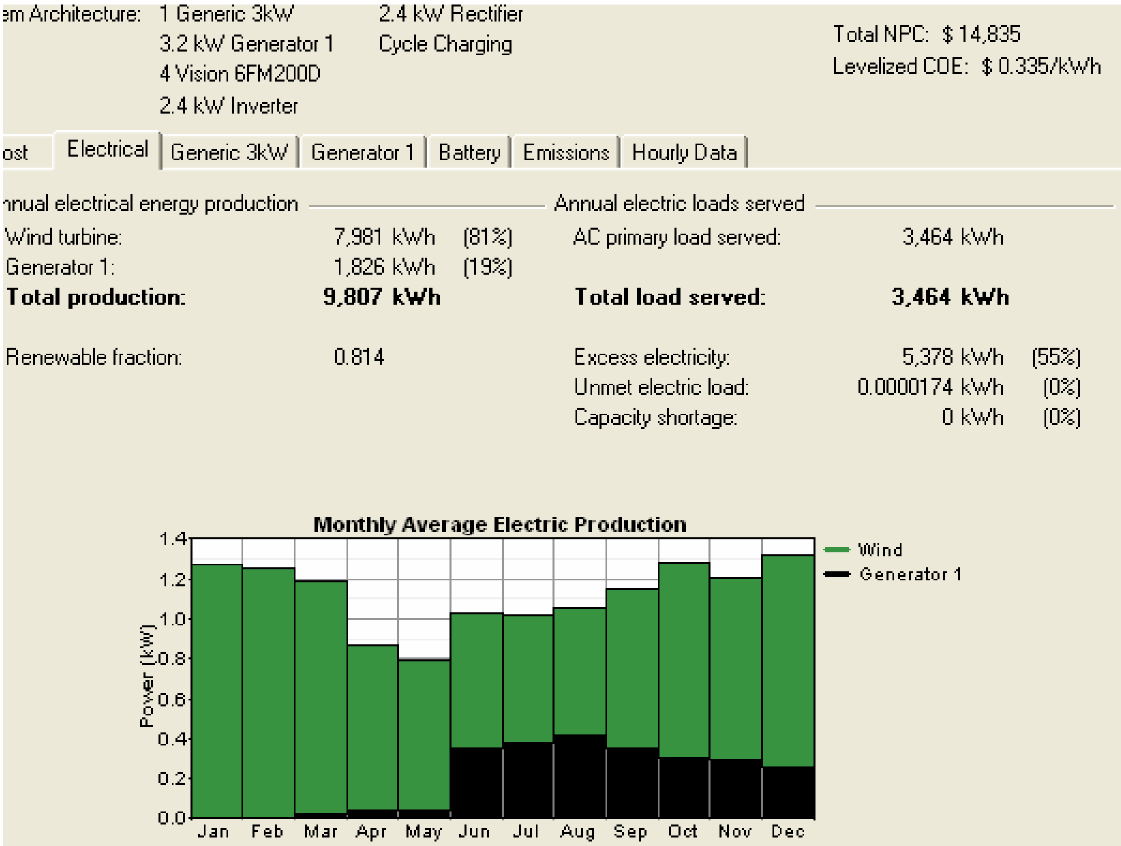


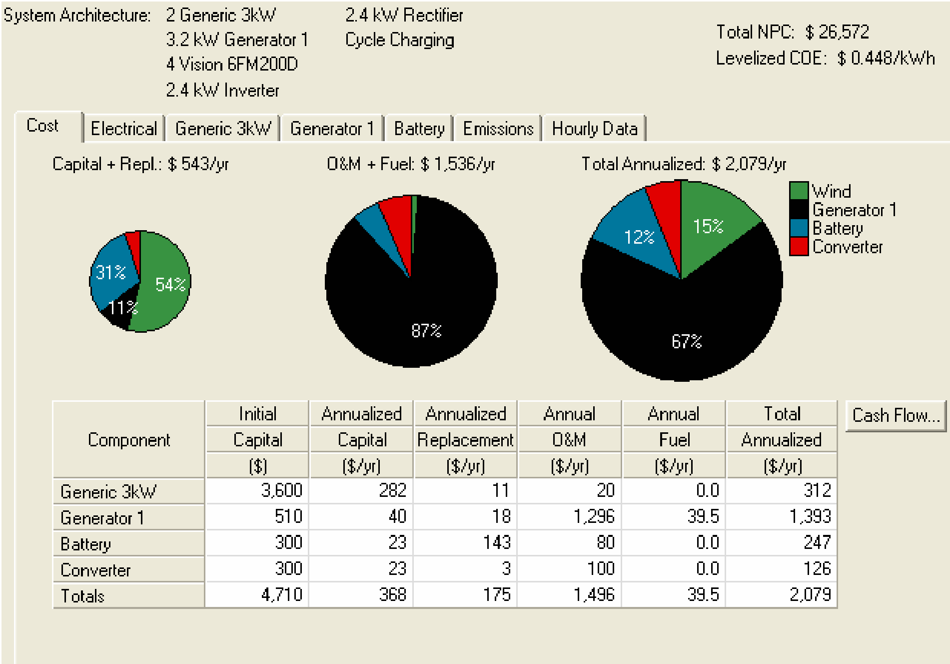
Figure 6.19: Simulation output for the electrical demand Scenario III

The third scenario shows by far better results than the other two. 81% of the electrical demand is covered by renewable energy, in this case only one wind turbine, therefore reducing the emission in a higher rate.

6.4 Economical and Environmental Impacts

6.4.1 Scenario I

The costs and emissions related to the optimum combination of REG are shown in the next graph and table. The highest cost is related to the 3.2 kW generator.



Component	Initial Capital ($)	Annualized Capital ($/yr)	Annualized Replacement ($/yr)	Annual O&M ($/yr)	Annual Fuel ($/yr)	Total Annualized ($/yr)
Generic 3kW	3,600	282	11	20	0.0	312
Generator 1	510	40	18	1,296	39.5	1,393
Battery	300	23	143	80	0.0	247
Converter	300	23	3	100	0.0	126
Totals	4,710	368	175	1,496	39.5	2,079

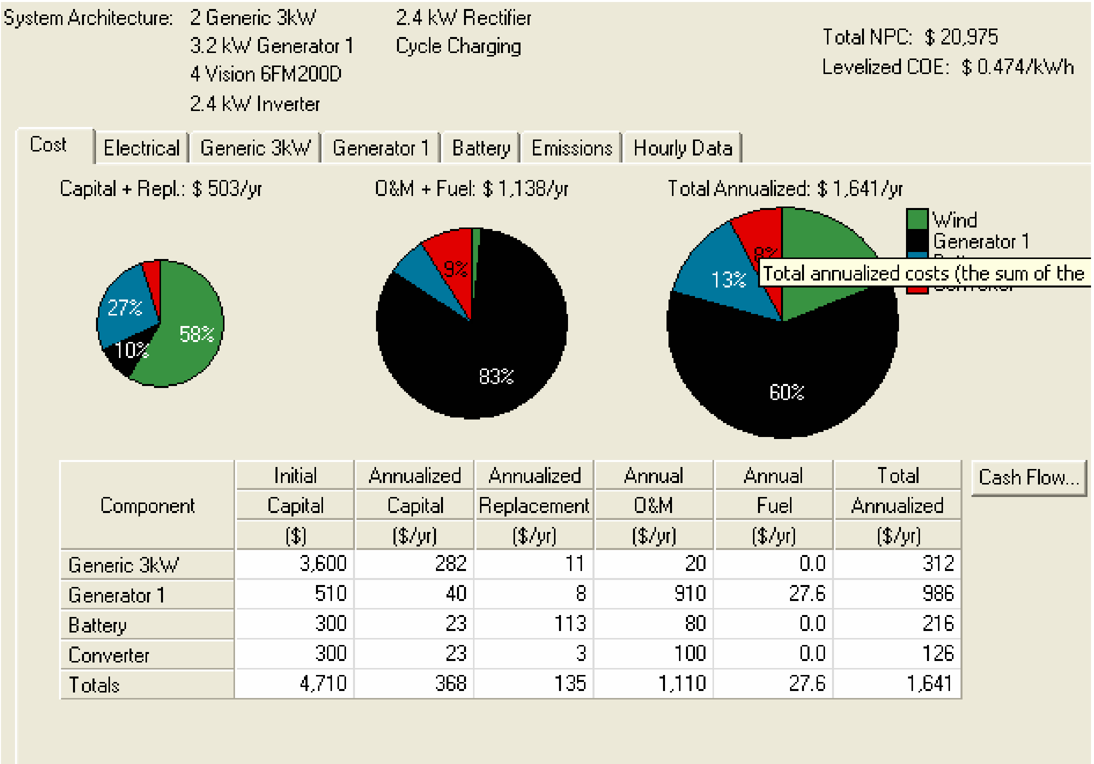
Figure 6.20: Costs for the optimized REG - Scenario I

Pollutant	Emissions
Carbon dioxide:	2,540 kg/yr
Carbon monoxide:	8.56 kg/yr
Unburned hydrocarbons:	0.948 kg/yr
Particulate matter:	0.645 kg/yr
Sulfur dioxide	6.71 kg/yr
Nitrogen oxides:	76.4 kg/yr

Table 6.2: Emissions for the optimized REG – Scenario I

6.4.2 Scenario II

The costs and emissions related to the optimum combination of REG are shown in the next graph and table. The highest cost is related to the 3.2 kW generator.



