Department of Mechanical Engineering

Decision Making Framework and Financial Tool For Hybrid Energy System Microgrids

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Abstract

There is a global push towards decreasing the carbon being emitted into the atmosphere from the way that people live. Generation of energy is moving from traditional large centralised plant burning fossil fuels towards more decentralised lower carbon means of generating energy. New incentives such as feed in tariffs and carbon trading make it possible to earn income from reducing carbon emissions. Microgrids have the potential to allow small communities, businesses and organisations to generate their own energy and reduce their carbon emissions and earn income from doing so.

Microgrids must meet engineering demands such as matching demands and having low carbon emissions. However, measures required to make an effective investment for a financier are different. This can mean that often potentially good hybrid energy systems in terms of sustainability would not have the necessary incentives for attracting investment. Investors will want to be assured that a project has potential to give them return on investment.

This document investigates the factors that are important for the optimal selection of hybrid energy systems for use in microgrid applications. Project will consider the both the technical measures involved in the selection of hybrid energy systems and the necessary financial requirements for successful investment.

Document develops a decision-making framework and an economic judgement tool that allows more informed decision-making to be made by investors and stakeholders in selection of hybrid energy system microgrid projects.

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Table of Contents

Table of Figures

Table of Tables

Table of Equations

1. Introduction

1.1. Background

There is global push towards reducing carbon being emitted into the atmosphere created through the way that people live and work. At the forefront of this push is the move from producing energy through traditional centralised means using fossil fuels such as coal and gas towards decentralised production using low carbon sources such as wind turbines and photovoltaics (Alanne & Saari 2006).

Governments throughout the world are taking great steps to reduce their carbon that they emit (Nations 1998). The UK has very strict aims in this regard, Scotland in particular; which has a stated aims to move towards 100% renewable energy production by 2020 (Government 2010). Fuel and electricity cost volatility is a large factor in this move as well as older generating plant being decommissioned. With recent price rises showing a general trend of increasing, taking a more diversified approach to energy supply would seem to be a sensible option (Mackay 2009).

The use of renewables and low carbon energy sources such as CHP systems is seen as an effective option of allowing organisations and groups to lower emissions (DTI 2003). As communities and businesses look for more ways to mitigate the effect of volatile energy markets and reduce carbon emissions the use of hybrid energy systems such as wind turbines and photovoltaics in combination as part of small microgrid applications is becoming an increasingly attractive as a method of meeting energy needs (Council 2005).

Organisations that take advantage of hybrid energy systems to provide their energy needs have the opportunity to generate income from energy that they produce through feed-in tariffs as well as having the opportunity to sell any surplus energy they produce back to the grid (DECC 2010). A recent development that has the potential to further increase the attractiveness of a hybrid energy system microgrid is the adoption of carbon markets that allow energy consumers and produces to buy and sell rights to CO2 emissions (Union 2009). There is massive opportunity to earn money if an organisation or community can reduce emissions. It is important to note that the appeal and attractiveness of such a microgrid scheme rests on the potential outcome for key stakeholders in the project (Council 2005). Organisations will want to see their energy demands met, their CO2 emissions reduced and the grids producing energy at high efficiency with low waste. Investors on the other hand will want to see completely different criteria from a scheme such as potential income, profit, suitable capital costs and incentives available (Short & Packey 1995).

Due to the conflicting interests of stakeholders, finding a scheme that can meet all parties' demands is a difficult task; a system that performs well on the engineering side may cost far too much and not provide enough income on the financial side meaning that there will be no investment (Government 2010). There are two sides that are important in the implementation of successful microgrid and it is difficult to keep all stakeholders completely happy with everything. For this reason, having the ability to bring the stakeholders needs together to find the optimal outcome for all is an important consideration and finding appropriate methodology to do this is essential (Government 2010).

For large energy consumers such as Universities and industry, there is a real financial impetus to drive forward reductions; failure to reduce carbon emissions could mean penalties to an organisation. Penalties such as the UKs Carbon Reduction Commitment (Capture 2012), which charges consumers for the CO2 that is being consumed for energy needs, are examples of this.

The importance of microgrids will be increased as organisations seek better means of energy reduction through embracing decentralised energy systems to provide energy (March 2010). Organisations that do not take steps to reduce their emissions will be behind the curve of the current technological trends and will have to pay to balance the effects caused from utilising fossil fuel derived energy.

1.2. Policy Drivers

There are several key policy drivers that are pushing forward the development of hybrid energy system microgrids in the UK with Scotland in particular providing stringent strategic aims.

1.2.1. Renewables

The Scottish government aims to make renewables an integral part of the Scottish economy, the aim is that 100% of all Scottish energy needs will be derived from renewable means by 2020 (Government 2010). The old method of having large centralised power stations fuelled by fossil fuels will be gone and greater adaption of decentralised grids will be the future of the industries. This is a seriously strict aspiration that will need a lot of investment to be realised, with the use of carbon markets and incentives the investment in hybrid energy microgrid schemes could form part of this requirement.

1.2.2. Financial Incentives

Further to this policy both the UK government and Scottish government support a system of feed in tariffs that seek to incentivise the development of renewable technologies by private consumers. Feed-In-Tariffs (FITs) and Renewable Heat Incentives (RHIs) allow generators of low carbon energy to earn a sum of money for every kilowatt hour produced (DECC 2011a; DECC 2010)

Generators that produce energy that is surplus to their needs also have the opportunity to sell that energy that they produce to the national grid thus allowing for further income streams.

Incentives	Generation Tariff	Duration
Energy System	**(£/kwh)**	**(Yr.)**
Wind Turbine <1.5kw	£0.36	20.00
Wind Turbine > 15-100kw	£0.25	20.00
Wind Turbine100kw-500kw	£0.20	20.00
Wind Turbine500kw-1MW	£0.10	20.00
Photovoltaics 4-10kw	£0.38	20.00
Photovoltaics 10-100kw	£0.33	20.00
Photovoltaics >100kw	£0.31	20.00
Heat Pump 0-100kw	£0.45	20.00
Heat Pump >100kw	£0.32	20.00
Biomass 0-200kw	£0.08	20.00
Biomass 200-1000kw	£0.05	20.00
Biome thane	£0.07	20.00
Export Tariff	£0.03	20.00

Table 1, Feed In Tariff and Renewable Heat Incentive rates (Anon 2012)

1.2.3. Carbon Trading

Carbon trading is the process of dealing in the rights to emit carbon dioxide (CO2) into the atmosphere (Gledhill et al. 2008). Governments set the limit for carbon dioxide to be emitted and emitters must buy and sell allowances for the right to emit carbon. Emitters are provided with a number of allowances to emit CO2 into the environment and if they exceed this limit they will have to buy additional allowances to make up for this (Union 2009).

The emission of CO2 has become a big issue with countries aiming to reduce their carbon emissions to reduce the effects of climate change. The carbon market cap system is seen as a way of pressing carbon emitters to find means to lower their emissions through energy efficiency measures (Gledhill et al. 2008). As time goes on there will be lower availability of allowances due to government CO2 reduction measures, this will mean the value will increase as the demand increases necessitating improvements as scarcity grows.

Emitters who can successfully lower their emissions however will be able to sell on allowances at the carbon market to other emitters and generate profit from that. There is a large impetus for improving the way that carbon emitters operate.

1.2.4. Carbon Markets

One of the most important policy drivers that have the potential to increase the use of microgrids is the development of worldwide carbon markets that allow entities to buy and sell carbon allowances. This is part of a “cap and trade” system that is set at the country level, whereby the country may only emit a set value of carbon into the environment (Linares et al. 2008). Organisations within the country are presented with carbon allowances, one carbon allowance unit being set as 1 metric ton of Co2 emissions.

Organisations receive a set limit of CO2 emissions for the year that they must meet, if they manage to reduce their carbon emissions they can sell allowances on the market, however if they go over their limit they must buy allowances to meet their emissions. The market value of carbon allowances can be a fixed value, guaranteeing the value of a unit for a set number of years. Value can also be market based, relying on supply and demand on the open market to provide the price and potentially could be very lucrative(Gledhill et al. 2008).

Global value of carbon markets is rising at a rapid pace, currently the global carbon market is valued at €92 billion and has been rising since its introduction (Reuters 2011) .The European market trading is currently the largest taking up largest share of the markets. Carbon markets are still in their early stages of implementation but are still proving valuable, it is clear that they have huge potential for being valuable commodities in the future and there is a possible profit that could be made for groups who exploit it (Agency 2010).

There is a large financial incentive presented by renewable incentives and carbon trading that can be exploited if carried out in the correct manner, microgrids are a good example of this.

1.3. Legislative Drivers

The global community sees the threat of global warming as having potentially catastrophic effects on the way that human beings live on the planet, to address this issue they have put into place a number of legislative drivers for change. At the forefront of this is the push towards the development and greater use of sustainable energy generation methods within the UK and the world.

Legislation covers the wide strategic global worldwide aims of the international community to reduce the effects of climate change and increase sustainable production as well as the more focussed local aims at the country level.

1.3.1. Global Legislation

The United Kingdom has signed up to the Kyoto Protocol (Nations 1998), which is a legally binding agreement that has a stated aim to reduce carbon emissions produced by nations. The aim of the agreement is to reduce the carbon emissions of member nations by 5.2% of 1990 levels by 2012.

UK has also signed up to the Copenhagen accord (Conference 2009) which was developed to be the successor to the Kyoto Protocol. However it is not legally binding but has the aims to reduce CO2 emissions further with the EU including the UK aiming for a reduction of 20-30% of 1990 emissions by 2030. Further to this provision was provided to allow for carbon emissions to be traded as a commodity on the open market as a vehicle for carbon reduction. This part of the treaty forms a substantial driving force to the greater use of microgrids as a means to produce energy and allow energy consumers to earn money on reductions that are made.

1.3.2. European Legislation

The European community as a whole has taken the lead towards a more sustainable future by employing strict legislative demands to make progress. To meet the demands set by the global community, the European union has created laws that seek to improve upon the emissions reductions promised globally. Legislation such as the 20-20-20 policies (Barroso 2008), which seeks to reduce green house gasses and primary energy consumption by 20%, while increasing the use of lower carbon renewable technologies by 20%. Legislation also promotes a European emissions trading scheme as one of the key methods to reduce CO2 emissions.

1.3.3. UK Legislation

UK has set stringent targets for the future to reduce carbon emissions; further to the 20-20-20 plan by the European Union, the Climate Change Act (Parliament 2008) that aims to lower carbon emission. A target decrease of 80% from baseline levels by 2050 has been set with the aim of significantly lowering the carbon intensity of the United Kingdom. These targets are some of the tightest in the EU and will require significant effort to be met successfully.

Scotland has taken this policy even further with the Climate Change (Scotland) Act (Art 2010) in an effort to seriously reduce carbon emissions with an aspiration to reduce carbon emissions by 42% by 2020 achieved largely through the decarbonisation of energy supply. Looking further to the future, similar legislative targets to the UK parliament with an 80% reduction in carbon emissions from the base level by 2050.

The Energy Performance Buildings Directive (Ilmarinen 2010) is another piece of legislation that has implications for the adaption of hybrid energy systems. This legislation requires that buildings fitting certain criteria must publish an energy certificate within the building that shows the energy rating of the building. The use of renewable energy systems is seen as a positive method to provide decentralised energy and allows the building to achieve a better rating (CIBSE 2003). As a greater number of organisations are striving towards more improved energy consumption the adaptation of low carbon energy systems applied to microgrids could be an important factor.

Another piece of legislation that seek to address the issue of global warming is the Carbon Reduction Commitment that is due to come into force for organisations who spend over £0.5million on energy every year (Capture 2012). This is a mandatory scheme that forces large energy consumers to take advantage of energy savings or have to pay penalties for failing to do so by having to buy allowances at fixed price per carbon unit to emit (DECC 2010). Large energy consumers must measure their energy usage through the use of half hourly metering for their electricity and thermal needs, they will then have to report energy consumption to the governing authority of the scheme. It is for this reason that it will be incredibly difficult to avoid making the savings necessary, as the true effects of organisations consumption will be apparent from the monitoring. The CRC scheme is essentially a carrot or stick system whereby organisations who do take advantage of energy savings will gain from investments and not face any penalty for failing. This scheme is part of the UK governments plan for reducing the level of CO_2 being sent into the atmosphere as this enforces a cap on emissions being emitted into the atmosphere (DTI 2003).

Clearly the task of meeting these targets will require a large level of investment and change within the country if these goals are to be met. The use of microgrids could be one of the weapons that could be applied to aid the reduction of carbon emissions within the United Kingdom and Scotland. However investments in this field are difficult to define and the ability to ensure investment security is important for the continued development of microgrids (DTI 2003).

1.4. Technological Drivers

Technology plays an important part in driving forward the increasing use of microgrids, as newer processes are adopted to improve the energy efficiency of the way energy is sourced and produced.

1.4.1. Microgrids

A microgrid is a system where energy is produced locally to supply local loads that are connected to the microgrid (Epri 2002). The microgrid is often connected to low carbon and renewable energy systems that generate energy to meet the demands of the loads connected to the grid (Sakis 2002). A microgrid can be applied at a small level, a single building for example, up to providing energy for large communities such as towns, villages and Islands (F J Born et al. n.d.).As microgrids produce energy on-site it is possible for heating demands to be met through the by-product of electricity generation when using cogeneration plant such as CHP (Mackay 2009).

Microgrids are decentralised from the traditionally centralised grid and can be considered as a single entity apart, however microgrids can be connected to the centralised grid allowing for import and export of energy to occur (Farhangi 2010). This allows microgrids to be considered as a source of highly reliable power, they can produce energy locally when it is possible, selling on any surplus to the grid and draw from the grid when there is a deficit in supply locally. Further to this microgrids can take advantage of storage technologies such as batteries and hot water storage systems to increase the efficiency of the energy produced (Marnay et al. 2007). It is for this reason microgrids are being considered as one of the more important developments for future energy production.

1.4.2. Hybrid Energy Systems

A Hybrid energy system is a combination of low carbon energy technologies that are combined to provide energy for a demand. Hybrid energy systems are often employed in microgrids; consist of renewables such as wind turbines, solar photovoltaics and low carbon plant such as combined heat and power systems to provide energy to meet demands. The vision behind the use of hybrid energy systems is that the whole is greater than the sum of its parts (Burch 2001). The combination of different sources allows for a greater efficiency of supply due to the fact that they all generate energy from different sources and this means that another can negate any limitations of a device.

The use of hybrid energy systems has increased recently with the push towards more low carbon generation and fears that fuel prices could rise. There are a number of ways that hybrid energy systems can be combined; however energy delivered by systems is dependant on the climate and the location that they are situated in.

1.4.3. Smart Metering

The development and application of smart metering could be an important factor in the future application and approach taken with regard to hybrid energy systems. The ability to accurately collect energy consumption data will allow policy makers and engineers to make better decisions is designing microgrids and will mean that they can be more assured in the outcome.