Component	Initial Capital ($)	Annualized Capital ($/yr)	Annualized Replacement ($/yr)	Annual O&M ($/yr)	Annual Fuel ($/yr)	Total Annualized ($/yr)
Generic 3kW	3,600	282	11	20	0.0	312
Generator 1	510	40	8	910	27.6	986
Battery	300	23	113	80	0.0	216
Converter	300	23	3	100	0.0	126
Totals	4,710	368	135	1,110	27.6	1,641

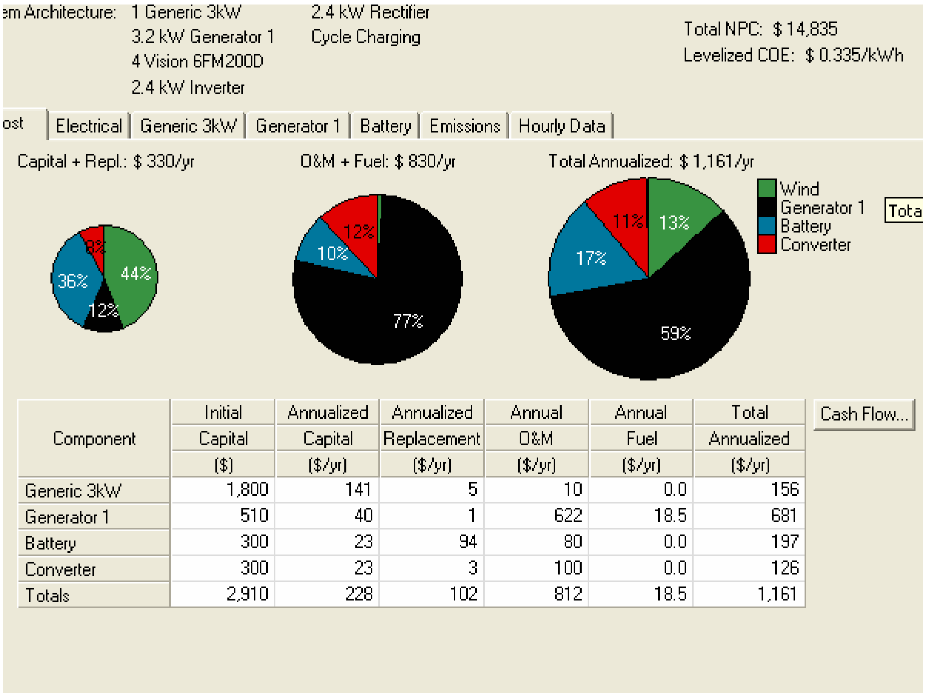
Figure 6.21: Costs for the optimized REG - Scenario II

Pollutant	Emissions
Carbon dioxide:	1,778 kg/yr
Carbon monoxide:	5.99 kg/yr
Unburned hydrocarbons:	0.664 kg/yr
Particulate matter:	0.452 kg/yr
Sulfur dioxide:	4.7 kg/yr
Nitrogen oxides:	53.5 kg/yr

Table 6.3: Emissions for the optimized REG – Scenario II

6.4.3 Scenario III

The costs and emissions related to the optimum combination of REG are shown in the next graph and table. The highest cost is related to the 3.2 kW generator.



Component	Initial Capital ($)	Annualized Capital ($/yr)	Annualized Replacement ($/yr)	Annual O&M ($/yr)	Annual Fuel ($/yr)	Total Annualized ($/yr)
Generic 3kW	1,800	141	5	10	0.0	156
Generator 1	510	40	1	622	18.5	681
Battery	300	23	94	80	0.0	197
Converter	300	23	3	100	0.0	126
Totals	2,910	228	102	812	18.5	1,161

Figure 6.22: Costs for the optimized REG - Scenario III

Pollutant	Emissions
Carbon dioxide:	1,788 kg/yr
Carbon monoxide:	4 kg/yr
Unburned hydrocarbons:	0.443 kg/yr
Particulate matter:	0.302 kg/yr
Sulfur dioxide:	3.14 kg/yr
Nitrogen oxides:	35.7 kg/yr

Table 6.4: Emissions for the optimized REG – Scenario III

6.5 Results Analysis

The simulation output is very big and complex, considering that it analyses all the combinations for wind, PV, batteries, converters, and generator with the energy load profile. There were 1,008 simulations for each one of the 63 sensitivities.

Only a summary of the optimum results for each one of the scenarios is displayed in the next table. The cost includes a turbine that is available in the UK market at the lowest price, without taking into account installation costs. It was assumed that the footprint displacement with the use of small scale wind energy is 25%

Component	Size or Unit	Scenario I	Scenario II	Scenario III
		Quantity		
Wind	3kW	2	1	1
	1kW	0	0	0
PV	55kW	0	0	0
	110W	0	0	0
	125W	0	0	0
Generator	3.2kW	1	1	1
Batteries	12V	24	4	4
Inverter	1.2kW	2	2	2
Cost	£	6,210	2,910	2,910
CO_2 Savings	kg/year	10.16	7.12	4.76

Table 6.5: Summary of results from REG simulation in HOMER

As mentioned before, all the optimized results from the simulation are in Appendix 5. From all that data, the optimum options for the three scenarios do not include PV, only wind turbines. Nevertheless, PV can still be considered as an option, although not the best. The costs for PV are too high and the solar radiation is not as effective as other sites, therefore it is not recommended. However, the wind turbine should be coupled with a generator in order to provide reliable energy to the household.

The most expensive scenario is the first one, just like in the first assessment for EES. The type of building, which is a Pre 1918 detached house, needs a large amount of money to become energy efficient and in order to have REG.

For the same reason, the first scenario has a higher carbon emission, because two generators need to be used to meet the demand. On the other hand, if another wind turbine and only one generator is used, then the emissions are lower, but the costs are much higher. The key aspect for REG is having an energy efficient dwelling, which is also expensive, as EES are expensive.

7. CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

From the data gathered in the survey carried out by the Energy Agency in the communities of Dailly, Barr, Pinwherry and Pinmore, three scenarios were built as a representation of the majority of the households

- Scenario I: Pre 1918 detached dwelling with two occupants;
- Scenario II: 1930-1949 semi detached dwelling with two occupants; and
- Scenario III: 1950-1963 semi detached dwelling with two occupants.

Energy Efficient Solutions were applied to all the scenarios, such as insulation (most of it already applied in situ), double glazing (when needed), ventilation and lighting solutions. If all these measures are carried on, there will be a reduction in emissions, energy use and costs of up to 51% (See table 5.6):

The CO_2 emissions reductions varied from 4.89 (Scenario III) to 10.95 (Scenario I) tonnes per year. Likewise the costs related to energy use were decreased in £552.61 for Scenario III, £525.2 for Scenario II, and £1401.43 for Scenario I.

Regarding the renewable electricity generation, the simulator showed that wind turbine is the best option for the three scenarios (See table 6.5):

The CO_2 emissions are reduced in 10.16 kg/year for Scenario I, 7.12 kg/year for Scenario II and 4.76 kg/year for Scenario III. Unfortunately, renewable generation is still an expensive option; therefore the main advantage of this technology is environmental, not economical. It can be seen that the results depend on the type of dwelling.

Thus, in order to tackle fuel poverty and to work towards having an energy efficient rural community, the best way to proceed is by assessing each dwelling as deep as money and time allow. The study showed that it is more cost-effective to apply basic low-cost energy efficiency solutions before any major change or investment. It is even more cost effective if all the solutions are applied at the same time, or during the same period of refurbishment. As a next step, renewable energy generation should be considered in order to reduce the carbon emissions. For this project, the best option for electricity generation was the wind turbine, with a generator, batteries and a converter. Photovoltaics was not listed as the optimum by the simulation because of higher costs, and because the southwest of Scotland does not have high solar radiation.

The results for all the measures are positive: energy efficiency is increased and carbon emissions are reduced in the households.

7.2 Recommendations

The present study has considered only domestic electricity generation. The results have shown that wind turbines are the best option for renewable electricity generation for the type of dwellings that are similar to the houses described in each scenario.

The first part of the study considered the improvements already being done in the community: cavity wall insulation and roof insulation. These measures have shown to improve notably the energy efficiency of the dwellings. The results show that the first part of the project was a success. The approach was cost-effective, and it reached most of the dwellings. The study done by the Energy Agency considered the key aspects that the Dundee Community Energy Partnership recommended in its lessons learned. This new more complete approach should definitely be considered to be applied in other communities with similar characteristics.

The second part of the energy efficiency solutions assessment had to assume some data which was not part of the survey. These assumptions were based on national averages or benchmarks. The survey had data that was more useful to determine energy efficiency solutions than renewable electricity generation. This is because the survey followed the NHER scheme. As an example, one of the drawbacks was that information about appliances was missing; this information is vital in order to determine the demand profile of the house. However, the assumptions were made according to the occupancy level and type of occupancy (i.e. children, unemployed, full time employed, etc.). As a recommendation, surveys should include this type of information, at least for major appliances. On the other hand, there was some information that was not used at all, such as the secondary heating system. Nevertheless, the information gathered in the survey would definitely help getting more accurate the results.

It is important to note that the same study can be done to more the rest of the data, which means that it the same procedure can be followed to assess the rest of the dwellings (such as those built after 1964); this was not possible in this study because of the time constraint. Another option would be to do the same analysis to households with only one elderly occupant, or with lower income. The results of these assessments would definitely help alleviate fuel poverty, since many studies have shown that in the UK fuel poverty is mainly present in those dwellings.

There was one important decision taken when the scenarios were built: the dwellings that used electricity (Domestic electricity or Economy 7) as a Primary Heating Fuel were not considered. The main reason for this decision was the fact that electricity as a heating fuel is not environmentally friendly. Many studies have shown that heat generated from electricity has to be changed to another source depending on the conditions of the area where the dwelling is located. According to the survey carried out in the communities, about 35% of the households use electricity as a primary heating fuel. The impact of these dwellings has to be considered as another case study, since their carbon emissions and costs for energy are different to the ones studied in the present paper. Therefore, it is strongly recommended a further study on this subject.

Regarding the assessment of renewable generation, only wind and solar generation were considered for electricity generation; the study had to be limited to both technologies because of the software used for the study (HOMER) and the time constraint. The option of renewable generation was not considered as a community solution but as a solution for each household. Another study can be done that can approach the area of community electricity generation: This approach can be tackled as generation for the community use, and another approach as electricity generation to be sold to the grid, where money is received by the distributor for the use of the community.

Furthermore, an option that has always been interesting due to its rapid increase of use in the UK is micro combined heat and power. Studies mentioned in the third chapter have shown that the option of using combined heat power in a small scale can be very cost-effective. A whole study about this sole technology should be considered.

Finally, in order to have some further studies for the project, funding is needed. There is a list of funding options that can be explored in order to apply the recommendations or evaluate new options such as mCHP.

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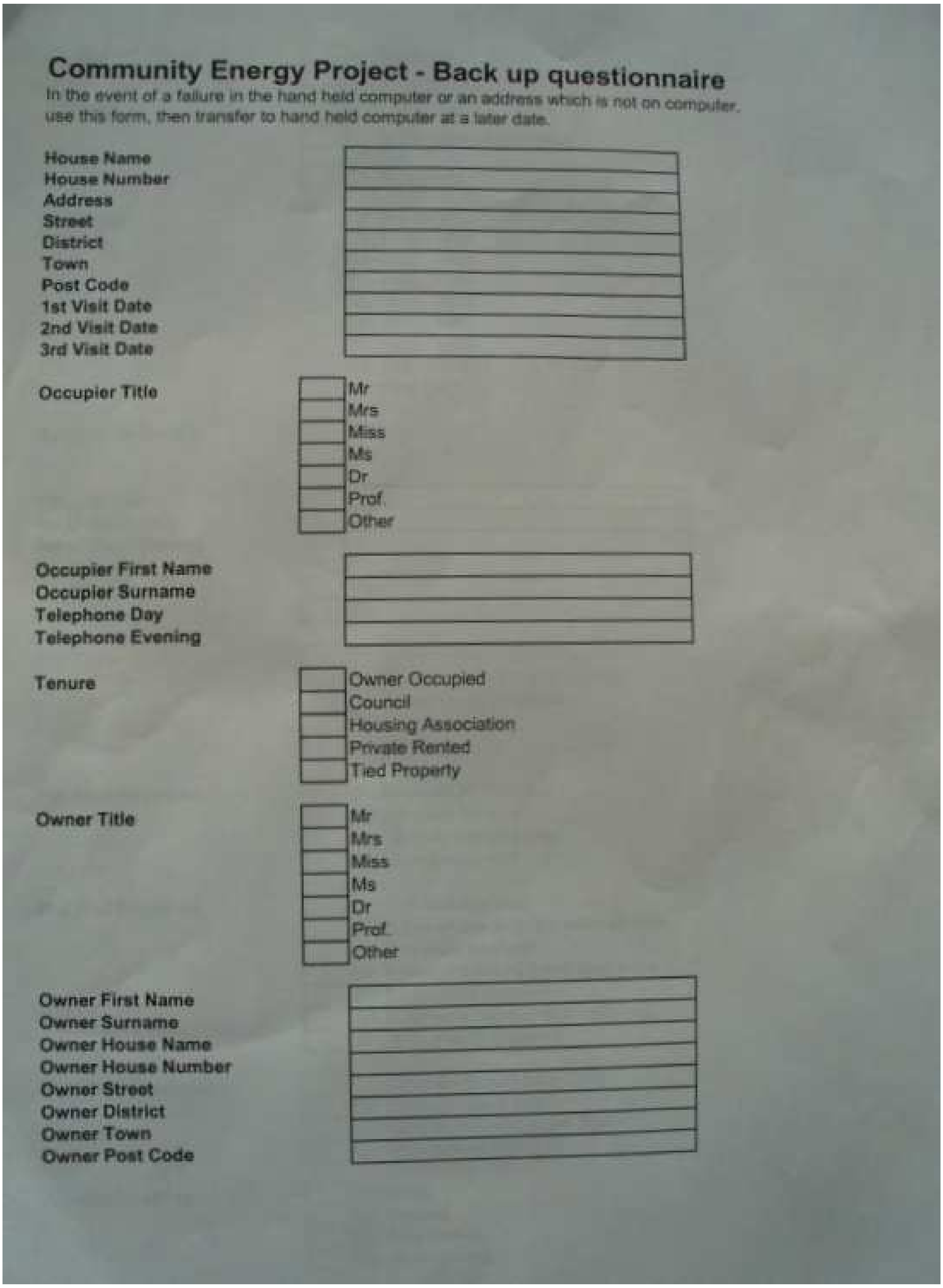
Appendix 1. Survey



Community Energy Project - Back up questionnaire

In the event of a failure in the hand held computer or an address which is not on computer, use this form, then transfer to hand held computer at a later date.

House Name
House Number
Address
Street
District
Town
Post Code
1st Visit Date
2nd Visit Date
3rd Visit Date

Occupier Title
- [ ] Mr
- [ ] Mrs
- [ ] Miss
- [ ] Ms
- [ ] Dr
- [ ] Prof.
- [ ] Other

Occupier First Name
Occupier Surname
Telephone Day
Telephone Evening

Tenure
- [ ] Owner Occupied
- [ ] Council
- [ ] Housing Association
- [ ] Private Rented
- [ ] Tied Property

Owner Title
- [ ] Mr
- [ ] Mrs
- [ ] Miss
- [ ] Ms
- [ ] Dr
- [ ] Prof.
- [ ] Other

Owner First Name
Owner Surname
Owner House Name
Owner House Number
Owner Street
Owner District
Owner Town
Owner Post Code

Built Form

- ☐ 01: Detached
- ☐ 02: Semi-detached
- ☐ 03: End of terrace
- ☐ 04: Mid terrace
- ☐ 05: Mid terrace with passage
- ☐ 06: Flat
- ☐ 07: Maisonette

Age Band

- 01: Pre 1918
- 02: 1918 - 1929
- 03: 1930 - 1949
- 04: 1950 - 1963
- 05: 1964 - 1974
- 06: 1975 - 1982
- 07: 1983 - 1990
- 08: 1991 -1997
- 09: Post 1997

Suitable for Solar

- ☐ Yes
- ☐ No

No of Storeys ____

No of Bedrooms ____

No of Other Rooms ____

No of Rooms ____

Roof Rooms

- ☐ Yes
- ☐ No

Flat Type

- ☐ 01: Tower block (> 5 storeys)
- ☐ 02: Custom block (up to 5 storeys)
- ☐ 03: Above shops or offices
- ☐ 04: Divided House
- ☐ 05: Other type

Flat Roof Exposure

- ☐ 01: Exposed pitched roof
- ☐ 02: Exposed flat roof
- ☐ 03: Partially exposed roof
- ☐ 04: Un-exposed roof