The great benefit of the predicted mass utilisation of smart metering is that with better knowledge of what is really going on, steps can be made to make improvements. With effective monitoring an organisation will be able to accurately predict energy needs and use this to size energy systems such as wind turbines to meet their demands. Smart Metering will also allow better comparisons to be made of the financial implications of an organisation receiving energy from grid or with decentralised technologies. With better understanding of the consumption of energy it will be easier for interested parties to see how much energy is being wasted and apply the necessary measures to make savings (DECC 2011b).

1.4.4. Smart Grids and Distributed Generation

The use of distributed generation has been increasing as the benefits are becoming more apparent; there is a movement from centralised generation towards spread out distributed generation. There is a movement towards greater reliance on distributed generation to provide the energy needs of the country, which directly influences the use of microgrids. There are benefits to providing energy locally to consumers make it worthwhile. The ability to generate energy locally will allow for cheaper transportation of fuels and greater implementation of the hybrid technologies that can be exploited in distributed areas. A greater push towards new features such as district heating from the use of cogeneration plant such as CHP will also provide impetus for more distributed energy generation.

Smart grids can are also a major driver for the use of microgrids for localised supply of energy due. The drive towards low carbon energy sources will require a greater deal of control over the way that grids are operated, moving from centralised grids towards decentralised ones.

With the increased adaptation of smart microgrids there will be noticeable benefits for the consumer. (Farhangi 2010) Asserts that as consumers have more control of the energy through decentralised smart grids they will be able to take a more active role in energy reduction.

1.5. Issues

Despite the varied range of drivers that are pushing for a greater development in microgrid systems, there are a number of barriers that could potentially hold back the growth.

1.5.1. Capital Costs

One of the key factors that could hold back the greater development of low carbon energy systems is the capital costs involved in setting up the investment. Capital costs involved in setting up a Microgrid are likely to be a major factor and are significant to investors when considering implementation (Pudjianto et al. 2005). Further to this, fuel-burning technologies are seen as a more economic option compared to potential renewable energy systems options that available. Greater employment of renewable technologies will rely on economies of scale to reduce the costs involved in setting up and purchasing these technologies (Sakis 2002).

1.5.2. Fuel Price

Fuel costs are important to microgrids due to the need for these to be provided for fuel consuming plant. CHP plant requires different fuels to operate and is reliant on the costs of the fuel being low enough to make using CHP plant economic. Fuel prices have been increasing over the past 10 years and are being forecasted to carry on doing so into the future. This has the potential to reduce the use of fuel burning plant as investors and engineers opt to go for more conventional means of power generation to avoid potential costs (DTI 2004).

1.5.3. Carbon Market Value

Investment in microgrids and the low carbon energy systems that are used in them is costly and will require that some method is available to provide income for this. Carbon markets have potential to drive the issue forward but they also could provide potential barriers to their use also. Carbon markets are a relatively new factor and are in their early stages of development, it is uncertain at this stage whether they will be sustainable in the long term. Additionally there is limited evidence that suggests that financing projects through selling carbon allowances on the market would be an effective method (Hill et al. 2008).

Volatility of the value of carbon allowances on the market price is also a potential barrier to greater implementation of microgrids. There is a degree of uncertainty for future prices due to the power of regulatory bodies limiting the number of allowances available. This control could cause the prices to rise dramatically through limiting, however if too many allowances are available prices will be lower which will cause the potential profit from schemes to decrease (Gledhill et al. 2008).

1.6. Summary

1.6.1. Policy Drivers

Government policies are providing impetus for the development of hybrid energy system microgrids in the United Kingdom. The drive for increased use of renewable energy systems to provide for the energy and their development away from the traditional centralised grids will mean that microgrids will become more popular.

Financial incentives will play a large part in driving forward this development with the government's use of FITs as a means of attracting investment in low carbon technologies to provide for the demands. Further incentive to invest and develop microgrid sites is the expansion of the carbon allowance markets that provide investors with real opportunity to make a profit on low carbon ventures.

1.6.2. Legislative Drivers

To summarise, there is a number legislative drivers that are pushing forward the increased use of hybrid energy systems for use in microgrid applications. There are global steps being taken such as the Kyoto and Copenhagen agreements as well as strict European efforts that are being to reduce CO2 emissions. The United Kingdoms legislative efforts show there is clearly a desire to make good on the global aims and take them even further with stricter targets for the future.

With legislation such as the Carbon Reduction Commitment and the Energy Performance Buildings Directive it can be said that there is a large impetus for communities, businesses and organisations to take advantage of cleaner energy technology and reduce their carbon emissions.

1.6.3. Technological Drivers

Technology is a major driver in the greater expansion of low carbon microgrids to provide energy; newer ideas and techniques provide a stimulus to improve the way that energy is sourced. Low carbon energy system usage will benefit directly from the greater implantation of distributed generation and smart grids in the energy mix.

With greater awareness of how energy is consumed through the use of smart metering, investors and consumers will be able to accurately predict their energy use. This will allow them to utilise newer methods of generation such as microgrids to precisely meet their demands. More accurate energy data from this will also mean that more evidence can be provided to investors on the potentials profits from adopting hybrid energy systems in microgrids.

1.6.4. Issues

There are issues that could possibly impede the development and greater implementation of hybrid energy system microgrids. It is important to ensure that a potential microgrid scheme is an affordable option for an investor; high capital costs can obstruct investment opportunities. There is a reliance on the economies of scale to drive the prices of hybrid energy system devices to a level where it would be acceptable to invest.

Schemes requiring fuel to provide energy could face rising costs due to volatile fuel markets. Investors will want to be assured that any future price increases would not have an effect on the financial outcome of the project, without this there will be too much uncertainty. Carbon markets are in the early stages of development, it is important that these markets are seen to have stability into the future to ensure return on investment into the future.

1.7. Research Focus

As stated above, the selection of the energy systems that are used in the microgrid is incredibly important when attempting to develop an effective system. The microgrid must be suitable for both the engineering needs of the system such as meeting demands and efficiency and meet the financial needs. To this end, research focused on the following factors:

1. How engineering and financial dynamics can assessed and be combined
2. How microgrid schemes can be ranked
3. How potential risk factors can be assessed

The overarching issue in this document is how a combination of hybrid energy systems can be evaluated so that all factors are taken into account. To find what schemes are going to be effective microgrid for the user. Research also looks into a method of ranking a microgrid financially in terms of how investors would perceive the benefits and risks of a scheme.

1.7.1. Overall Research Aim

There are three main research areas that are part of this study; an in-depth literature review that assesses the current trends and knowledge, the development of a methodology that allows potential investors in hybrid energy system microgrids to make informed decisions and the development of a financial tool that can be used in conjunction with the methodology and common energy demand/supply matching appraisal software such as Merit to assess the value of individual projects. The financial tool is developed using a spreadsheet model that takes into account all financial constraints and also gives the user an indication of potential risk involved in the scheme.

The overall research aim of this document is to push forward the current understanding of hybrid energy system microgrids in particular the process behind the selection of devices to be used in the microgrid, advancing a clear methodology that can be applied towards future projects allowing them to assess in terms of financial effectiveness. Including this, a detailed analysis will be carried out on the current driving forces behind the adoption of microgrids to produce power and heating for communities, businesses and organisations. An exploration of the barriers to further development in this field will also be carried out to find areas that could cause issue with progress.

1.7.2. Methodology Aims

Methodology development seeks to take into account all stages of the design and specification process and take a logical approach to the selection of devices in the microgrid. Through application of this methodology it should be possible for an investor to find a viable scheme for a microgrid, assess the economics and finally assess possible risks that could be issues in the future. It is important to set out a straightforward and concise set of procedures that can be followed by focussing on the salient points that are necessities for stakeholders in the organisation.

1.7.3. Tool Aims

In order to apply this methodology effectively it is important to utilise tools that available and develop new ones that can aid in decision-making. Merit software is used to find the correct combination of renewables for a systems energy demands, this will be used in combination with the development of a financial assessment tool that allows the stakeholder to assess the financial outcomes of schemes developed using Merit. Through utilisation of the methodology along with the software tools, it should be possible to find the best combination of renewables and CHP for a given scheme.

2. Hybrid Energy Systems Feasibility

2.1. Factors for successful microgrid

The first step to consider is the renewable technologies that can be applied to a site; some may not be feasible due to space available or not having enough of the energy resource to be exploited. Examination of the site will allow a decision to be made as to the selection of technologies; for example, if there is a river available possible hydro schemes can be assessed.

The next step is to examine the demands that are required on the scheme; this is achieved by taking into account the half hourly electrical and thermal demands of the proposed scheme. With this data it is possible to assess the capacity that would be needed to meet the demands on the system. This is important as the costs involved in setting up plant and infrastructure for a scheme are expensive, an investor will want to know exactly what they need to spend to meet the demands. Engineers who scope out the microgrid will want to make sure they can provide the correct energy supply and not need to add extra to meet loads.

Once the energy demands are understood it will be practical to consider the combinations of renewables that can be used to meet this demand. This step can be achieved by using a suitable tool to find the best combination for the engineering need. Further questions can then be asked on the scheme such as would CHP be an effective choice if used with system or is it possible to operate without it.

Refinement of the scheme can now take place to consider factors such as CHP duty cycles to improve fuel efficiency of the system and take into consideration possible thermal and electrical storage options that could improve the operation. At this stage analysis should be carried out to assess how well the system matches the requirements of the site and the demands. If a scheme is found to perform well on the factors that highlight a good microgrid then it has potential to be invested in.

2.2. Engineering Expectations

Engineering constraints for a successful microgrid are important to be met, the hybrid energy systems must be meeting these requirements to guarantee supply of electricity. The following factors are important in examination and discovery of an effective scheme using Merit:

- Match Rate
- Energy Surplus
- Energy Deficit
- Fuel Consumption
- CO2 Emissions

2.2.1. Match Rate

The match rate metric is used as a measure of how well a combination of low carbon technologies matches the demands created by the buildings being examined. This equation carried out in Merit provides a percentage value of how well the proposed system matches the requirements of the demands; a 100% match meets the demands of the scheme without any deficit. When considering what schemes are better than others, higher match rates should be looked on positively as it shows a greater ability to meet the demands.

2.2.2. Energy Surplus

If the scheme being analysed provides a large surplus of energy produced beyond the needs of the demands it will be possible to sell this back to the grid. However if a potential scheme is found to produce far too much surplus energy it can be said that it is not meeting the requirements of the scheme and is not matching the demands. A balance has to be found where by the financial benefits of selling to the grid is optimised through the needs to the demand

2.2.3. Energy Deficit

Schemes that have an energy deficit will have to source energy from the grid to meet their demands; a good microgrid scheme seeks to meet the demands of the system as accurately as possible. If there is a large deficit that has to be derived from other energy sources such as the grid then the microgrid is not considered to be as good a match as one that does meet the demands.

2.2.4. Fuel Consumption

Fuel consumed in the process of generating energy to meet the demands on the microgrid is important. Where fuels are consumed on site they will produce CO2 that will be emitted into the atmosphere and with the current price volatility of fuels such as gas and oil, it is important that scheme does not rely too heavily on the use of fuels to provide energy. To avoid this problem schemes can use a greater proportion of renewable energy supplies to make up the demand thus lowering the demands on CHP. However with the unreliable nature of renewables that rely on the weather and climate to generate energy this can be difficult to avoid. Fuel consumption can also be improved by taking advantage of different duty cycles, which utilise the CHP plant in a more efficient manner.

2.2.5. CO2 Emissions

This is an important metric for a microgrid scheme; the low carbon energy systems used must combine to provide a reduction in carbon emissions for the installation to be worthwhile. The ability to reduce the CO2 emissions of a site is potentially a profitable enterprise and therefore should be taken advantage of. Schemes with good carbon reductions should be considered as potential financial investments. Fuel consumption has an effect on the CO2 emissions made by the scheme from plant such as CHP. Schemes wishing to reduce their CO2 should avoid using too high a ratio of fuel burning plant to zero carbon renewables, as they will produce more.

2.3. Factors for successful investment

Investors in microgrids are interested in a number of opportunities that may be presented by a microgrid system. Investors are interested in the economic value of a potential scheme and the costs involved in setting one up. The initial capital cost is important, as it must be within the reasonable limits, if the capital cost of implementing a scheme is too high it will not be a successful scheme. Further to this, the scheme must provide sufficient income to the investor to payback the initial capital outlay. Most importantly however, it is necessary that the scheme will provide sufficient profit to make it worth the investment in the first place (Owens 2002).

Investors are concerned with the following factors:

- Capital Costs
- Running Costs
- Income
- Net Present Value
- Payback Time
- Rate of Return
- Profitability Index
- Future Value
- Investment Risks

2.3.1. Capital Costs

The capital costs of a scheme are important to the investor as they put a value to the level of investment that they will have to inject into a project for it to be realised. Level of investment required to put into place the hybrid energy systems microgrid is important to an investor who has to be assured that they can afford to implement the scheme.

If the scheme is found to be too expensive then it will be ignored for a more economical option. However the investor will want to weigh this against the potential income that could be derived from the scheme over the projects life. A scheme may cost more than another but this could benefit to a greater extent from feed in tariff incomes and as such be a better option for the investor in the long run.

2.3.2. Running Costs

Costs of operating a scheme are also important to a microgrid investor, they will want to know the how much money will be required to pay for fuel for CHP plant or how much maintenance on the scheme will cost. As well as this the investor will want to know the capital repayments that will be required to pay off any loans taken to gain capital.

Investors will be concerned with the return on the investment that they are making, costs that have to be paid to run the scheme could have an negative effect on this. It is important that the see the effect of changes to costs on the value of their investment.

2.3.3. Income

As well as running costs the investor will want to know what income streams can be generated by the microgrid and how much this is worth to them yearly. Incomes derived through feed in tariffs and selling carbon emission allowances on the markets will have to meet provide enough for the investor to see a return on their investment.

The investor will also want to consider what the effects of the value of income streams changing positively or negatively would have on the outcome of their investment in the long run.

2.3.4. Payback Time

If the scheme was to be implemented it is important for an investor to know how long it will take for the investment to payoff the initial capital outlay. Through payback time the investor can assess different schemes in terms of the number of years it takes to clear the investment. Investors can use their judgement based on the outcome, for example a microgrid with a shorter payback may be favoured over a longer term.

A shorter payback period could mean that the system was a better investment for a financier, as it would mean that the investment would begin producing a profit for the investor sooner and mean that there would be a lower risk of losing money on the project if it were to fail before the end of the project life.

2.3.5. Rate of Return

This metric allows the investor to assess at a glance whether or not the investment will be worthwhile over the project period. This metric provides the investor a percentage of the value of the money gained or lost during a project. If this value is negative then overall project return of investment will be negative which an investor will want to avoid at all costs. The size of the return of the project will also be important to the investor, if it is not high enough, the investor will want to consider the risk involved and possibly avoid this scheme in favour of another (Owens 2002).

2.3.6. Profitability Index

The profitability index (PI) of a scheme is a useful factor for an investor to consider as it provides the investor with a ratio of the investment made against payoff received from a project. This ratio will provide the investor with an idea of whether the project is worth investing in or not.

A PI rating of less than 1 highlights to the investor that the investment may not be worth investing, with ratios greater than 1 highlighting increasing payoff values of the project (Owens 2002).

2.3.7. Future Value

The future value of the microgrid investment is the value of the project at the end of the project life this takes into account of interest over the years to provide the end value of the investment. This metric provides the investor with insight into what their initial investment will be worth at the end of the project life.

2.3.8. Investment Risks

Finally the investor will want to have an understanding of the risks involved in making an investment in a microgrid system for this scheme. They must be able to understand what factors will have an effect on the value of the microgrid so that they can have a better picture of what is important to secure their investment.

Further to this the investor will wish to be able to judge the risk of the investment as a whole against the profit. They will want to see if the investment is high, medium and low risk as well as how the profit will match up to this risk valuation. For example an investor may consider a high risk scheme if it will provide a high profit margin but will able to avoid schemes that are high risk, low profit.

2.3.9. Importance

With large sums of capital being needed to put into place a microgrid scheme it is extremely important that they perform financially so that the investment is paid back correctly and the investor sees return on the money spent. It must be clear to the investor that the return received is better than simply having the money earning interest in the bank.

For microgrid schemes to be attractive for potential financiers they must be able to clearly see the financial benefits of making an investment in such a scheme. They must be able to assess a scheme in terms of the key factors in making an investment decision. They will have their own criteria such as a limit to capital or minimum return on investments that schemes will have to meet before they decide to invest.

3. Approaches and Models

3.1. Approaches

Carrying out feasibility on microgrid sites relies on the methodology that is taken to scope out the needs of a site, for example how the demand is generated or the selection of low carbon devices to be used. There have been a number of different approaches taken to assess the feasibility of implementing hybrid energy system microgrids to a site. These feasibility studies are taken to find a methodology to provide the correct approach for the sizing and type of systems that will be connected to the microgrid.

(Herman 2001) takes the approach of estimating a peak demand of a site based on the number of consumers connected to the grid and then selecting low carbon energy systems to meet the demand. This approach utilises reliability analysis to assess whether the devices connected to the grid will meet the demand on the grid from the consumers. (Hoff et al. 1997.) Uses a similar methodology through estimation of loads and reliability, capacity for the scheme is developed through calculating an approximation of the capacity required meeting demands. This approach is unreliable however as it does not utilise detailed data and is an overly simplified method of assessing the feasibility of a microgrids needs with the design being an approximation.

(F.J. Born 2001) Advocates the use of demand supply matching through the use of demand profiles developed from measurement using half hourly meters and applied to climate data that can be use to predict operation of low carbon technologies at a site. This method is far more reliable as it uses real energy demands and representative climate data to provide a more accurate representation of the microgrid system.

A Financial feasibility approach that could be taken to analyse renewable energy projects economically is suggested by the GreenX project (Cleijne 2004). The project recommends the use of sensitivity analysis to address the issue of variability in future financial outcomes. As well as this the project recommends providing an investor with an indication of risk involved in a project to allow for better decisions to be made.

3.2. Software Models

There are some models that are currently available for the simulation and analysis of microgrid systems that take into account factors such as demand, climate conditions and finance.

3.2.1. Merit

Merit energy tool developed by the University of Strathclyde and allows the user to carry out analysis of renewable energy schemes through the use of demand profiles. Feasibility analysis using merit is through demand/supply matching that seeks to find energy supply devices that can be used to meet demand from the consumer. Merit uses built-in climate data that is used in conjunction with demand profiles with data resolution down to half hourly for electrical and thermal consumption that have been specified by the user.

Merit allows the user to create possible scenarios of renewables and CHP systems and attempt to match them to the defined demand. Merit allows the analysis of a number of renewable systems such as wind turbines, photovoltaics, heat pumps and CHP that can be used in different combinations to meet the demand. Merit uses climate data along with combinations of selected renewables then outputs the results of utilising this system in terms of energy deficit, energy surplus, CO2 consumption and fuel consumption among others. This allows the user to, at a glance, examine the possible effects of implemented the scenario as a microgrid.

However Merit has limited functionality in terms of financial or economic analysis meaning that further analysis is necessary to assess whether or not a scenario is good for investment or not.

3.2.2. RETScreen

RETScreen developed by the Canadian Government that allows users to carry out analysis on low carbon energy system projects. RETScreen allows the user to assess the feasibility of a scheme financially using built in financial analysis. The tool also has risk and sensitivity analysis available for the user to allow for improved decision making when selecting schemes.

Unlike Merit, RETScreen utilises monthly thermal and electrical data that analyses annual results for a single system. Users can select project templates and apply relevant data to find out how effective a scheme will be if realised.

A microgrid feasibility study was carried out to assess potential site using RETScreen at Ashton Hales school in Chester, England that would provide energy for the school and local area (Consulting 2009). Feasibility study utilised RETScreen to carry out demand/supply matching analysis for potential devices for the site based on measured data for wind speed and weather data. Load profile for a typical house was obtained and scaled up to provide demand profile for the site. Economic feasibility for this site was carried out using a spreadsheet model that focussed on energy being sold to the grid.

This microgrid feasibility study is an effective one to an extent, however load profiles utilised are estimations that have been scaled up and this will not improve the accuracy of the analysis. Further to this, monitoring of energy data such as wind speeds took place over a short period and is assumed as being similar all year round. In terms of financial assessment there is little analysis on the sensitivity of the project or the financial risks involved in carrying the project.

3.2.3. Homer

Homer developed by National Renewable Energy Laboratory used to carry out analysis on off-grid and connected low carbon energy systems. It allows the user to analyse the electrical characteristics of implementing renewables into buildings and microgrids. Homer allows for hourly data resolution for analysis to be carried out on demands by simulating the energy production of energy systems every hour.

Homer allows the user to find out the performance of selected devices on the system and analyse the annual performance. Homer carries out simulations on a system and provides an optimised list of the best possible outcomes based on annual and operating costs of running a system over its lifecycle.

Feasibility study using Homer was carried out to find a microgrid that could supply energy for a large hotel in Australia (Dalton et al. 2009). Homer was used to find a scheme that would economically fit the site. Local climate data was used alongside detailed energy data for the hotel to carry out analysis. Economic analysis was carried out using Homers sensitivity analysis function to assess potential payback times. Further to this, the case study assessed the future cash flows of the project over 20 years.

This case study is an effective one; the data used is detailed and relevant to the site and economic analysis considers the potential changes in value that could occur if costs and incomes change.

3.2.4. Approaches and Models Summary

Approaches taken to find out the feasibility of a project is important as the accuracy of an approach will determine how accurate the outcome of the study is and how well it will relate to the real operation of the microgrid. Data that is available on the site is important, as the demands that the scheme will have on the microgrid supply will have to match as closely as possible. Estimation of demands is possible, however this is an approach that will lead to inaccuracies in the outcome. A better approach is to utilise real data that has been monitored over a period of time to get a better picture of a schemes requirements and find the best combination of devices to meet the demands.

The software models that are currently available to be used to carry out feasibility studies on microgrids each have different features that can be employed to improve decision-making. The models are able to carry out analysis on a microgrid system are capable of providing effective analysis on the engineering side with detailed investigation possible into the energy demand and supply matching.

With respect to the financial assessment capabilities of the models RETScreen is the leader in this respect with detailed feasibility analysis possible on microgrid schemes. Homer also provides the ability to analyse simulations to find the lowest cost option from the output. Both these tools provide the ability to carry out sensitivity analysis on projects and allow risks to be assessed in the analysis.

Merit on the other hand does not have the capability to provide financial analysis of scenarios that are developed using the demand supply matching. Merit has a gap in its ability to aid in the greater use and development of low carbon microgrids due to the fact that it cannot provide financial analysis. Merit has the some of the most in-depth features to provide analysis but has no way to improve an investor's view of a project. There is a need to provide a tool that can take advantage of the potential of Merit and provide financial analysis that can be used to inform Merit users on what schemes are effective and which ones will be good options for investment.

4. Microgrid Feasibility Framework

4.1. Decision Making Framework

The steps taken to find a good microgrid for an a given scheme are important as they will decide whether or not a scheme is going to meet the needs of all the stakeholders or only manage to meet some of their demands. As discussed in the in the previous chapters, the requirements of stakeholders in hybrid energy system microgrids are varied and diverse. The approach taken in a carrying out a feasibility study of potential microgrids cannot just focus on meeting the demands, as stated before, the scheme must be viable financially too so that it can be considered a sound investment and have a greater chance of being implemented.

There is a need to find a middle ground of all the desires of the stakeholders, a joined-up approach to the way that schemes are imagined from the initial feasibility stage onwards. To this aim, the following joined-up methodology detailing steps necessary to be addressed to ensure that a stakeholder in a scheme makes an effective decision. This methodology has been developed to work in conjunction with Merit energy software and the financial decision aid tool to allow the best decision to be made.

4.2. Framework Process

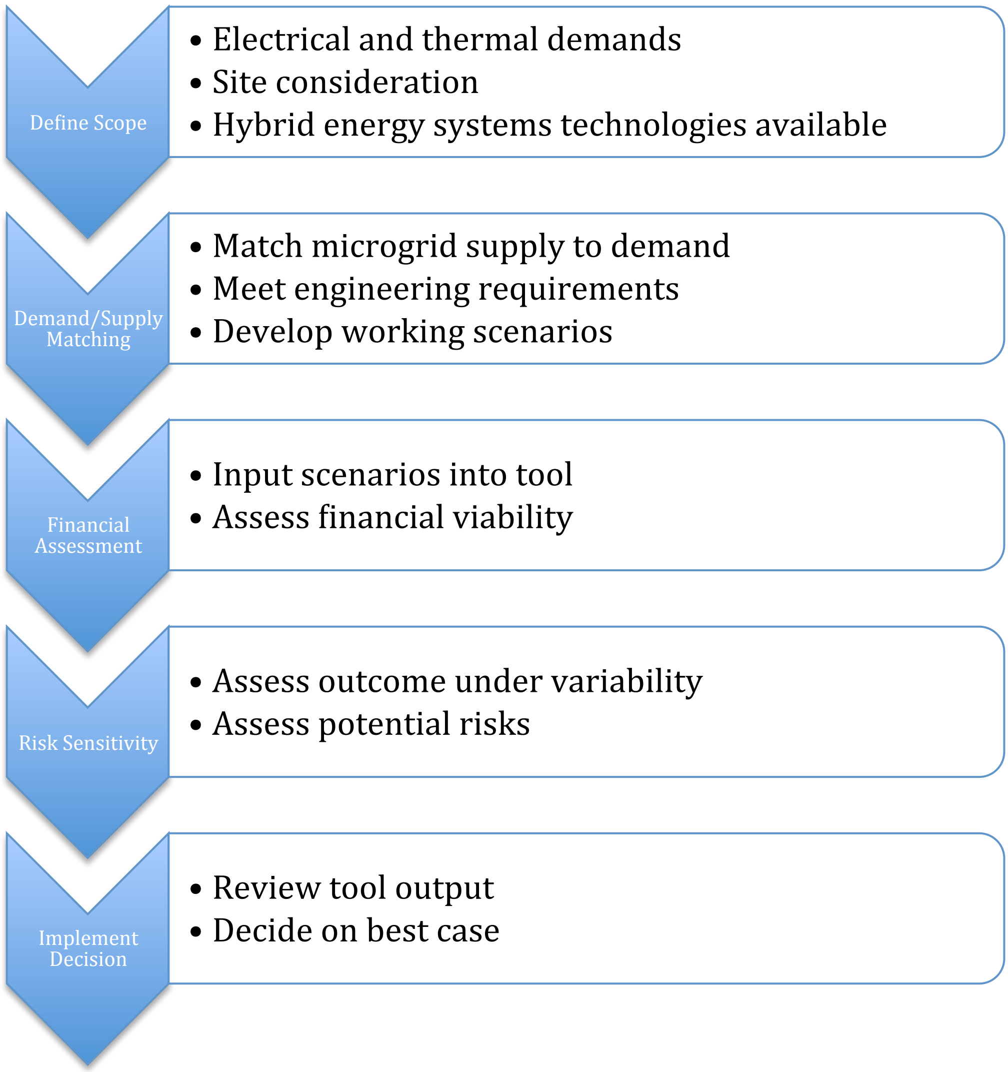

Figure 1, Methodology Process

4.2.1. Define Scope

The first stage in the methodology is to define the scope of the scheme, this requires the stakeholder to consider what sort of technologies can be applied to the site as well as considering the available space that implement hybrid energy systems. Further to this detailed demand profiles of the energy consumption should be prepared for the loads so that they can be analysed.

4.2.2. Demand/Supply Matching

The next stage in applying the methodology is to utilise a feasibility tool such as Merit to find a number of possible scenarios that could be applied to meet the organisations demands. This analysis should focus on the engineering characteristics that are needed for the microgrid to be successful; good match rate, low energy deficit, reduced CO2 etc. At this stage in the methodology any financial considerations are not taken into account, focus is on finding scenarios that only meet the required engineering demands. The benefit of using tools such as Merit is that they allow the user to match a number of scenarios quickly and see what outcomes can be found.

Once a number of possible scenarios for a successful microgrid are found using Merit the next step is apply the data gained from this process into a financial tool that will assess the financial benefits of the system.

4.2.3. Financial Assessment

The next stage in the methodology should be carried out once a number of potential scenarios have been identified in Merit. There must be analysis of the financial potentials of a project to allow an investor to judge the benefits and pitfalls of investing in such a scheme. This is achieved through the use of an Excel financial decision aid tool that has been developed to allow the user to examine how good an investment that has proven engineering benefits in Merit is for them.

Assessment of the potential financial incentives of the scheme should be made in the first place. The questions that should be asked is will the scheme provide enough incentive for the investor to provide sufficient profit and will it be financially viable? At this stage the system being assessed should be assured of its energy producing ability and the only concern for the stakeholder of this project is whether or not it is a good investment or not.

When considering the income gained from investment in microgrid projects in this analysis, there is a reliance on producing profit via carbon allowance market selling.

Carbon markets are expanding a rapid rate at the moment and values of carbon allowances has been increasing year on year. However, carbon markets are a new feature in energy economics and is still considered to be an emerging factor. If the carbon markets were to be replaced or axed at any point this would have an effect on the attractiveness and viability of such a scheme. An important issue for potential investors and interested stakeholders in a microgrid scheme is whether incentives such as FITs will allow for enough profit to be made to make an investment viable? Analysis should be carried out to assess the financial effect of removing the carbon trading potential on the scheme to improve the investors understanding.

If the project is shown through analysis conducted by the tool to have the potential to provide incentive through the investors judgement the process can proceed to the next stage of the methodology. If there are a number of potential schemes being assessed in the tool the investor can rank them in terms of preference before moving towards the sensitivity analysis stage of the methodology.