Flat Wall Exposure

- ☐ 01: One wall exposed
- ☐ 02: Between one and two walls expose
- ☐ 03: Two walls exposed
- ☐ 04: Between two and three walls expo
- ☐ 05: Three walls exposed
- ☐ 06: Between three and four walls exp
- ☐ 07: All four walls exposed

Flat Floor Exposure

- ☐ 01: Exposed ground floor
- ☐ 02: Exposed upper floor
- ☐ 03: Partially exposed upper floor
- ☐ 04: Un-exposed floor

Window Proofing

- ☐ 01: None
- ☐ 02: Minimal
- ☐ 03: Well sealed
- ☐ 04: Non-opening

Door Proofing

- ☐ 01: None
- ☐ 02: Minimal
- ☐ 03: Well Sealed
- ☐ 04: Non-opening

Window Type

- ☐ 01: Wood
- ☐ 02: Metal
- ☐ 03: Thermal
- ☐ 04: UPVC
- ☐ 05: Sash

Window Glazing

- ☐ 01: Single
- ☐ 02: Double
- ☐ 03: Triple
- ☐ 04: Double + Low E
- ☐ 05: Double + Low E Argon filled
- ☐ 06: Triple + Low E
- ☐ 07: Triple + Low E Argon filled
- ☐ 08: Double Argon filled

Roof Type

- ☐ 01: Pitched
- ☐ 02: Flat
- ☐ 03: Mixture (of flat and pitched)
- ☐ 04: Thatched

Loft Insulation (mm) ________________

Wall Type

- ☐ 01: Solid
- ☐ 02: Cavity
- ☐ 03: Timber frame
- ☐ 04: Stone

Wall Insulation (mm) ________________

Floor Insulation (mm) ________________

Prim Heat Fuel

- ☐ 01: Gas (mains)
- ☐ 02: Bulk LPG
- ☐ 03: Bottled Gas
- ☐ 04: Oil (35 sec)
- ☐ 05: Oil (28 sec)
- ☐ 06: Housecoal/pearls
- ☐ 07: Smokeless (processed)
- ☐ 08: Anthracite Nuts
- ☐ 09: Anthracite Grains
- ☐ 10: Wood
- ☐ 11: Domestic (on-peak) electricity
- ☐ 13: Economy 7 (off-peak)
- ☐ 17: Community Heating with no CHP
- ☐ 18: Community Heating with CHP

Prim Heat Sys

- [ ] 06: Community heating
- [ ] 01: Boiler system (elec)
- [ ] 02: Warm air system (elec)
- [ ] 03: Room Heaters (elec)
- [ ] 04: Storage heaters
- [ ] 05: Heat Pump on-peak(elect)
- [ ] 05: Heat Pump on-peak(elect)
- [ ] 01: Boiler system (gas)
- [ ] 02: Warm air system (gas)
- [ ] 03: Room Heaters (gas)
- [ ] 01: Boiler system (oil)
- [ ] 02: Warm air system (oil)
- [ ] 01: Boiler system (solid)
- [ ] 03: Room Heaters (solid)

Prim.Heat Code

- [ ] N/A or Other Type
- [ ] 040: Std Oil boiler (pre 1985)
- [ ] 042: Condensing Oil boiler
- [ ] 043: Std Oil boiler (1998 or later)
- [ ] 080: Open sf room heater
- [ ] 082: Open sf room heater with BB
- [ ] 083: Closed sf room heater
- [ ] 082: Closed sf room heater with BB
- [ ] 130: Modern (slimline) storage heater
- [ ] 132: Old (large vol) storage heaters
- [ ] 133: Fan assisted storage heaters
- [ ] 221: Wall-mounted boiler pre 98
- [ ] 282: Gas room heater (condensing)
- [ ] 301: Gas room heater (old)
- [ ] 304: Room heater (new) BB (no rads)
- [ ] 523: Condensing boiler >= 98
- [ ] 525: Non-condensing combi >= 98

Heating System Age

- [ ] Less Than 7 Years
- [ ] 8 - 15 Year
- [ ] More Than 15 Years

L1 Prim Heat Controls

- [ ] 01: No controls
- [ ] 02: Programmer only
- [ ] 03: Programmer & roomstat
- [ ] 04: Programmer, roomstat & TRVs
- [ ] 05: TRVs, programmer and bypass
- [ ] 06: Programmer, TRVs and flow switch
- [ ] 07: Prog.,TRVs and boiler manager
- [ ] 08: Full Zone Control
- [ ] Delay start stat and prog
- [ ] 17: Delay start stat and prog/TRV
- [ ] 20: None
- [ ] 21: Programmer only
- [ ] 22: Room thermostat only
- [ ] 23: Programmer and roomstat
- [ ] 24: Zone control
- [ ] 30: None
- [ ] 31: Appliance stat
- [ ] 32: Appliance stat and programmer
- [ ] 33: Programmer only
- [ ] 34: Programmer and room stat
- [ ] 35: Roomstat only
- [ ] 36: Time and Temp Control
- [ ] 40: Manual charge control
- [ ] 41: Auto charge control (internal)
- [ ] 42: Auto charge control (external)
- [ ] 43: Celect-type control
- [ ] 60: Flat rate- no stat
- [ ] 61: Flat rate- prog+stat
- [ ] 62: Flat rate- prog+TRVs
- [ ] 63: Link to use- prog+TRVs

Sec Heat Sys

- [ ] 000: None
- [ ] 080: Open Fire
- [ ] 083: Closed Fire
- [ ] 120: Electric
- [ ] 302: Other Gas
- [ ] 312: Gas Coal Effect

Hot Water Fuel

- [ ] 01: Gas (mains)
- [ ] 02: Bulk LPG
- [ ] 03: Bottled Gas
- [ ] 04: Oil (35 sec)
- [ ] 05: Oil (28 sec)
- [ ] 06: Housecoal/pearls
- [ ] 07: Smokeless (processed)
- [ ] 08: Anthracite Nuts
- [ ] 09: Anthracite Grains
- [ ] 10: Wood
- [ ] 11: Domestic (on-peak) electricity
- [ ] 13: Economy 7 (off-peak)
- [ ] 17: Community Heating with no CHP
- [ ] 18: Community Heating with CHP

Hot Water Sys

- ☐ 01: From boiler
- ☐ 02: Dual immersion
- ☐ 03: Single off-peak immersion
- ☐ 04: Single on-peak immersion
- ☐ 05: Electric instantaneous
- ☐ 06: Gas instantaneous (single point
- ☐ 07: Gas instantaneous (multi point)
- ☐ 08: Gas fired kitchen range
- ☐ 09: Oil fired kitchen range
- ☐ 10: Coal fired kitchen range
- ☐ 11: Gas circulator
- ☐ 23: Community Heating (with tank)
- ☐ 24: Community Heating (no tank)

Cylinder Thermostat

- ☐ Yes
- ☐ No

Cylinder Insulation

- ☐ 00: None
- ☐ 01: Jacket 12-5mm
- ☐ 02: Jacket 25mm
- ☐ 03: Jacket 50mm
- ☐ 04: Jacket 80mm
- ☐ 05: Jacket 100mm
- ☐ 06: Jacket > 100mm
- ☐ 07: Spray foam 12-5mm
- ☐ 08: Spray foam 25mm
- ☐ 09: Spray foam 37-5mm
- ☐ 10: Spray foam 50mm
- ☐ 11: Spray foam > 50mm

Low Energy Bulbs

- ☐ None
- ☐ 25%
- ☐ 50%
- ☐ 75%
- ☐ 100%

Draft Proofing Required

- ☐ Yes
- ☐ No

Cylinder Insulation Req

- ☐ Yes
- ☐ No

Cav Wall Ins Required

- ☐ Yes
- ☐ No

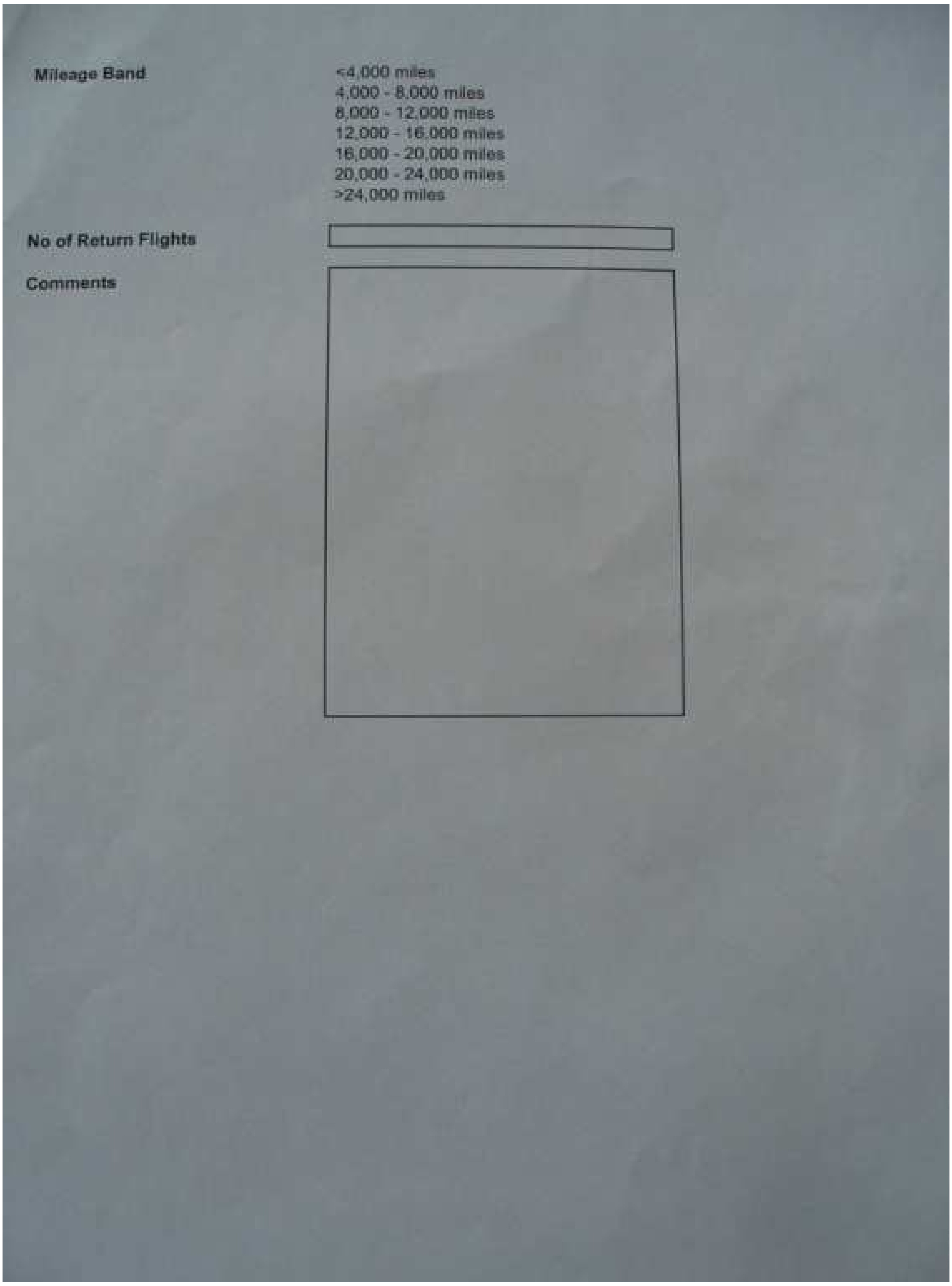
HLA Exposed Wall ____________________

Loft Ins Required

- ☐ Yes
- ☐ No

HLA Roof ____________________

Loft Ins Depth Req	☐	N/A
	☐	300mm
	☐	250mm
	☐	200mm
	☐	150mm
	☐	100mm
No of Occupants		
Over 60s	☐	Yes
	☐	No
No Retired		
No Working >16hrs		
No Working <16hrs		
No Full Time Carer		
No Unemployed		
No in Full Time Education		
No Ill Health		
No Children Not in Education		
Any Benefits	☐	Yes
	☐	No
Benefit Type	☐	None
	☐	Attendance Allowance
	☐	Child Tax Credit <£15,050 income
	☐	Council Tax Benefit
	☐	Disability Living Allowance
	☐	Disabled Person's Tax Credit
	☐	Housing Benefit
	☐	Income Based JSA
	☐	Income Support
	☐	IIDB with CAA
	☐	Pension Credit
	☐	WDP with MS or CAA
	☐	Working Tax Credit <£15,050 income
	☐	Any other benefit - please state
Other Ben, Description		
Income Advice Wanted	☐	Yes
	☐	No
Energy Application Pending	☐	Yes
	☐	No
Income Band	☐	<£100 pw (<£5,000 pa)
	☐	£100 - £200 pw (£5,000 - £10,000 pa)
	☐	£200 - £300 pw (£10,000 - £15,000 pa)
	☐	£300 - £400 pw (£15,000 - £20,000 pa)
	☐	£400 - £600 pw (£20,000 - £30,000 pa)
	☐	£600 - £900 pw (£30,000 - £45,000 pa)
	☐	> £900 pw (>£45,000 pa)
Energy Fuel Spend Last Year		



Mileage Band	<4,000 miles 4,000 - 8,000 miles 8,000 - 12,000 miles 12,000 - 16,000 miles 16,000 - 20,000 miles 20,000 - 24,000 miles >24,000 miles
No of Return Flights	
Comments	

Appendix 2. Costs Benefit tables according to Built Form [20]

Detached house or bungalow	Saving (£/yr)	Typical installed cost (£)	Payback (yrs)	Typical DIY Cost (£)	Payback (yrs)
Cavity wall insulation	£210 - £250	£300	Less than 2 years	-	-
Solid wall insulation (external)	£460 - £560	£2,300	4 - 5	-	-
Solid wall insulation (internal)	£430 - £530	From £40/m2	-	£1,900	Around 4 years
Loft insulation (new installation)	£210 - £250	£250	Less than 1 year	£330	Less than 2 years
Loft insulation (top up)	£60 - £70	£260	Around 4 years	£250	Around 4 years
Floor insulation	£60 - £70	-	-	£120	Around 2 years
Replacement condensing boiler	£130 - £160	-	-	-	-
Hot water tank insulation	Approx £20	-	-	£10	Around 6 months
Full heating control package	£70 - £90	£200	2 - 3	-	-
Draught-stripping	Approx £20	£75	Around 4 years	£45	Around 2 years
Lighting (4 x lamps)	£15 - £20	up to £15	Less than 1 year	up to £15	Less than 1 year

Semi-detached or end-of-terrace	Saving (£/yr)	Typical installed cost (£)	Payback (yrs)	Typical DIY Cost (£)	Payback (yrs)
Cavity wall insulation	£130 - £160	£260	Less than 2 years	-	-
Solid wall insulation (external)	£290 - £350	£1,800	5 - 6	-	-
Solid wall insulation (internal)	£270 - £340	From £40/m2	- - -	£1,200	Around 4 years
Loft insulation (new installation)	£180 - £220	£230	Around 1 year	£290	Less than 2 years
Loft insulation (top up)	£50 - £60	£240	4 - 5	£215	Around 4 years
Floor insulation	£40 - £50	-	-	£100	Less than 2 years
Replacement condensing boiler	£100 - £120	-	-	-	-
Hot water tank insulation	Approx £20	-	-	£10	Around 6 months
Full heating control package	£60 - £70	£200	Around 3 years	-	-
Draught-stripping	Approx £20	£75	Around 4 years	£45	Around 2 years
Lighting (4 x lamps)	£15 - £20	up to £15	Less than 1 year	up to £15	Less than 1 year

Appendix 3. Climate data for Prestwick

	Unit	Climate data location	Project location
Latitude	?N	55.5	55.5
Longitude	?E	-4.6	-4.6
Elevation	m	20	20
Heating design temperature	°C	-2.9	
Cooling design temperature	°C	21.0	
Earth temperature amplitude	°C	13.0	

Month		Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
		°C	%	$kWh/m^2/d$	kPa	m/s	°C	°C-d	°C-d
January		4.5	84.6%	0.6	99.4	5.9	1.8	419	0
February		4.7	81.8%	1.2	99.7	5.9	2.3	372	0
March		5.9	80.6%	2.2	99.6	5.6	4.5	375	0
April		7.5	77.6%	3.5	99.6	4.7	6.8	315	0
May		10.6	75.4%	4.8	99.9	4.5	10.7	229	19
June		12.9	78.6%	5.0	99.9	4.3	13.8	153	87
July		15.0	80.2%	4.6	99.9	4.2	16.3	93	155
August		14.6	80.8%	3.9	99.8	4.2	16.2	105	143
September		12.4	82.4%	2.7	99.8	4.6	12.8	168	72
October		10.0	83.3%	1.5	99.4	5.1	8.4	248	0
November		6.9	84.0%	0.7	99.4	4.9	4.7	333	0
December		5.1	85.4%	0.4	99.5	5.3	2.6	400	0
Annual		9.2	81.2%	2.6	99.7	4.9	8.4	3,210	476
Measured at	m					10.0	0.0		