4.2.4. Sensitivity Analysis

Confident that the project has potential financial viability the next stage for an investor is analyse the possible effects of the risks of the variability of factors such as fuel prices. This stage in the methodology is used to visually represent the potential risks that are involved in the implementation and running of a microgrid. This stage requires the investor to assess these potential risks and make a judgement on whether or not the project should go ahead based on the data presented by the tool.

4.2.5. Implementation Decision

The final stage in the methodology is the decision on whether or not to go ahead with the project or not, at this stage the investor should take into account all of the relevant data provided by the software tools used in the methodology.

The investor should consider the relevant engineering merits of the scheme; are the CO_2 savings enough? Does the hybrid energy systems meet the demands of the scheme? Will there be large energy deficits at any point?

Investor should also consider the financial qualities of the scheme taking into account factors such as payback period and return on investment. Investor should also closely consider the issues that are raised in the sensitivity analysis section of the methodology; they should consider if the potential risks of any factor changing are too high for their liking.

4.2.6. Discussion

Following this approach will allow the investor to take account of all the facts surrounding the project and will ultimately allow a better decision to be made for the scheme and the finances of the investor.

The methodology follows the logical process of first ensuring that the scheme will meet the demands of the loads and only after that does the scheme get assessed in terms of financial viability. This means that the investor or stakeholder will not become overloaded with potential schemes that may not meet all demands; focussing only on schemes that that can meet the demand needs.

If the methodology process is followed to the end and it is found that no microgrid scheme is found that would be suitable then the process can be started again at the beginning with the search for schemes that meet the load.

4.3. Framework Application

There are a number of assumptions, data and tools required to utilise the decision-making framework process effectively.

4.3.1. Demand/Supply Matching Tools

Analysis to define hybrid energy systems for use in microgrids carried out using demand/supply-matching tool such as Merit. This allows different scenarios to be created in order to find the best combination to meet the needs of the energy demands of the system. In this particular analysis focus is on the use of Merit to provide demand/supply-matching.

4.3.2. Demand Data

Energy data must be obtained for the site that is being analysed. This should be derived from half hourly or hourly energy meters that have monitored the energy consumption of the buildings that will be connected to the microgrid. Data should be collated into two half hourly demand data files; electrical and thermal, which takes into account the energy consumption throughout one year. Having accurate demand data is important as it allows the selection of devices for the microgrid to match the demand with greater accuracy and allows for better financial forecasting.

4.3.3. Key Variables Definition

Variables that will be required to be met in order for the microgrid system to be considered effective and a good investment are examined. The key variables such as efficiency and payback time will be considered as part of the methodology which will form part of the decision making process of the system development which will be used alongside the tool.

4.3.4. Technologies Considered

The technologies that are considered in this framework analysis are the technologies that are available within a demand/supply-matching tool. Tools such as Merit provide databases that can be used to define renewable technologies such as wind turbines, photovoltaics, solar collectors etc. Merit also provides databases that allow auxiliary energy sources such as CHP and battery storage systems to be analysed.

Merit has the capability to carry out simulations with regards to other renewable technologies such as hydro, marine current turbines and wave energy convertors. However these were not considered as part of the analysis as there is a limited number of sites that could exploit this, any microgrid would have to be situated near an area that could benefit from this technology. This does not however rule out the possibility for this to be exploited in a scheme that would suit this.

4.3.5. Development of Tool

A financial decision-aiding tool was developed using Excel to improve the financial capability of the Merit energy software by allowing financial investment to be assessed as over investment periods of 20 years. Tool provides financial outcomes of up to 5 different schemes that have defined in Merit and provides analysis on potential risks that can enlighten the user and give insight on how effective a microgrid investment would be.

Tool is focussed towards users of Merit who have a number of potential scenarios for a microgrid in mind that wish to analyse the financial implications of adopting such a system. Users of the tool could range from engineers, financiers, communities and business organisation.

This tool will be discussed in greater detail in the following chapters, a case study will also be carried out to highlight how the tool works and highlight useful features.

4.4. Tool Development

Development of a tool to work in conjunction with the output of merit analysis was carried out to apply financial approach to the outcomes gained from Merit analysis.

4.4.1. Scope of Tool

The Merit financial analysis tool was developed using a standard Excel spreadsheet to allow for easy analysis and modification of values to match the needs of the microgrid project being looked into. Through adoption of the methodology defined in the previous chapter and use of the tool it should be possible to find the most effective solution for both the engineering and financial demands.

Tool is designed to analyse up to 5 different potential schemes that have been developed using Merit, this allows a comparison to be made between all the systems that are being consider. Examination of the schemes is applied from 2011 to 2031, over 20 years of project life. This was selected as this represents the term that feed in tariffs are available to be taken advantage of, over this period it should be possible for an investor to see the conceivable benefits and drawbacks of the schemes being assessed.

Tool is targeted towards users of Merit energy software who wish to analyse the financial outcomes that would be possible when carrying out a feasibility study to find a combination of low carbon technologies used in a microgrid. Potential users of this excel tool are engineers, investors and organisations who have an interest in gaining the most benefit from the scheme.

The tool is split into a number of worksheets that carry out different functions in the tool and provide the user with different data. The first sector of the tool provides the user with a short guide on how to use the tool correctly with the expected inputs and outputs. Second sheet is used to receive more input from the user to enable the model to calculate the correct values. Third sheet allows the user to set the basic assumptions that the tool will use to carry out analysis on the schemes being analysed. Further worksheets include the financial worksheet that takes into account the main financial outcomes of the schemes and the worksheets that deal with the sensitivity and risk analysis. Finally, the tool summarises all the key relevant data for the user to allow them to consider which of the schemes is best for them going forward.

4.4.2. Data from Merit

Tool is designed to carry out financial calculations based on the output of scenario optimisation from Merit. The tool requires the user to add this data to the tool by pasting the scenarios that the user wishes to analyse into the "Merit Paste" tab. This section allows the optimisation data from Merit to be used directly from the output of a scenario. This section allows the user to analyse up to 5 different scenarios that can be added to the tool. The user must add the electrical and thermal optimisations for each scheme being assessed.

Case 1			
Electrical	Demand	Resupply	Aux
Paste Here	StrathElec2010 (real)	167 W Sharp Poly+proven15 city10	jen526k electr follow2
Thermal	Demand	Resupply	Aux
Paste Here	2010StrathThermalHH	Capstone C60	Jenbacher 212 526kWe

Figure 1, Merit Input to Tool

4.4.3. Assumptions Made

Assumptions section of the tool deals with the basic assumptions used to carry out calculations on the financial outcomes of the schemes. There were a number of assumptions made in the development of the tool, these included assumptions on standard financial values based on current available data, these values are not set and if more detailed data is available this can be changed. Assumptions are made on the annual maintenance costs as a percentage, inflation, discount, and interest rate are taken into account. Project length is assumed to be 20 years so all analysis is carried out over this length of time.

Annual Costs	
Year	
Assumptions	**Value**
Maintainance	10.00%
Operation	1.00%
Inflation Rate %	4.20%
Discount Rate %	5.00%
Interest Rate %	5.00%
Capital Loan Term yr	15
Project Life	20
Carbon Credit Price Increase Rate	5.0%
€ to £	0.88

Table 2, Financial Assumptions for Scheme

Capital costs are set as a value in £/kW, which allows for a capital costing to be carried out base on supply installed. The user is able to make changes to these values if there is more detailed data on costing available to allow for greater accuracy. Tool takes into account two cases for each scheme being assessed, high and low. This allows the financial analysis to be carried out over the range of capital values, giving the investor the opportunity to assess the worst-case and best-case scenario.

Price/kw Renewables		
Year	**Low**	**High**
Energy System	**£/kw**	**£/kw**
Wind Turbine	2500.00	5000.00
Large Wind Turbine	800.00	1000.00
Photovoltaics	6000.00	8000.00
Heat Pump	600.00	800.00
CHP	700.00	1000.00
CHP >500kW	2700.00	3100.00
CHP >1000kW	2000.00	2500.00
Battery		
Hot Water Storage		

Table 3, Low Carbon Technologies - Cost per kw capacity

Feed in Tariffs and Renewable Heat Incentive prices rates are based on the current value as set by the UK government as well as the current grid import rate p/kwh. Further to this there is the current carbon value based on the European carbon market rates for a single unit of carbon (1 metric ton of CO_2).

Incentives	Generation Tarriff	Duration
Energy System	**(£/kwh)**	**(yr)**
Wind Turbine <1.5kw	£0.36	20.00
Wind Turbine > 15-100kw	£0.25	20.00
Wind Turbine100kw-500kw	£0.20	20.00
Wind Turbine500kw-1MW	£0.10	20.00
Photovoltaics 4-10kw	£0.38	20.00
Photovoltaics 10-100kw	£0.33	20.00
Photovoltaics >100kw	£0.31	20.00
Heat Pump 0-100kw	£0.45	20.00
Heat Pump >100kw	£0.32	20.00
Biomass 0-200kw	£0.79	20.00
Biomass 200-1000kw	£0.49	20.00
Biomethane	£0.68	20.00
Export Tariff	£0.03	20.00

Table 4, Renewables Incentives UK

The assumptions section also deals with cost of fuels that are used to carry out calculations in the tool. The user must supply the value of the fuels so that accurate analysis can be carried out, in either £/MW or £/kW. The tool allows for fixed rate analysis that only takes into account the increase via inflation on the costs or an increase rate per year can be set.

Rate		Fuel Cost per year	2011
5.0%	Electricity Price	£/MWh	50.000
5.0%	Electricity Price	£/kWh	0.050
5.0%	Gas Price	£/MWh	26.44
5.0%	Gas Price	£/kWh	0.026
0%	Biomass	£/MWh	
0%	Biomass	£/kWh	
0%	Oil	£/MWh	
0%	Oil	£/kWh	

Table 5, Fuel Price Assumptions

This section also deals with the value of the carbon credits that are being considered in the analysis, as there are lots of schemes available that can be used this section allows the user to set the price as required. As with the fuel value the user can select a static value that rises with inflation or can use an annual increase/decrease percentage. Important data that needs to be provided by the user is the current CO2 emissions that are being generated by the organisation being analysed, this allows further calculations to be carried out by the tool.

Current CO_2 Emissions	tCO_2
Gas	11770.00
Electricity	19700.00
Carbon Credits Applicable	**2011**
Certified Emission Reduction Unit Value	£19.45

Table 6, Carbon Data

4.4.4. Input Data

This section requires that the user must input certain data so that it can be used to carry out further calculations, ensuring that any calculations that are made are as precise as possible. This section is necessary to allow for correct formatting of data so that financial calculations carried out are correct.

The tool needs to get the data from merit to be formatted properly before calculations can be carried out. The user is required to add in data into certain cells that are linked to calculations; this is required to ensure that the correct scaling of the scenarios data such as GWh, MWh and kWh is applied to the case. The user looks at the scales provided by Merit then adds them to the blue cells as appropriate, this is required to be carried out for both electrical and thermal data.

Case 1	Electrical Data						
Number Conversion							
Merit Data	Merit Format	Tool Format	GWh	MWh	kWh	Value	
Total Demand	2.11 GWh	2.11	2.11			2110000	kwh
Total Resupply	306.27 MWh	306.27		306.27		306270	kwh
Total Aux	1.80 GWh	1.80	1.80			1800000	kwh
Energy Delivered	2.11 GWh	2.11	2.11			2110000	kwh
Energy Surplus	267.78 kWh	267.78			267.78	267.78	kwh
Energy Deficit	172.02 kWh	172.02			172.02	172.02	kwh
Fuel Consumption	1030364.13	1030364.13				1030364.13	m3
CO2 Emissions	4562.42	4562.42				4562.42	t co2

Figure 2, Data Scaling

Input data section also requires the user to add values into cells that take into account the capital costs of the system. The user is required to provide the capacity of each hybrid energy system and the number installed on the scheme, from this representative capital costs can be made. The tool provides the scenario name data that has been generated in Merit; this is to allow for easier data addition to the model.

Merit Scenario Selected						
Renewables				Aux		
167 W Sharp Poly+proven15 city10				cap60 x5 follow e		
Systems Selected	Device Power (kw)	No. Devices	Capacity (k	% of Capac	Capital Cost	
					LOW	HIGH
Wind Turbine <1.5kw			0	0.00	£0.00	£0.00
Wind Turbine > 15-100kw	15.00	100	1500	0.90	£3,750,000.00	£7,500,000.00
Wind Turbine100kw-500kw			0	0.00	£0.00	£0.00
Wind Turbine500kw-1MW			0	0.00	£0.00	£0.00
Photovoltaics 4-10kw	0.17	1000	167	0.10	£1,002,000.00	£1,336,000.00
Photovoltaics 10-100kw			0	0.00	£0.00	£0.00
Photovoltaics >100kw			0	0.00	£0.00	£0.00
Heat Pump 0-100kw			0	0.00	£0.00	£0.00
Heat Pump >100kw			0	0.00	£0.00	£0.00
CHP	60.00	5	300	0.18	£210,000.00	£300,000.00
CHP >500kW			0	0.00	£0.00	£0.00
CHP >1000kW			0	0.00	£0.00	£0.00

Figure 3, Capital Costs Input

4.4.5. Financial Calculations

This section is used to calculate the main financial outcomes of the tool. The tool is designed to carry out analysis over a project length of 20 years, based on the data gained through Merit scenario analysis. The tool calculates the total capital cost of the scenarios hybrid energy systems that have been selected and then takes this as the starting point for future years.

Annual costs are calculated using data gained from user input and merit, values such as maintenance costs, fuel costs and repayments are produced and are adjusted to increase with inflation. Repayments on capital used in implementing a scheme are assumed to be the initial capital outlay in the tool, repayments are set for the to last for the project life which is defaulted at 20 years. These calculations are important to develop an accurate cash flow of a microgrid scheme.

Capital Costs	Low	High
Energy Systems	-£1,377,000.00	-£2,086,000.00
Capital Repayment Annually	£126,346.03	£191,400.01
Year	0	1
Annual Costs	**2011**	**2012**
Maintenance	£31,700.00	£31,700.00
Fuel	£533,557.69	£560,235.58
Deficit Grid Electricity	£0.11	£0.11
Total Annual Costs	**£565,257.80**	**£591,935.69**

Figure 4, Example Annual Costs

The values taken from the merit analysis are also used to calculate the income per year from incentives such as FITs and RHIs, these values are set to increase with the rate of inflation assumed. The CO2 savings are calculated from the data gained from Merit and the current CO2 emissions from the input data section; the savings is used to calculate the annual income gained from selling carbon allowances on the open market.