Appendix 4. Demand Load Profiles data for all the Scenarios

Demand load profile Scenario I

Electrical		Heating	
Hour	Load kW	Hour	Load kW
01:00	0.0358	01:30	2.447
02:00	0.0358	02:30	2.709
03:00	0.0358	03:30	3.123
04:00	0.0358	04:30	3.340
05:00	0.2327	05:30	3.446
06:00	0.4152	06:30	3.506
07:00	1.2119	07:30	4.760
08:00	0.4990	08:30	6.363
09:00	0.0358	09:30	3.354
10:00	0.0358	10:30	1.590
11:00	0.0358	11:30	1.444
12:00	0.0358	12:30	1.336
13:00	0.0358	13:30	3.744
14:00	0.0358	14:30	5.486
15:00	0.0358	15:30	5.494
16:00	0.0358	16:30	4.627
17:00	1.0083	17:30	4.587
18:00	1.8473	18:30	4.810
19:00	1.7327	19:30	5.033
20:00	1.4336	20:30	5.206
21:00	1.8802	21:30	5.336
22:00	1.5170	22:30	5.433
23:00	0.6562	23:30	5.506
00:00	0.0358	00:30	3.719

Demand load profile Scenario II

Electrical		Heating	
Hour	Load kW	Hour	Load kW
01:00	0.0135	01:30	1.8671
02:00	0.0135	02:30	2.1086
03:00	0.0135	03:30	2.4771
04:00	0.0135	04:30	2.6957
05:00	0.0520	05:30	2.8143
06:00	0.1753	06:30	2.8686
07:00	0.4726	07:30	3.9786
08:00	0.1856	08:30	4.9929
09:00	0.0135	09:30	2.5500
10:00	0.0135	10:30	1.4129
11:00	0.0135	11:30	1.2743
12:00	0.0135	12:30	1.1643
13:00	0.0135	13:30	3.2000
14:00	0.0135	14:30	4.5643
15:00	0.0135	15:30	4.4914
16:00	0.0135	16:30	3.9057
17:00	0.2849	17:30	3.9800
18:00	0.8021	18:30	4.2629
19:00	0.6547	19:30	4.0343
20:00	0.5638	20:30	3.7143
21:00	0.6863	21:30	3.8014
22:00	0.5601	22:30	3.8657
23:00	0.2305	23:30	3.9243
00:00	0.0135	00:30	2.6814

Demand load profile Scenario III

Electrical		Heating	
Hour	Load kW	Hour	Load kW
01:00	0.0135	01:30	0.9529
02:00	0.0135	02:30	0.9629
03:00	0.0135	03:30	1.0700
04:00	0.0135	04:30	1.2029
05:00	0.0453	05:30	1.2643
06:00	0.1621	06:30	1.2657
07:00	0.5011	07:30	2.3157
08:00	0.1797	08:30	3.1129
09:00	0.0135	09:30	1.8771
10:00	0.0135	10:30	1.3571
11:00	0.0135	11:30	1.2571
12:00	0.0135	12:30	1.2300
13:00	0.0135	13:30	2.5057
14:00	0.0135	14:30	3.3671
15:00	0.0135	15:30	3.4471
16:00	0.0135	16:30	3.1600
17:00	0.3012	17:30	3.1514
18:00	0.7796	18:30	3.1943
19:00	0.6651	19:30	2.7786
20:00	0.5701	20:30	2.3414
21:00	0.6956	21:30	2.3543
22:00	0.5400	22:30	2.3671
23:00	0.2424	23:30	2.3857
00:00	0.0135	00:30	1.9514

Appendix 5. Simulations Output - HOMER

Scenario I

Wind (m/s)	OR Solar (%)		OR Wind (%)	PV (kW)	G1	G3	Gen1(kW)	Battery	Converter (kW)		Initial capital		Total NPC
($/kWh)	Renewable fraction		Natural gas (m3)	Gen1 (hrs)									
4.500	25	50		2	3.2	4	2.4	$ 4,710	$ 26,572	0.448	0.55	1,317	1,296
4.500	25	100		2	3.2	4	2.4	$ 4,710	$ 26,758	0.452	0.55	1,327	1,311
4.500	25	75		2	3.2	4	2.4	$ 4,710	$ 26,683	0.450	0.55	1,323	1,305
4.500	0	50		2	3.2	4	2.4	$ 4,710	$ 26,572	0.448	0.55	1,317	1,296
4.500	0	100		2	3.2	4	2.4	$ 4,710	$ 26,758	0.452	0.55	1,327	1,311
4.500	0	75		2	3.2	4	2.4	$ 4,710	$ 26,683	0.450	0.55	1,323	1,305
4.500	50	50		2	3.2	4	2.4	$ 4,710	$ 26,572	0.448	0.55	1,317	1,296
4.500	50	100		2	3.2	4	2.4	$ 4,710	$ 26,758	0.452	0.55	1,327	1,311
4.500	50	75		2	3.2	4	2.4	$ 4,710	$ 26,683	0.450	0.55	1,323	1,305
4.000	25	50		2	3.2	4	2.4	$ 4,710	$ 28,555	0.482	0.42	1,474	1,440
4.000	25	100		1	3.2	4	2.4	$ 2,910	$ 28,625	0.483	0.25	1,632	1,589
4.000	25	75		1	3.2	4	2.4	$ 2,910	$ 28,631	0.483	0.25	1,632	1,589
4.000	0	50		2	3.2	4	2.4	$ 4,710	$ 28,555	0.482	0.42	1,474	1,440
4.000	0	100		1	3.2	4	2.4	$ 2,910	$ 28,625	0.483	0.25	1,632	1,589
4.000	0	75		1	3.2	4	2.4	$ 2,910	$ 28,631	0.483	0.25	1,632	1,589
4.000	50	50		2	3.2	4	2.4	$ 4,710	$ 28,555	0.482	0.42	1,474	1,440
4.000	50	100		1	3.2	4	2.4	$ 2,910	$ 28,625	0.483	0.25	1,632	1,589
4.000	50	75		1	3.2	4	2.4	$ 2,910	$ 28,631	0.483	0.25	1,632	1,589
5.000	25	50		3	3.2	24	2.4	$ 8,010	$ 24,606	0.415	0.87	508	512
5.000	25	100		3	3.2	24	2.4	$ 8,010	$ 24,606	0.415	0.87	508	512
5.000	25	75		3	3.2	24	2.4	$ 8,010	$ 24,606	0.415	0.87	508	512
5.000	0	50		3	3.2	24	2.4	$ 8,010	$ 24,606	0.415	0.87	508	512
5.000	0	100		3	3.2	24	2.4	$ 8,010	$ 24,606	0.415	0.87	508	512
5.000	0	75		3	3.2	24	2.4	$ 8,010	$ 24,606	0.415	0.87	508	512
5.000	50	50		3	3.2	24	2.4	$ 8,010	$ 24,606	0.415	0.87	508	512
5.000	50	100		3	3.2	24	2.4	$ 8,010	$ 24,606	0.415	0.87	508	512
5.000	50	75		3	3.2	24	2.4	$ 8,010	$ 24,606	0.415	0.87	508	512
5.500	25	50		2	3.2	24	2.4	$ 6,210	$ 22,595	0.381	0.86	507	512
5.500	25	100		2	3.2	24	2.4	$ 6,210	$ 22,580	0.381	0.86	506	511
5.500	25	75		2	3.2	24	2.4	$ 6,210	$ 22,595	0.381	0.86	507	512
5.500	0	50		2	3.2	24	2.4	$ 6,210	$ 22,595	0.381	0.86	507	512
5.500	0	100		2	3.2	24	2.4	$ 6,210	$ 22,580	0.381	0.86	506	511
5.500	0	75		2	3.2	24	2.4	$ 6,210	$ 22,595	0.381	0.86	507	512
5.500	50	50		2	3.2	24	2.4	$ 6,210	$ 22,595	0.381	0.86	507	512
5.500	50	100		2	3.2	24	2.4	$ 6,210	$ 22,580	0.381	0.86	506	511
5.500	50	75		2	3.2	24	2.4	$ 6,210	$ 22,595	0.381	0.86	507	512
6.000	25	50		2	3.2	24	2.4	$ 6,210	$ 20,742	0.350	0.91	368	385
6.000	25	100		2	3.2	24	2.4	$ 6,210	$ 20,808	0.351	0.91	373	390
6.000	25	75		2	3.2	24	2.4	$ 6,210	$ 20,742	0.350	0.91	368	385
6.000	0	50		2	3.2	24	2.4	$ 6,210	$ 20,742	0.350	0.91	368	385
6.000	0	100		2	3.2	24	2.4	$ 6,210	$ 20,808	0.351	0.91	373	390
6.000	0	75		2	3.2	24	2.4	$ 6,210	$ 20,742	0.350	0.91	368	385
6.000	50	50		2	3.2	24	2.4	$ 6,210	$ 20,742	0.350	0.91	368	385
6.000	50	100		2	3.2	24	2.4	$ 6,210	$ 20,808	0.351	0.91	373	390
6.000	50	75		2	3.2	24	2.4	$ 6,210	$ 20,742	0.350	0.91	368	385
6.500	25	50		2	3.2	24	2.4	$ 6,210	$ 19,478	0.329	0.94	278	304
6.500	25	100		2	3.2	24	2.4	$ 6,210	$ 19,478	0.329	0.94	278	304
6.500	25	75		2	3.2	24	2.4	$ 6,210	$ 19,478	0.329	0.94	278	304
6.500	0	50		2	3.2	24	2.4	$ 6,210	$ 19,478	0.329	0.94	278	304
6.500	0	100		2	3.2	24	2.4	$ 6,210	$ 19,478	0.329	0.94	278	304
6.500	0	75		2	3.2	24	2.4	$ 6,210	$ 19,478	0.329	0.94	278	304
6.500	50	50		2	3.2	24	2.4	$ 6,210	$ 19,478	0.329	0.94	278	304
6.500	50	100		2	3.2	24	2.4	$ 6,210	$ 19,478	0.329	0.94	278	304
6.500	50	75		2	3.2	24	2.4	$ 6,210	$ 19,478	0.329	0.94	278	304
7.000	25	50		2	3.2	24	2.4	$ 6,210	$ 18,880	0.319	0.96	238	273
7.000	25	100		2	3.2	24	2.4	$ 6,210	$ 18,880	0.319	0.96	238	273
7.000	25	75		2	3.2	24	2.4	$ 6,210	$ 18,880	0.319	0.96	238	273
7.000	0	50		2	3.2	24	2.4	$ 6,210	$ 18,880	0.319	0.96	238	273
7.000	0	100		2	3.2	24	2.4	$ 6,210	$ 18,880	0.319	0.96	238	273
7.000	0	75		2	3.2	24	2.4	$ 6,210	$ 18,880	0.319	0.96	238	273