Total Fits income	£134,358.83	£139,603.14	£145,067.71
Carbon Market			
CERs Income	**-£105,430.33**	**-£110,701.85**	**-£116,236.94**
Total Income	**£28,928.50**	**£28,901.29**	**£28,830.77**
Net Low	**-£7,339,874.51**	**-£7,916,281.13**	**-£8,514,688.67**
Net High	**-£9,961,674.51**	**-£10,538,081.13**	**-£11,136,488.67**
Net Present Value Low	-£2,766,321.51	-£2,983,563.10	-£3,209,096.61
Net Present Value High	-£3,754,450.35	-£3,971,691.95	-£4,197,225.46

Figure 5, Example Financial Cash Flow

From these calculations the net profit of the scheme is calculated over the 20 years showing allowing the investor to assess the value of the system. The tool also allows the investor to analyse the net present value of the project at different stages and assess how long it would take for the project to payback the initial capital outlay.

Financial Outcomes	Low	High
Simple Payback (yr)	1.84	2.79
Future Value Low at Project End	£2,862,684.10	£4,336,644.18
Present Value	-£1,377,000.00	-£4,336,644.18
Internal Rate of Return	17.00%	6.91%
Profitability Index	1.0	2.1

Figure 6, Example Financial Outcomes

Simple payback is used to provide the user with the number of years required for the project income to payback the initial investment, capital costs are derived from user input to the tool and annual income is collected from the tool financial output:

$$Simple\ Payback = \frac{Capital\ Cost}{Annual\ Income}$$

Equation 1, Simple Payback

The following equation is used to calculate the NPV at different stages of the project, where C_t is the net cash flow derived from the financial output of the tool, i is the discount rate set in the assumption section of the tool and t is the number of years at each stage in tool analysis:

$$Net\ Present\ Value = \frac{C_t}{(1+i)^t}$$

Equation 2, Net Present Value Equation

The tool also calculates critical criteria that investors will require to judge the investment quality. The rate of return is a function of NPV and is calculated to provide the user with a percentage value of how profitable the project would be for investment.

The tool calculates the present value of the project at the scheme through the following equation where; C is the cash flow from the tool financial output, i is the interest rate set in assumptions and n is the number of years.

$$Present\ Value = \frac{C}{(1+i)^n}$$

Equation 3, Present Value Equation

The future value at the end of the project period is calculated through the following equation, where C_o is the cash flow at start of project derived from the tool, r is the rate of return set in the assumptions and n is the number of years:

$$Future\ Value = C_o * (1+r)^n$$

Equation 4, Future Value at project end

Profitability index ratio is calculated using the following calculation; values are taken from the financial output gained from the tool:

$$Profitability\ Index = \frac{PV\ of\ Future\ Cash\ Flows}{Initial\ Investment}$$

Equation 5, Profitability Index

This section also provides the user with graphs showing the cash flows of the schemes being assessed over the 20-year period. This is beneficial to the investor as they can see at a glance the financial outcomes of the scheme such as the value of the project and the time to payback the initial investment.

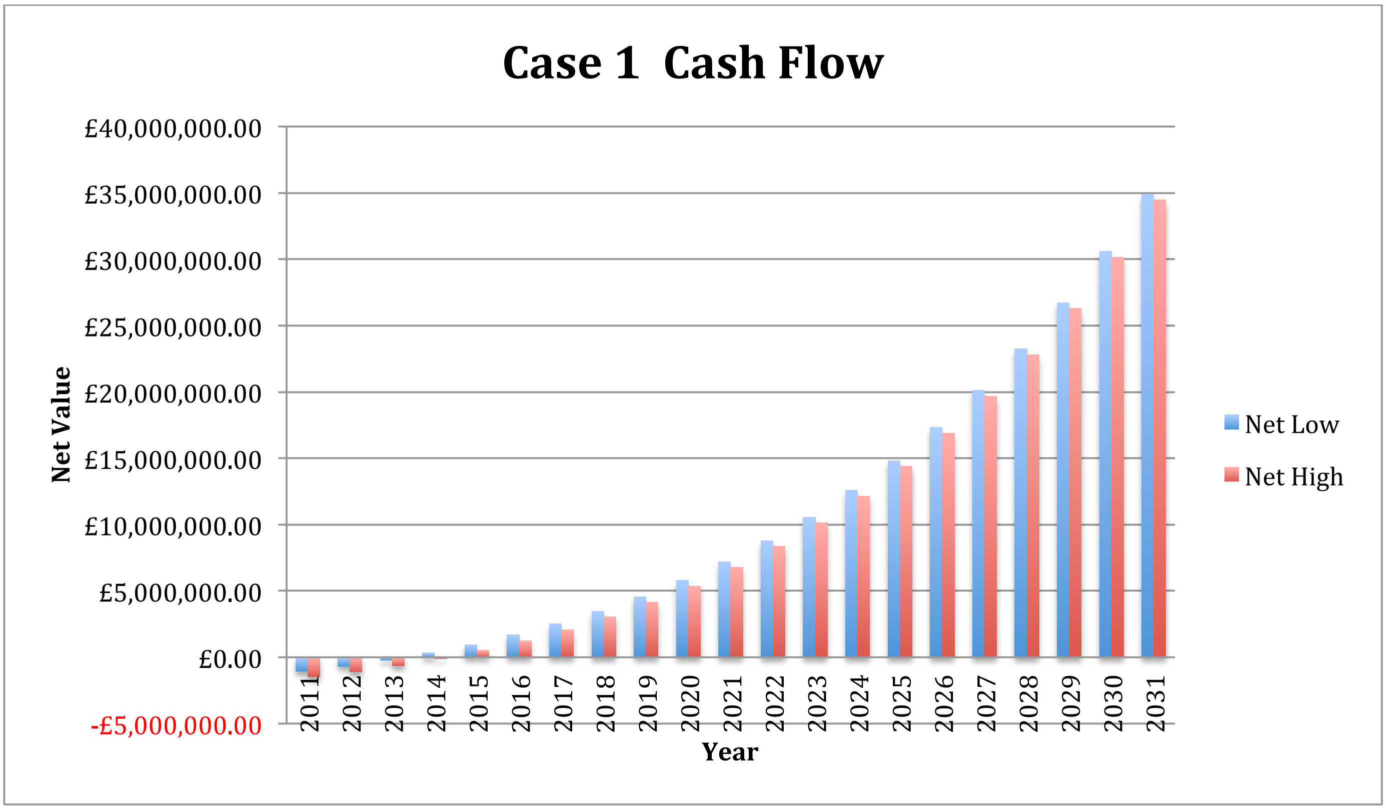

Figure 7, Example Cash Flow Output, Financial Section

4.4.6. Sensitivity Analysis

The tool is designed to carry out a range of sensitivity analysis calculations to aid potential investors in making effective decisions. These sensitivity calculations are based on the net present value (NPV) of the system; the NPV of the investment is an important factor as it is a measure of the value of the system at a given point in the cash flow.

At the heart of the sensitivity analysis is the desire to assess what factors are likely to have an effect positive or negative on the value of the investment. This is achieved through calculating the net present value a number of times with important factors such as the fuel costs, maintenance costs and discount rate is changed. This is a static analysis that considers the parameter being assessed and its effects on NPV only, for example the effect on the NPV if the fuel price was to increase by 15% suddenly or likewise decrease.

This analysis is carried out for the following parameters:

- Discount Rate Variance
- Fuel Price
- Operations and Maintenance
- Carbon Credit Value

These parameters are then calculated through 6 different iterations from the base NPV value:

Iteration	Parameter Change
1	**5%**
2	**10%**
3	**15%**
4	**-5%**
5	**-10%**
6	**-15%**

Figure 8, Sensitivity Analysis Iterations

This sensitivity analysis allows the user to see what parameters used in the analysis have the greatest effect on the value of the scheme.

Low Case	Current	Iteration 1	Iteration 2
Fuel Cost rate	0.00%	5.00%	10.00%
Fuel Price Iteration	2011	2012	2013
Net Present Value Low	-£2,539,229.58	-£2,517,845.76	-£2,492,643.69
Iteration 1	-£2,560,987.47	-£2,529,252.47	-£2,504,463.67
Iteration 2	-£2,582,745.35	-£2,540,659.18	-£2,516,283.64
Iteration 3	-£2,604,503.24	-£2,552,065.88	-£2,528,103.62
Iteration 4	-£2,517,471.69	-£2,403,778.66	-£2,374,443.93
Iteration 5	-£2,495,713.81	-£2,495,032.34	-£2,469,003.74
Iteration 6	-£2,473,955.92	-£2,483,625.63	-£2,457,183.76

Figure 9, Example Sensitivity Analysis - Fuel Price Iteration

With these calculations completed, it is possible to display a sensitivity graph that shows to the investor exactly what constraints could have an effect on the value of the project allowing them to gauge whether or not the investment would be of worth.

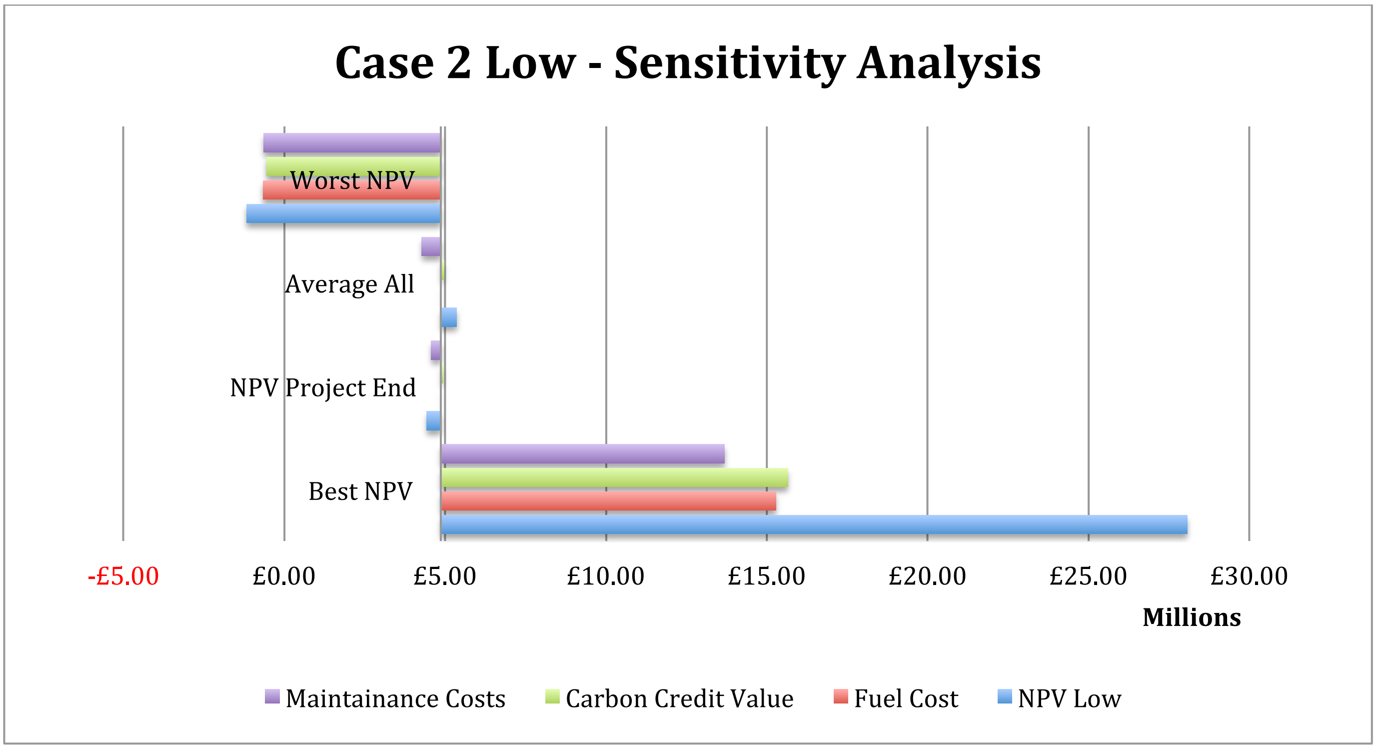

Figure 10, Example Sensitivity Analysis Chart

This chart allows the user to see at a glance what potentials are possible if the project was to go ahead. Values taken into consideration are the best, worst and average of the calculations taken in the NPV iteration analysis. This allows the user to see not only the potential upwards value of the project but potential negative values that could become apparent. The idea behind this analysis is that a user must be able to judge the potential benefits against potential negatives before they make an informed decision on whether this project is viable or not.

Another feature that the tool includes is further analysis that allows the potential investor to assess the profit and risk of the project together. The NPV of the project is plotted against the variance of the NPV calculations carried out in the sensitivity analysis. This allows the investor to gauge the whether or not the project is high, medium or low risk and profit at the same time. The greater the variance in NPV, the greater the risk involved in the project due to the NPV volatility. Where the data is situated on the graph will determine how what sort of investment the project will be to the investor. This chart works as follows:

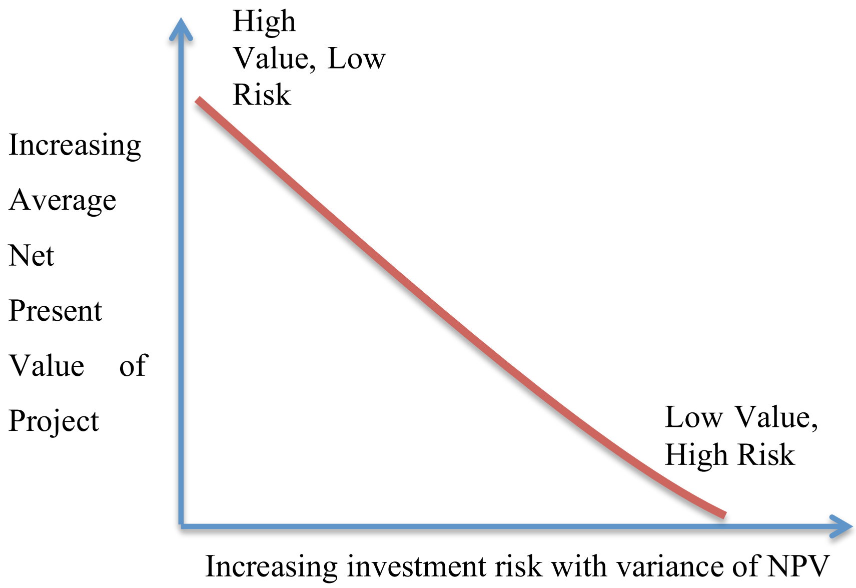

Figure 11, Average NPV Against Variance in NPV

Application of this method in the tool will allow the user to assess the output of the financial calculations and will help them make an informed decision on whether it is worth investing in. This is applied to the tool to provide charts for each case being analysed as well as being combined with them all to give the investor the opportunity to assess all the cases together providing the bigger picture of all the schemes allowing them to judge all at once.