7.000	50	50	2	3.2	24	2.4	$ 6,210	$ 18,880	0.319	0.96	238	273
7.000	50	100	2	3.2	24	2.4	$ 6,210	$ 18,880	0.319	0.96	238	273
7.000	50	75	2	3.2	24	2.4	$ 6,210	$ 18,880	0.319	0.96	238	273

Scenario II

Wind (m/s)	OR Solar (%)		OR Wind (%)	PV (kW)	G1	G3	Gen1(kW)	Battery	Converter (kW)		Initial capital		Total NPC	COE
($/kWh)	Renewable fraction		Natural gas (m3)	Gen1 (hrs)										
4.500	25	50		2	3.2	4	2.4	$ 4,710	$ 20,975	0.474	0.64	922	910	
4.500	25	100		2	3.2	4	2.4	$ 4,710	$ 20,975	0.474	0.64	920	910	
4.500	25	75		2	3.2	4	2.4	$ 4,710	$ 20,947	0.474	0.64	920	908	
4.500	0	50		2	3.2	4	2.4	$ 4,710	$ 20,975	0.474	0.64	922	910	
4.500	0	100		2	3.2	4	2.4	$ 4,710	$ 20,975	0.474	0.64	920	910	
4.500	0	75		2	3.2	4	2.4	$ 4,710	$ 20,947	0.474	0.64	920	908	
4.500	50	50		2	3.2	4	2.4	$ 4,710	$ 20,975	0.474	0.64	922	910	
4.500	50	100		2	3.2	4	2.4	$ 4,710	$ 20,975	0.474	0.64	920	910	
4.500	50	75		2	3.2	4	2.4	$ 4,710	$ 20,947	0.474	0.64	920	908	
4.000	25	50		1	3.2	4	2.4	$ 2,910	$ 22,300	0.504	0.31	1,179	1,148	
4.000	25	100		1	3.2	4	2.4	$ 2,910	$ 22,461	0.508	0.31	1,186	1,160	
4.000	25	75		1	3.2	4	2.4	$ 2,910	$ 22,314	0.504	0.31	1,180	1,149	
4.000	0	50		1	3.2	4	2.4	$ 2,910	$ 22,300	0.504	0.31	1,179	1,148	
4.000	0	100		1	3.2	4	2.4	$ 2,910	$ 22,461	0.508	0.31	1,186	1,160	
4.000	0	75		1	3.2	4	2.4	$ 2,910	$ 22,314	0.504	0.31	1,180	1,149	
4.000	50	50		1	3.2	4	2.4	$ 2,910	$ 22,300	0.504	0.31	1,179	1,148	
4.000	50	100		1	3.2	4	2.4	$ 2,910	$ 22,461	0.508	0.31	1,186	1,160	
4.000	50	75		1	3.2	4	2.4	$ 2,910	$ 22,314	0.504	0.31	1,180	1,149	
5.000	25	50		2	3.2	4	2.4	$ 4,710	$ 19,203	0.434	0.74	788	784	
5.000	25	100		2	3.2	4	2.4	$ 4,710	$ 19,308	0.437	0.74	795	792	
5.000	25	75		2	3.2	4	2.4	$ 4,710	$ 19,248	0.435	0.74	792	788	
5.000	0	50		2	3.2	4	2.4	$ 4,710	$ 19,203	0.434	0.74	788	784	
5.000	0	100		2	3.2	4	2.4	$ 4,710	$ 19,308	0.437	0.74	795	792	
5.000	0	75		2	3.2	4	2.4	$ 4,710	$ 19,248	0.435	0.74	792	788	
5.000	50	50		2	3.2	4	2.4	$ 4,710	$ 19,203	0.434	0.74	788	784	
5.000	50	100		2	3.2	4	2.4	$ 4,710	$ 19,308	0.437	0.74	795	792	
5.000	50	75		2	3.2	4	2.4	$ 4,710	$ 19,248	0.435	0.74	792	788	
5.500	25	50		2	3.2	4	2.4	$ 4,710	$ 17,924	0.405	0.81	694	697	
5.500	25	100		2	3.2	4	2.4	$ 4,710	$ 18,019	0.407	0.81	698	704	
5.500	25	75		2	3.2	4	2.4	$ 4,710	$ 17,990	0.407	0.81	697	702	
5.500	0	50		2	3.2	4	2.4	$ 4,710	$ 17,924	0.405	0.81	694	697	
5.500	0	100		2	3.2	4	2.4	$ 4,710	$ 18,019	0.407	0.81	698	704	
5.500	0	75		2	3.2	4	2.4	$ 4,710	$ 17,990	0.407	0.81	697	702	
5.500	50	50		2	3.2	4	2.4	$ 4,710	$ 17,924	0.405	0.81	694	697	
5.500	50	100		2	3.2	4	2.4	$ 4,710	$ 18,019	0.407	0.81	698	704	
5.500	50	75		2	3.2	4	2.4	$ 4,710	$ 17,990	0.407	0.81	697	702	
6.000	25	50		2	3.2	4	2.4	$ 4,710	$ 16,784	0.379	0.86	611	619	
6.000	25	100		2	3.2	4	2.4	$ 4,710	$ 16,917	0.382	0.86	618	629	
6.000	25	75		2	3.2	4	2.4	$ 4,710	$ 16,771	0.379	0.86	610	618	
6.000	0	50		2	3.2	4	2.4	$ 4,710	$ 16,784	0.379	0.86	611	619	
6.000	0	100		2	3.2	4	2.4	$ 4,710	$ 16,917	0.382	0.86	618	629	
6.000	0	75		2	3.2	4	2.4	$ 4,710	$ 16,771	0.379	0.86	610	618	
6.000	50	50		2	3.2	4	2.4	$ 4,710	$ 16,784	0.379	0.86	611	619	
6.000	50	100		2	3.2	4	2.4	$ 4,710	$ 16,917	0.382	0.86	618	629	
6.000	50	75		2	3.2	4	2.4	$ 4,710	$ 16,771	0.379	0.86	610	618	
6.500	25	50		1	3.2	4	2.4	$ 2,910	$ 15,762	0.356	0.77	683	685	
6.500	25	100		1	3.2	4	2.4	$ 2,910	$ 15,972	0.361	0.77	695	701	
6.500	25	75		1	3.2	4	2.4	$ 2,910	$ 15,877	0.359	0.77	690	694	
6.500	0	50		1	3.2	4	2.4	$ 2,910	$ 15,762	0.356	0.77	683	685	
6.500	0	100		1	3.2	4	2.4	$ 2,910	$ 15,972	0.361	0.77	695	701	
6.500	0	75		1	3.2	4	2.4	$ 2,910	$ 15,877	0.359	0.77	690	694	
6.500	50	50		1	3.2	4	2.4	$ 2,910	$ 15,762	0.356	0.77	683	685	
6.500	50	100		1	3.2	4	2.4	$ 2,910	$ 15,972	0.361	0.77	695	701	
6.500	50	75		1	3.2	4	2.4	$ 2,910	$ 15,877	0.359	0.77	690	694	
7.000	25	50		1	3.2	4	2.4	$ 2,910	$ 14,834	0.335	0.81	616	622	
7.000	25	100		1	3.2	4	2.4	$ 2,910	$ 15,022	0.340	0.81	626	636	
7.000	25	75		1	3.2	4	2.4	$ 2,910	$ 14,847	0.336	0.81	616	623	
7.000	0	50		1	3.2	4	2.4	$ 2,910	$ 14,834	0.335	0.81	616	622	
7.000	0	100		1	3.2	4	2.4	$ 2,910	$ 15,022	0.340	0.81	626	636	
7.000	0	75		1	3.2	4	2.4	$ 2,910	$ 14,847	0.336	0.81	616	623	
7.000	50	50		1	3.2	4	2.4	$ 2,910	$ 14,834	0.335	0.81	616	622	
7.000	50	100		1	3.2	4	2.4	$ 2,910	$ 15,022	0.340	0.81	626	636	
7.000	50	75		1	3.2	4	2.4	$ 2,910	$ 14,847	0.336	0.81	616	623	