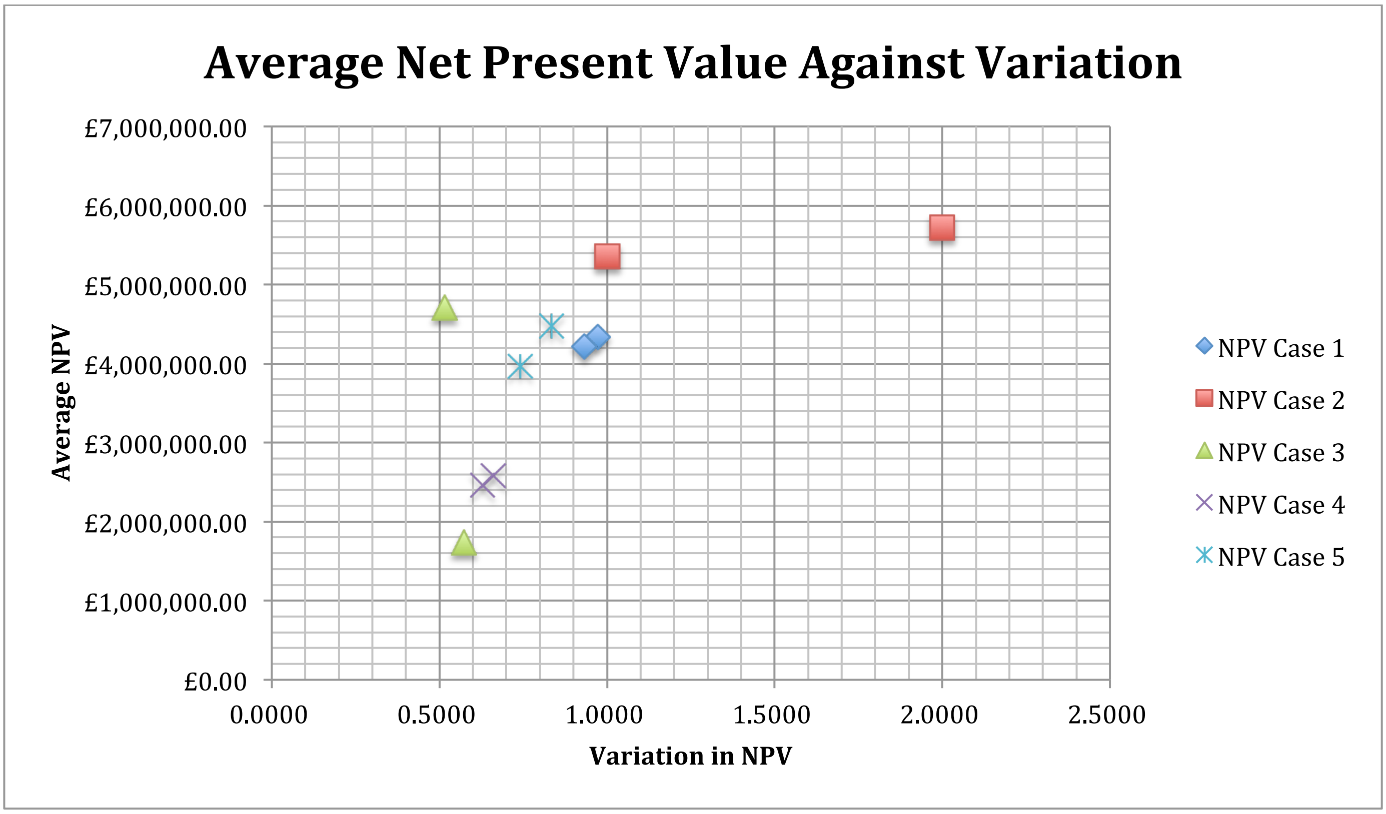

Figure 12, Average NPV against Variation showing investment risk

4.4.7. Tool Summary

Finally, the tool provides a summary of the important data for all the cases being considered in the analysis, which provides the key data in shortened form. This is the first area that an investor using the tool should look to get an at a glance view of the schemes being assessed. If they feel they need greater detail on the systems they can go through the other tabs, which will provide more in depth data on the schemes.

4.4.8. Outcomes

The real benefit to using this tool is the ability for investors to apply data directly from Merit into the tool and find out how it will perform. Investing in schemes is expensive and carries potential risk for the security of that investment, the tool allows them to find out whether the returns they will receive is worth it. It aids the investor by removing the element of doubt surrounding the project and allows them to compare results with other prospective schemes.

The features used in the tool make the decision process of a potential investor such as a small community or a businessman far simpler as they display the results graphically in a clear and concise manner. Through close adherence to the decision-making methodology, financial data from the project is easily understood and allows the investor at a glance to see the potential benefits or pitfalls in adopting a project. Investors can find suitable schemes from the summary tab and can assess these schemes in the greater detail in the other tabs, which will assure them of a successful project.

Using the sensitivity analysis and the NPV variance charts the user can also assess the potential risks involved in the project, finding what factors may affect the value of the project and through doing this make a more informed decision.

5. Case Study

To highlight the use of the methodology and the tool, it is important to show an example of the methodology being used in a real situation and to highlight the benefits of using the tool it through a case study. This case study follows the stages as defined in the methodology in order to show its effectiveness in improving decision making for hybrid energy system projects used in microgrids.

5.1. Define Scope

5.1.1. University of Strathclyde

A case study was carried out with the University of Strathclyde as a model for a small community or a medium sized organisation that is seeking to reduce their carbon footprint through the use of hybrid energy systems in a microgrid.

Strathclyde university seeks to become more sustainable by embracing sustainable development as described by Brundtland *"meeting the needs of a generation without compromising the ability of future generations to meet their own needs"*(Commission & General 1987). Strathclyde has a stated ambition to reduce the carbon emissions of its buildings and residences by 80% of base levels by 2050 (Estates 2010).

To achieve this aim the University must invest in energy savings to reduce emissions and the application of a microgrid to provide localised energy could be an effective method of achieving this.

This case study seeks to analyse the university estates energy consumption and find a viable investment that meets the demands and will be suitable economically for an investor. It is assumed for the purpose of the case study that the investor will be the University Estates department.

The University has a total of 64 buildings and student residences that make up the John Anderson campus in the centre of Glasgow, the site for the Microgrid will be located here. Together these buildings cost the university around £5million a year to heat and power.

Figure 15, John Anderson Campus, University of Strathclyde

Due to the universities city based location, renewables that are location based are not such as Hydro generation and marine current tidal systems to be considered as part of the analysis.

The University of Strathclyde's estates department provided the following assumptions that could be used as values for the fuel costs assumptions in the decision making tool.

Year		2010
Assumptions	**Units**	
Electricity Price: excluding CCL	£/MWh	63.42
Gas Price: excluding CCL	£/MWh	26.44
CO2 Market price (CRC)	£/tonne	0.00
Climate Change Levy Electricity	£/MWh	4.70
Climate Change Levy Gas	£/MWh	1.64
Electricity Price: Including CCL	£/MWh	68.12
Gas Price: Including CCL	£/MWh	28.08
CO2 emissions factor - electricity	tonnes/MWh	0.54
CO2 emissions factor - electricity Decarbonised	tonnes/MWh	0.54
CO2 emissions factor - gas	tonnes/MWh	0.19

Figure 13, University Energy Assumptions

5.1.2. Define Demands

Energy data was obtained from the university for 2010 for both thermal (gas) and electrical consumption of all the buildings in the university for the year. This data was monitored through half hourly meters that took measurements of the consumption at different times of the day. The electrical and thermal data was collated into a form that would work with Merit providing the following demand profiles for the university.

5.1.3. Climate Data

The representative climate data for Glasgow was used to carry out analysis in Merit; this will allow Merit to calculate the output of the renewable energy systems being used in the microgrid.

5.1.4. **Electricity Demand Profile**

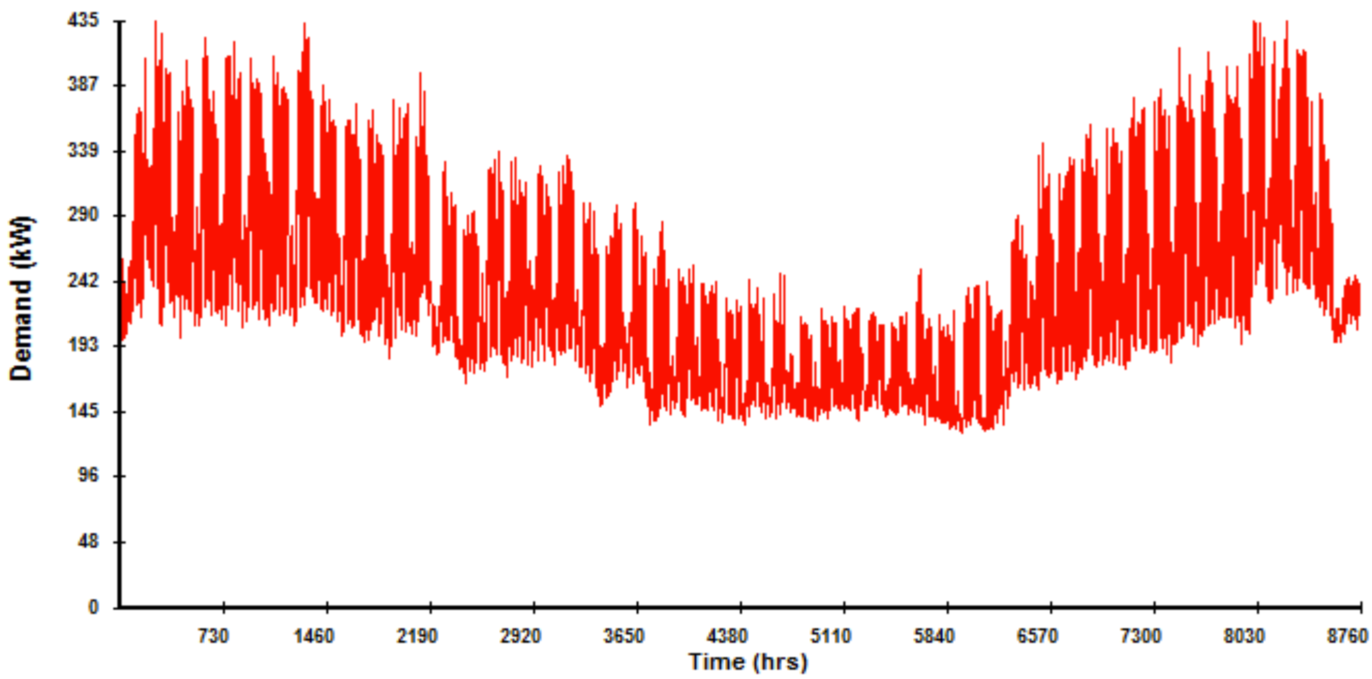

Figure 14, Electrical Demands, University of Strathclyde 2010

Electrical profile for the entire John Anderson campus was created in Merit, this took into account an entire year of data that was collected by half hourly meters. The data is based off electrical energy consumption during 2010; data selected was from 1st of January to the 31st of December. It can be noted that there is always a load being drawn by the campus from the grid. The loads are higher during the colder months of the year with noticeable electrical consumption at these times.

5.1.5. Thermal Demand Profile

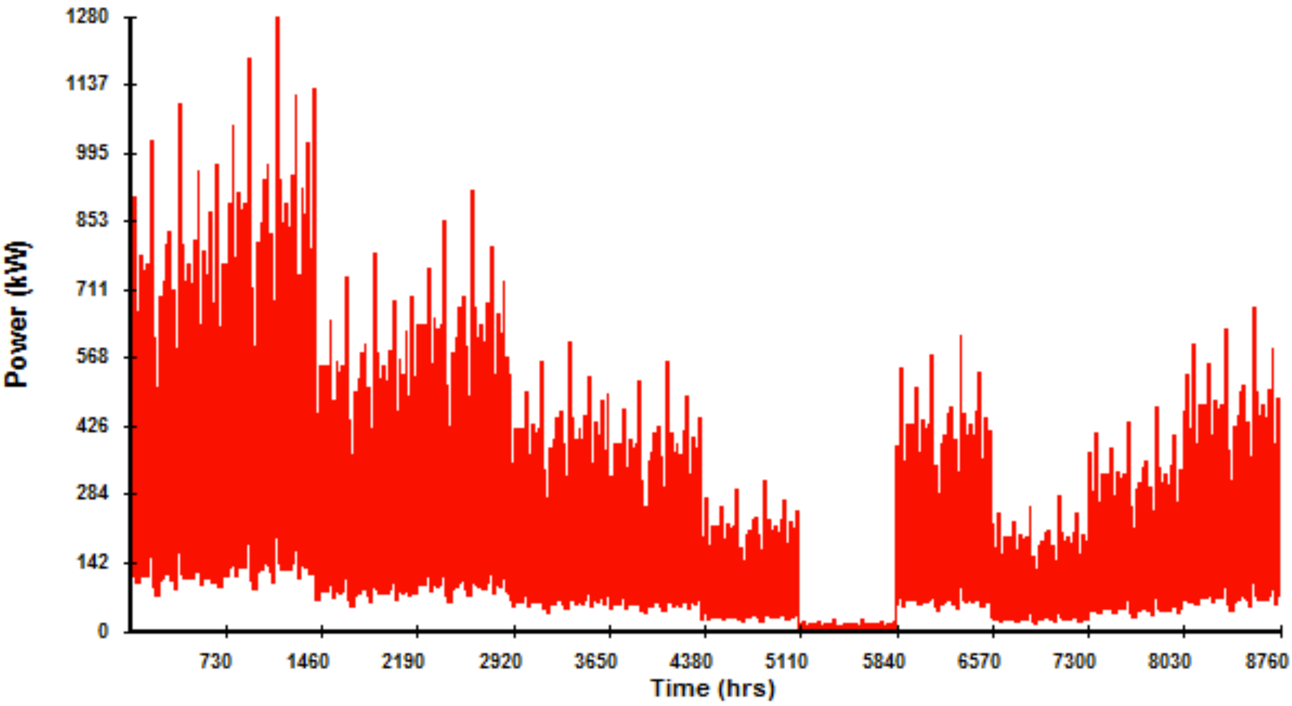

Figure 15, Thermal Demands, University of Strathclyde 2010

Again using the thermal demand data provided it was possible to create a thermal profile of the campus. Demand is made up of the gas being used by the University to provide heating within the campus over the year in 2010. As with the electrical demands it can be noted that the loads are higher in the winter due to the cold weather and the greater use of heating devices because of this. In the summer months demands drop considerably with the demands dropping to almost zero demand levels at certain stages due the better weather meaning that lower heating is required in buildings.

5.2. Demand/Supply Matching

With the energy data included in Merit it was possible to put together a number of scenarios that would be acceptable for a microgrid to be install at the University. A number of scenarios were run using the software to find the combination of renewables that provided a best match for the demands required of the system.

Due to the universities city based location, technologies such as marine current tidal and hydro were not part of the deliberation and reasonable consideration was made as to the size of renewables due this. For this reason larger wind turbines with ratings >500kW were not considered, as there would not reasonably be space to install them. A selection of devices were selected from the Merit databases that could be used in the microgrid, these were added to the Merit project in batches of different power capacities to assess what effect having different numbers of renewables and low carbon plant would have on the matching the universities demands.

Device	Type	Function	No. Off
Calorex 12000	Heat Pump	Auxiliary	50, 100
Sharp Poly 167W	PV	Supply	500, 1000, 1500
Proven 15kW	Wind Turbine	Supply	10, 20, 30
Generic 10kW	Wind Turbine	Supply	10, 20, 30
Jenbacher 526kWe	CHP – Electrical Follow	Auxiliary	1, 2
Jenbacher 526kWe	CHP – Thermal Follow	Auxiliary	1, 2
Jenbacher 526kWe	CHP – Constant Load	Auxiliary	1, 2
Capstone 60	CHP – Thermal Follow	Auxiliary	1, 3, 5, 10
Capstone 60	CHP – Thermal Follow	Auxiliary	1, 3, 5, 10
Nexus 30	CHP – Thermal Follow	Auxiliary	1, 3, 5, 10

Table 7, Demand/Supply Matching Devices

A number of scenarios were created and simulated using Merit in an attempt to find a number of potential scenarios that can be used in the microgrid. Demand/supply matching was carried out using these technologies for the electrical and thermal demands required by the microgrid; all possible combinations of these combinations were assessed. Demand/supply matching scenario output data was collected and selection of scenarios that would were potentially good microgrids was carried out.

It was found that the microgrid could consist of only CHP plant to provide for the energy needs of the Universities demands, for this reason one of the scenarios selected for analysis used this method. There is a risk in that if a microgrid relies too heavily on burning fuels for energy this is not beneficial to the environment or for the costs of buying the fuel, however this was still investigated. There were other scenarios identified that utilised renewables to meet a large part of demand with CHP providing the rest of the energy needs, these scenarios still performed well enough to be considered.

Five different scenarios were selected that had met the needs of the demands were selected for this. Selection was based on the match rate of the combination provided by Merit and consideration was take to ensure that the other values as described in previous chapters were fulfilled. The following selections were taken for further analysis as cases in the financial tool:

Scenario	Demand Type	Supply	Aux	Match Rate %
Case 1	Electrical	n/a	Jenbacher 212 526kWe	85.32
Case 1	Thermal	calorex12000 x100	Jenbacher 212 526kWe	100
Case 2	Electrical	167x1500PV+proven15x20 Wind Turbine	capstone60 x5 follow e	94.82
Case 2	Thermal	Capstone C60	capstone60 x5 thermal	79.82
Case 3	Electrical	167 W Sharp Poly+proven15 city10+Energy Nexus	n/a	79.72
Case 3	Thermal	NULL	Jenbacher 212 526kWe+Energy Nexus Group	99.77
Case 4	Electrical	167x1000+proven15city30	Capstone C60	84.5
Case 4	Thermal	n/a	Jenbacher 212 526kWe+Capstone C60	84.73
Case 5	Electrical	167 W Sharp Poly+proven15city30	Jenbacher 212 526kWe	94.63
Case 5	Thermal	calorex12000 x100	Jenbacher 212 526kWe	85.32

Table 8, Case Study - Scenarios Selected

These scenarios were added them to the decision making tool to carry out further analysis on them to fin what cases would perform financially and assess potential risk effects.

5.3. Financial Assessment Using Tool

With the selected scenarios developed using Merit it was possible to apply these results in to the tool. Using the Merit data selected the optimisations that were produced was added into the merit paste section of the tool. The relevant data was added to the input page ensuring that all data could be used in the financial calculations of the tool.

5.3.1. Tool Assumptions

In order for the tools output to be considered accurate, a number of assumptions had to be applied to the tool based on current values and best guess estimates. The following assumptions were used in the tool:

Assumptions	Value
Maintenance	5.00%
Operation	5.00%
Inflation Rate %	4.20%
Discount Rate %	5.00%
Interest Rate %	5.00%
Capital Loan Term yr	15
Project Life	20
Carbon Credit Price Increase Rate	10.0%
€ to £	0.88

Table 9, Case Study Assumptions

The assumptions provided by the Universities estates service were used as the basis for the current fuel costs being used, it was decided that the cost of fuel would increase rate of 2% year on year. Additionally, the current CO2 consumption provided by the estates service was added into the assumptions tab to allow the tool to calculate the correct carbon emission savings.

Current CO2 Emissions	tCO2
Gas	11770.00
Electricity	19700.00
Total	31470.00

Table 10, Case Study Current CO2 Emissions

5.3.2. Economic Assessment

Once the data was correctly entered into the tool and the assumptions were made it was possible to investigate the economic viability of each case. Over the project life it was discovered that all schemes would be profitable for a financier if they were to make an investment in a microgrid for the University.

All of the cases investigated were different and this produced varying profitability of schemes that could be invested and more choice for an investor. The tool provided the following financial outcomes:

Case	Payback Years	Future Value	Present Value (£)	Rate of Return	Profitability Index
Low – 1	1.6	2,589,512.94	-2,245,600.00	52.84%	1.00
High - 1	2.16	3,494,262.48	-3,494,262.48	40.95%	2.08
Low – 2	2.75	1,245,600.00	-1,245,600.00	48.70%	0.58
High – 2	1.62	3,494,262.48	-3,494,262.48	89.20%	2.77
Low – 3	3.60	1,245,600.00	-1,245,600.00	12.42%	0.44
High – 3	3.05	3,494,262.48	-3,494,262.48	14.60%	1.46
Low – 4	3.81	1,245,600.00	-1,245,600.00	17.01%	0.35
High – 4	4.12	3,494,262.48	-3,494,262.48	15.65%	0.90
Low – 5	5.96	1,245,600.00	-1,245,600.00	19.67%	0.23
Low – 5	4.60	3,494,262.48	-3,494,262.48	25.51%	0.85

Table 11, Case Study Financial Outputs

This analysis that has been derived from the tool provides an insight into which of the cases being assessed will be good investments. This analysis should provide an investor with the relevant data that is important to a microgrid investment.

The outcomes gained from the financial section of the tool is that Case 1 and Case 2 can be seen as good investment potential due to their high rate of returns, short payback periods and good profit investment ratios. Of all the cases being assessed, Case 1 provided the highest profit by the end of the project time of 20 years; Case 3 provided the lowest potential profit.

It can be noted that the Case 1, the only scenario that does not use renewables performs well financially despite not having the advantage of feed in tariffs and heat incentives. Cases that are heavy in renewables cost require a larger capital investment installed, in a financial sense this is not a positive, nevertheless if the emphasis on the microgrid is carbon reduction this could be accepted.

However, all of the cases investigated are potentially good investments with good cash flows as shown in the cash flow graphs produced by the tool. Additional assessment was carried out to further investigate the tools financial evaluation with respect to microgrid selection and investments.

To investigate what effect the termination of carbon allowance trading would have on this case study the carbon value assumption was marked as £0. Through setting this in the tool it would allow the carbon market value to be completely removed from the tool's analysis. What was discovered was that without carbon trading the ability for the schemes being assessed to generate a profit was removed. To provide basis for comparison, the cash flow found in the case study for scenario 5 with carbon trading available is as follows:

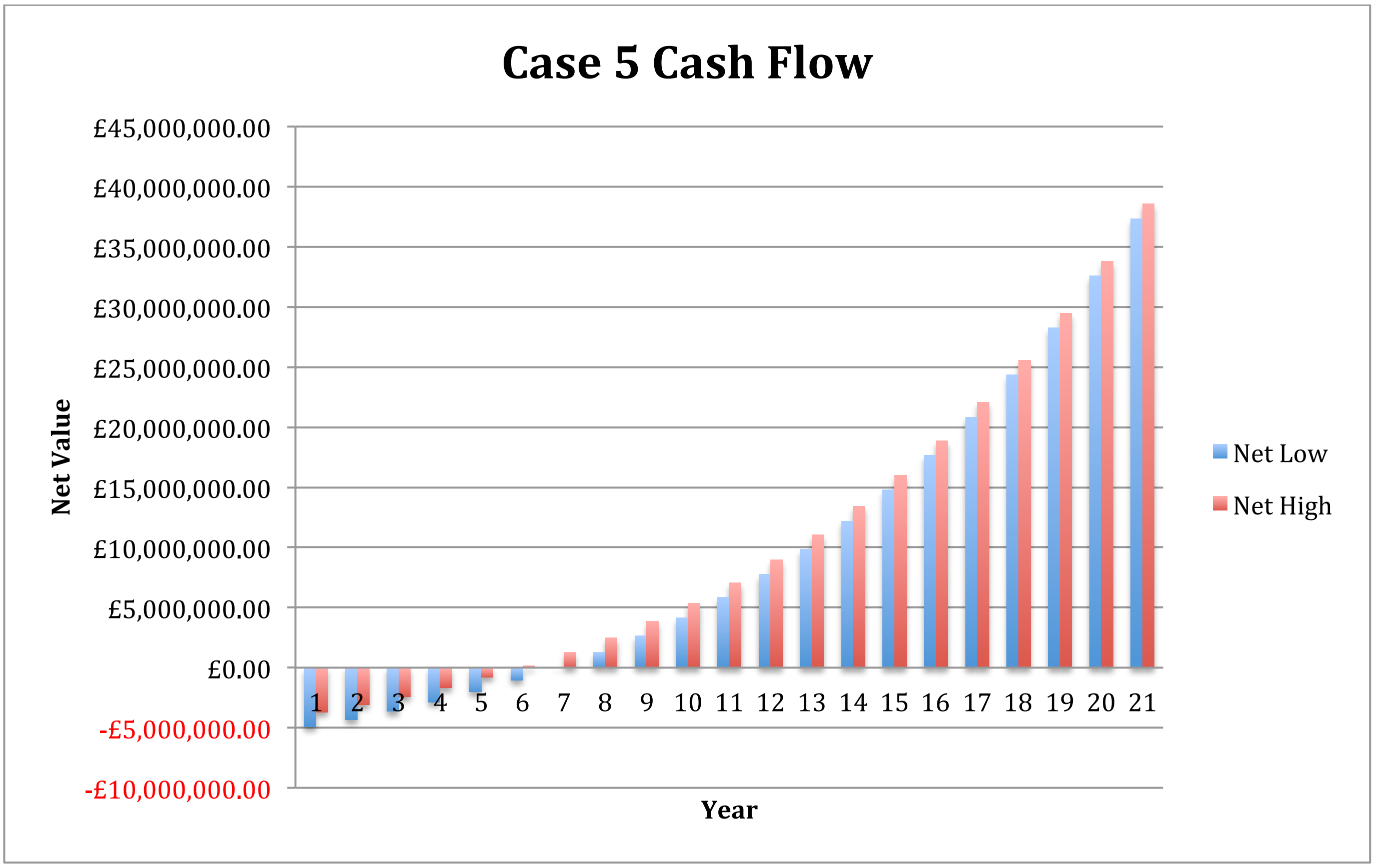

Figure 16, Cash Flow Case 5 - With Carbon Trading

With the availability of carbon trading for this microgrid it can be seen that the project will not be producing a profit for 6 years and will provide substantial value by the end of the 20-year period.

Through setting the value of carbon allowances for trading to £0 over the period it is possible to assess what effects this would have on the case 5 microgrid. The tool produces the following case flow with this setting:

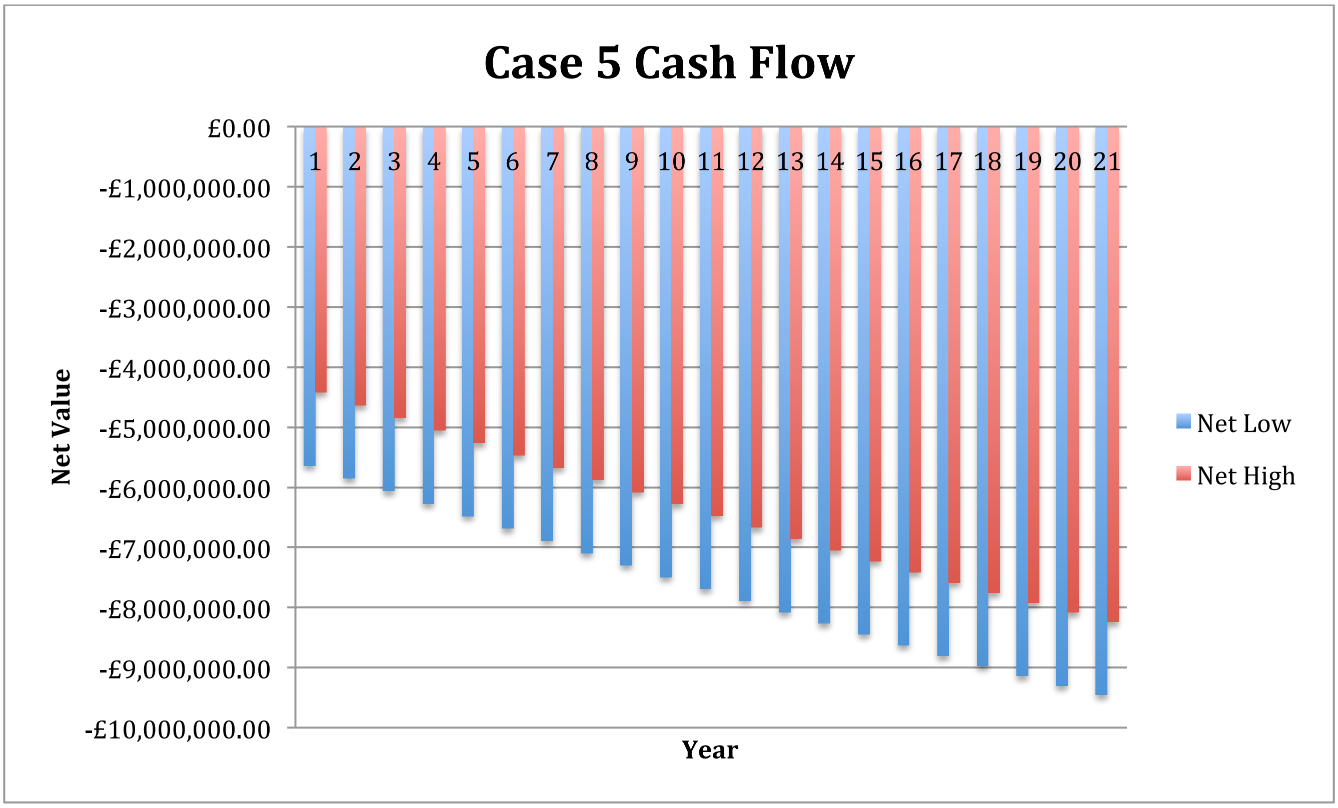

Figure 17, Cash Flow Case 5 - Without Carbon Trading

What can be seen from this analysis is that without the availability of carbon allowance trading the cash flows on a project would be unsustainable producing negative value. This situation clearly would not provide for a good investment opportunity for an investor and would not be acceptable to an investor. Despite the availability of FITs and RHI schemes for these types of investment it can be seen that the income generated by these systems does not provide enough on their own to produce a net profit. If this system was to be assessed not from an investor viewpoint but as an energy consumer perspective whereby the main goal is not to earn profit from the scheme but to save on energy bills, this may be acceptable. However what is clear from the output gained from the tool is that for these microgrid schemes to be successful as an investment option there is a need to utilise the carbon allowance trading potential of the global markets. The investor can take this analysis into account when considering whether or not to go ahead with the project.