Scenario III

Wind (m/s) ($/kWh)	OR Solar (%) Renewable fraction		OR Wind (%) Natural gas (m3)	PV (kW) Gen1 (hrs)	G1	G3	Gen1(kW)	Battery	Converter (kW)		Initial capital		Total NPC	COE
4.500	25	50		1	3.2	4	2.4	$ 2,910	$ 20,975	0.474	0.43	1,079	1,052	
4.500	25	100		2	3.2	4	2.4	$ 4,710	$ 21,017	0.475	0.64	923	913	
4.500	25	75		2	3.2	4	2.4	$ 4,710	$ 20,976	0.474	0.64	922	910	
4.500	0	50		1	3.2	4	2.4	$ 2,910	$ 20,975	0.474	0.43	1,079	1,052	
4.500	0	100		2	3.2	4	2.4	$ 4,710	$ 21,017	0.475	0.64	923	913	
4.500	0	75		2	3.2	4	2.4	$ 4,710	$ 20,976	0.474	0.64	922	910	
4.500	50	50		1	3.2	4	2.4	$ 2,910	$ 20,975	0.474	0.43	1,079	1,052	
4.500	50	100		2	3.2	4	2.4	$ 4,710	$ 21,017	0.475	0.64	923	913	
4.500	50	75		2	3.2	4	2.4	$ 4,710	$ 20,976	0.474	0.64	922	910	
4.000	25	50		1	3.2	4	2.4	$ 2,910	$ 22,440	0.507	0.31	1,187	1,158	
4.000	25	100		1	3.2	4	2.4	$ 2,910	$ 22,517	0.509	0.31	1,190	1,164	
4.000	25	75		1	3.2	4	2.4	$ 2,910	$ 22,422	0.506	0.31	1,185	1,157	
4.000	0	50		1	3.2	4	2.4	$ 2,910	$ 22,440	0.507	0.31	1,187	1,158	
4.000	0	100		1	3.2	4	2.4	$ 2,910	$ 22,517	0.509	0.31	1,190	1,164	
4.000	0	75		1	3.2	4	2.4	$ 2,910	$ 22,422	0.506	0.31	1,185	1,157	
4.000	50	50		1	3.2	4	2.4	$ 2,910	$ 22,440	0.507	0.31	1,187	1,158	
4.000	50	100		1	3.2	4	2.4	$ 2,910	$ 22,517	0.509	0.31	1,190	1,164	
4.000	50	75		1	3.2	4	2.4	$ 2,910	$ 22,422	0.506	0.31	1,185	1,157	
5.000	25	50		2	3.2	4	2.4	$ 4,710	$ 19,232	0.434	0.74	790	786	
5.000	25	100		2	3.2	4	2.4	$ 4,710	$ 19,338	0.437	0.74	797	794	
5.000	25	75		2	3.2	4	2.4	$ 4,710	$ 19,278	0.435	0.74	794	790	
5.000	0	50		2	3.2	4	2.4	$ 4,710	$ 19,232	0.434	0.74	790	786	
5.000	0	100		2	3.2	4	2.4	$ 4,710	$ 19,338	0.437	0.74	797	794	
5.000	0	75		2	3.2	4	2.4	$ 4,710	$ 19,278	0.435	0.74	794	790	
5.000	50	50		2	3.2	4	2.4	$ 4,710	$ 19,232	0.434	0.74	790	786	
5.000	50	100		2	3.2	4	2.4	$ 4,710	$ 19,338	0.437	0.74	797	794	
5.000	50	75		2	3.2	4	2.4	$ 4,710	$ 19,278	0.435	0.74	794	790	
5.500	25	50		2	3.2	4	2.4	$ 4,710	$ 17,939	0.405	0.81	695	698	
5.500	25	100		2	3.2	4	2.4	$ 4,710	$ 18,035	0.407	0.81	699	705	
5.500	25	75		2	3.2	4	2.4	$ 4,710	$ 17,993	0.406	0.81	697	702	
5.500	0	50		2	3.2	4	2.4	$ 4,710	$ 17,939	0.405	0.81	695	698	
5.500	0	100		2	3.2	4	2.4	$ 4,710	$ 18,035	0.407	0.81	699	705	
5.500	0	75		2	3.2	4	2.4	$ 4,710	$ 17,993	0.406	0.81	697	702	
5.500	50	50		2	3.2	4	2.4	$ 4,710	$ 17,939	0.405	0.81	695	698	
5.500	50	100		2	3.2	4	2.4	$ 4,710	$ 18,035	0.407	0.81	699	705	
5.500	50	75		2	3.2	4	2.4	$ 4,710	$ 17,993	0.406	0.81	697	702	
6.000	25	50		2	3.2	4	2.4	$ 4,710	$ 16,785	0.379	0.86	611	619	
6.000	25	100		2	3.2	4	2.4	$ 4,710	$ 16,904	0.382	0.86	617	628	
6.000	25	75		2	3.2	4	2.4	$ 4,710	$ 16,770	0.379	0.86	610	618	
6.000	0	50		2	3.2	4	2.4	$ 4,710	$ 16,785	0.379	0.86	611	619	
6.000	0	100		2	3.2	4	2.4	$ 4,710	$ 16,904	0.382	0.86	617	628	
6.000	0	75		2	3.2	4	2.4	$ 4,710	$ 16,770	0.379	0.86	610	618	
6.000	50	50		2	3.2	4	2.4	$ 4,710	$ 16,785	0.379	0.86	611	619	
6.000	50	100		2	3.2	4	2.4	$ 4,710	$ 16,904	0.382	0.86	617	628	
6.000	50	75		2	3.2	4	2.4	$ 4,710	$ 16,770	0.379	0.86	610	618	
6.500	25	50		1	3.2	4	2.4	$ 2,910	$ 15,803	0.357	0.77	685	688	
6.500	25	100		1	3.2	4	2.4	$ 2,910	$ 15,950	0.360	0.77	694	699	
6.500	25	75		1	3.2	4	2.4	$ 2,910	$ 15,893	0.359	0.77	691	695	
6.500	0	50		1	3.2	4	2.4	$ 2,910	$ 15,803	0.357	0.77	685	688	
6.500	0	100		1	3.2	4	2.4	$ 2,910	$ 15,950	0.360	0.77	694	699	
6.500	0	75		1	3.2	4	2.4	$ 2,910	$ 15,893	0.359	0.77	691	695	
6.500	50	50		1	3.2	4	2.4	$ 2,910	$ 15,803	0.357	0.77	685	688	
6.500	50	100		1	3.2	4	2.4	$ 2,910	$ 15,950	0.360	0.77	694	699	
6.500	50	75		1	3.2	4	2.4	$ 2,910	$ 15,893	0.359	0.77	691	695	
7.000	25	50		1	3.2	4	2.4	$ 2,910	$ 14,835	0.335	0.81	616	622	
7.000	25	100		1	3.2	4	2.4	$ 2,910	$ 15,049	0.340	0.81	628	638	
7.000	25	75		1	3.2	4	2.4	$ 2,910	$ 14,849	0.335	0.81	616	623	
7.000	0	50		1	3.2	4	2.4	$ 2,910	$ 14,835	0.335	0.81	616	622	
7.000	0	100		1	3.2	4	2.4	$ 2,910	$ 15,049	0.340	0.81	628	638	
7.000	0	75		1	3.2	4	2.4	$ 2,910	$ 14,849	0.335	0.81	616	623	
7.000	50	50		1	3.2	4	2.4	$ 2,910	$ 14,835	0.335	0.81	616	622	
7.000	50	100		1	3.2	4	2.4	$ 2,910	$ 15,049	0.340	0.81	628	638	
7.000	50	75		1	3.2	4	2.4	$ 2,910	$ 14,849	0.335	0.81	616	623	