Further analysis was required using sensitivity analysis to test the cases further and allow for a better more informed decision.

5.4. Risk Sensitivity Assessment

Taking into account the financial outcomes developed by the financial section of the tool it was possible to use the tools risk assessment features to get a more accurate picture of the cases and allow for an easier decision to be made. An investigation was made on the potential factors that could affect the size of the NPV of the projects. Due to the promising results gained from the financial analysis Cases 1 & 2 have been selected for closer examination, however sensitivity analysis for the remaining scenarios are included in the appendix.

5.4.1. Sensitivity Analysis

From the sensitivity graphs produced for case 1 it is apparent that the discount rate being used in the analysis is an important factor. A change in the discount rate provides huge potentials for extra profit being made by the scheme if it were to be implemented. Changes in the maintenance costs would have the largest negative effect on the NPV value of the project with changes in the fuel prices being the second most important value. As is seen from both the low and high graphs these do not make too much of a difference to the net present value of the scheme and can be looked on positively by an investor.

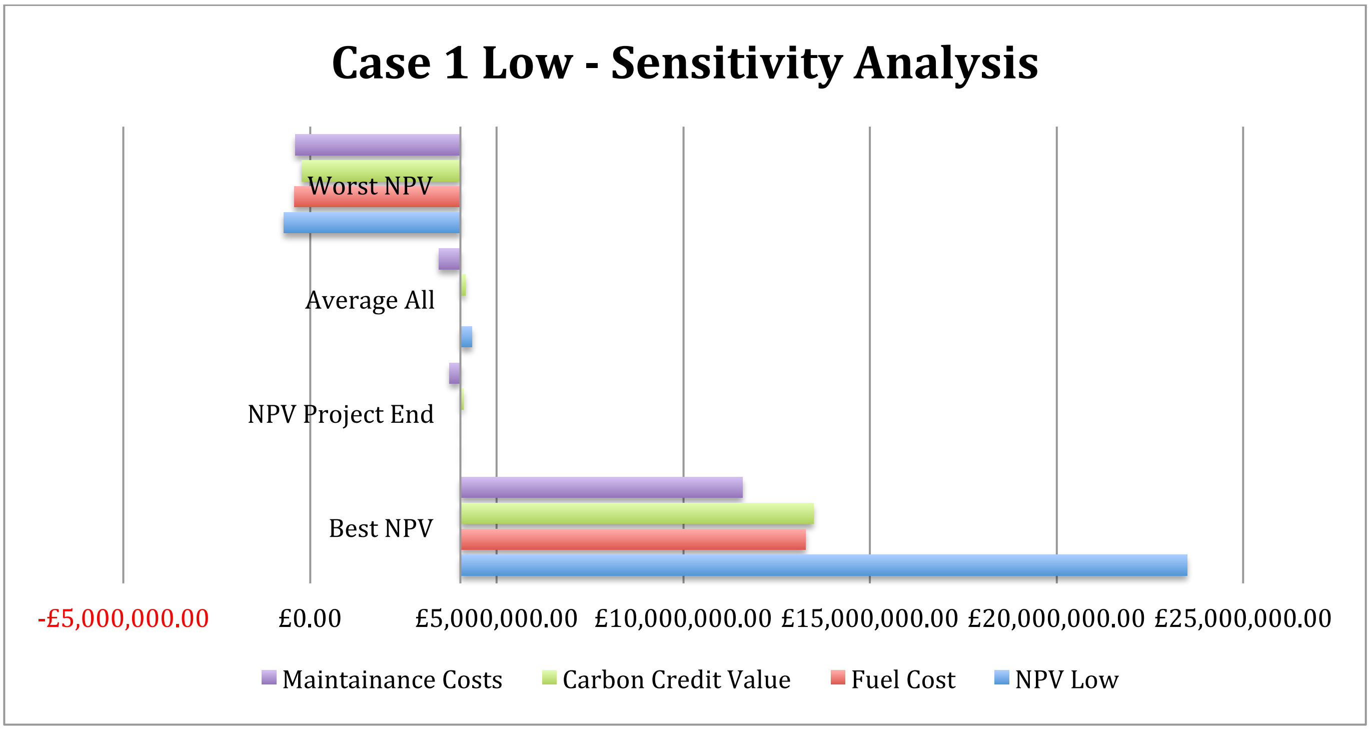

Figure 18, Case 1 Low Sensitivity Analysis

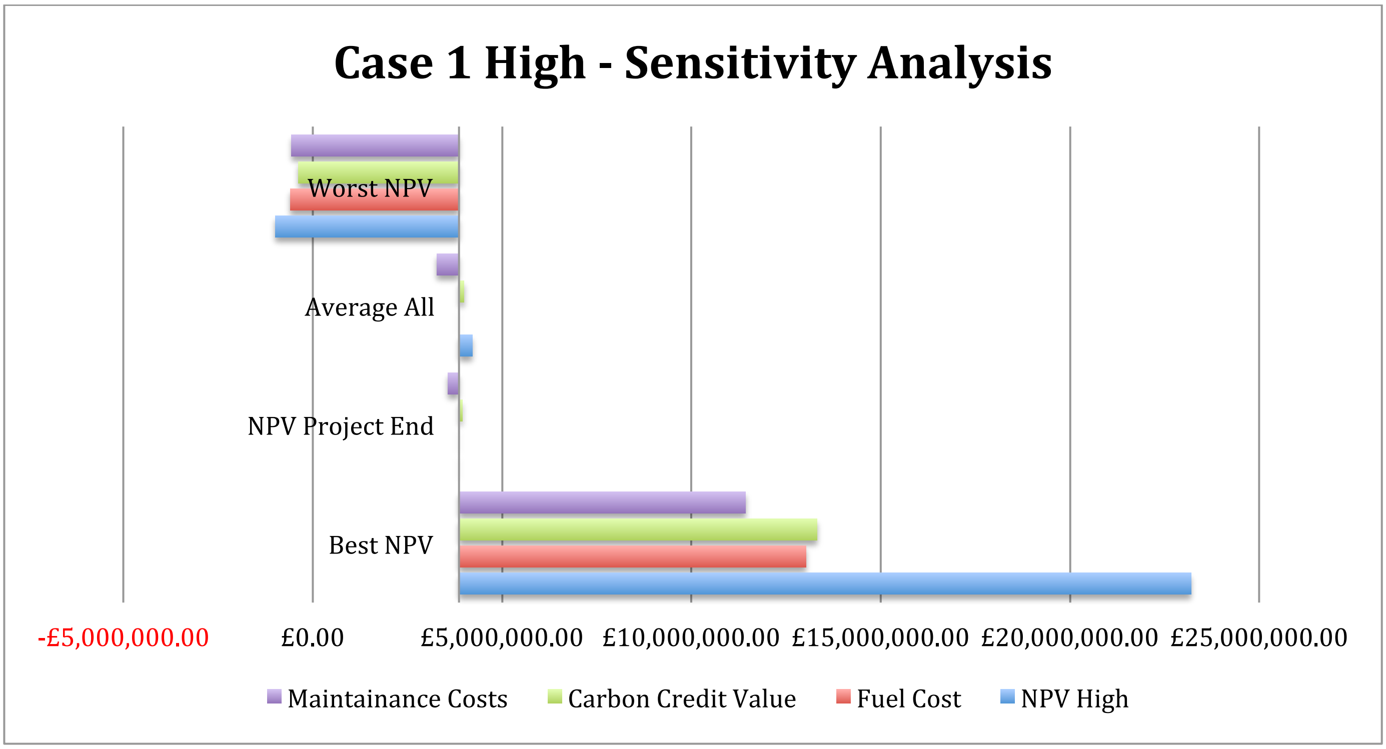

Figure 19, Case 1 High Sensitivity Analysis

With respect to the case 2 in the analysis there is a different picture that emerges with potential value of the scheme. Due to case 2s greater inclusion of renewable devices in the scheme it has an opportunity to benefit more from the selling of carbon credits due to the lower carbon emissions. Potential negative influences on the scheme are the maintenance costs that are required to keep the system in top shape.

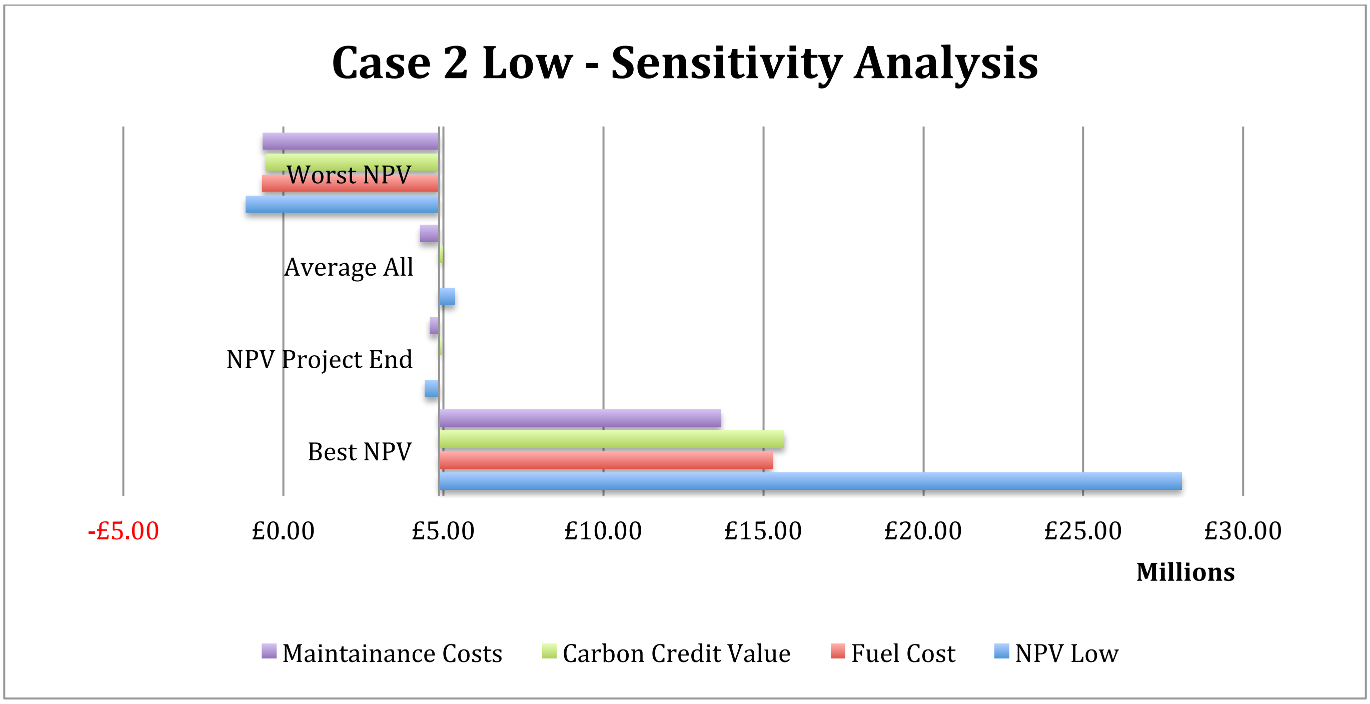

Figure 20, Case 2 Low Sensitivity Analysis

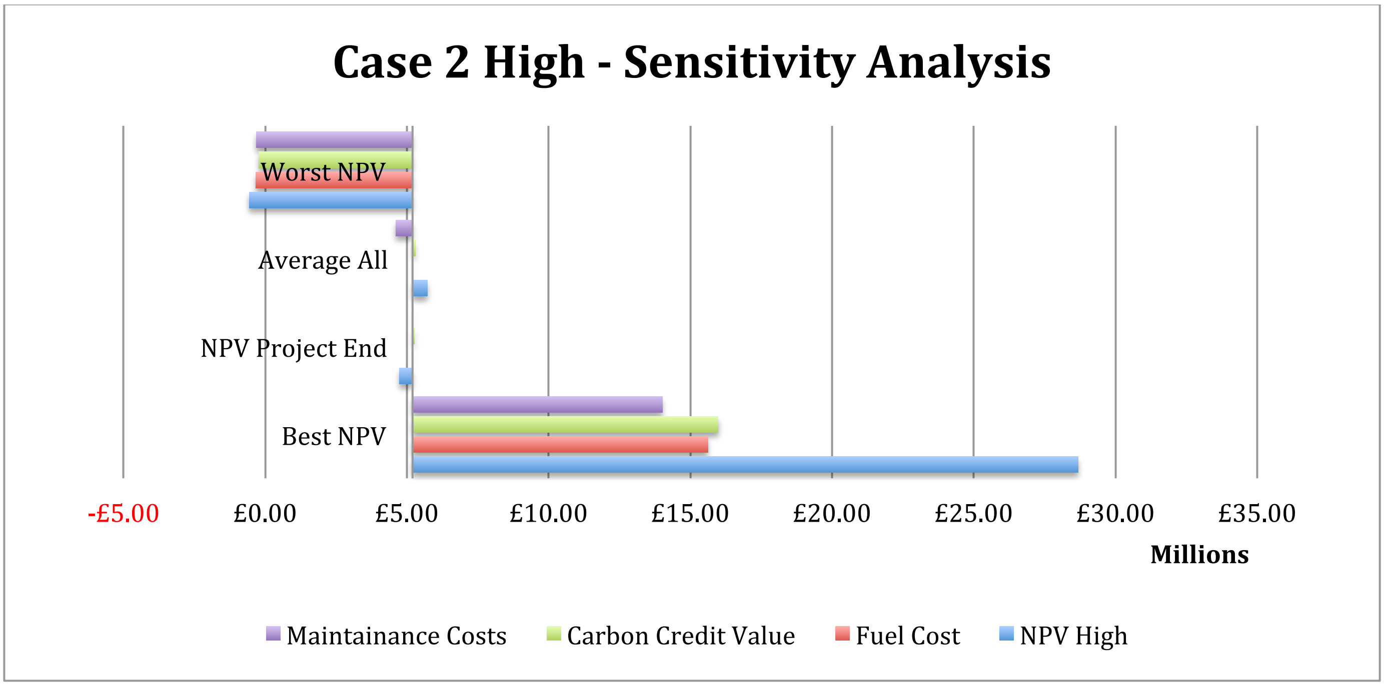

Figure 21, Case 2 High Sensitivity Analysis

5.4.2. NPV Variance Assessment

The next stage of the development was to assess the average NPV against the variance of NPV calculated from the schemes in the sensitivity analysis; this would allow the schemes to be assessed in terms of profit and risk. The tool provided the following result:

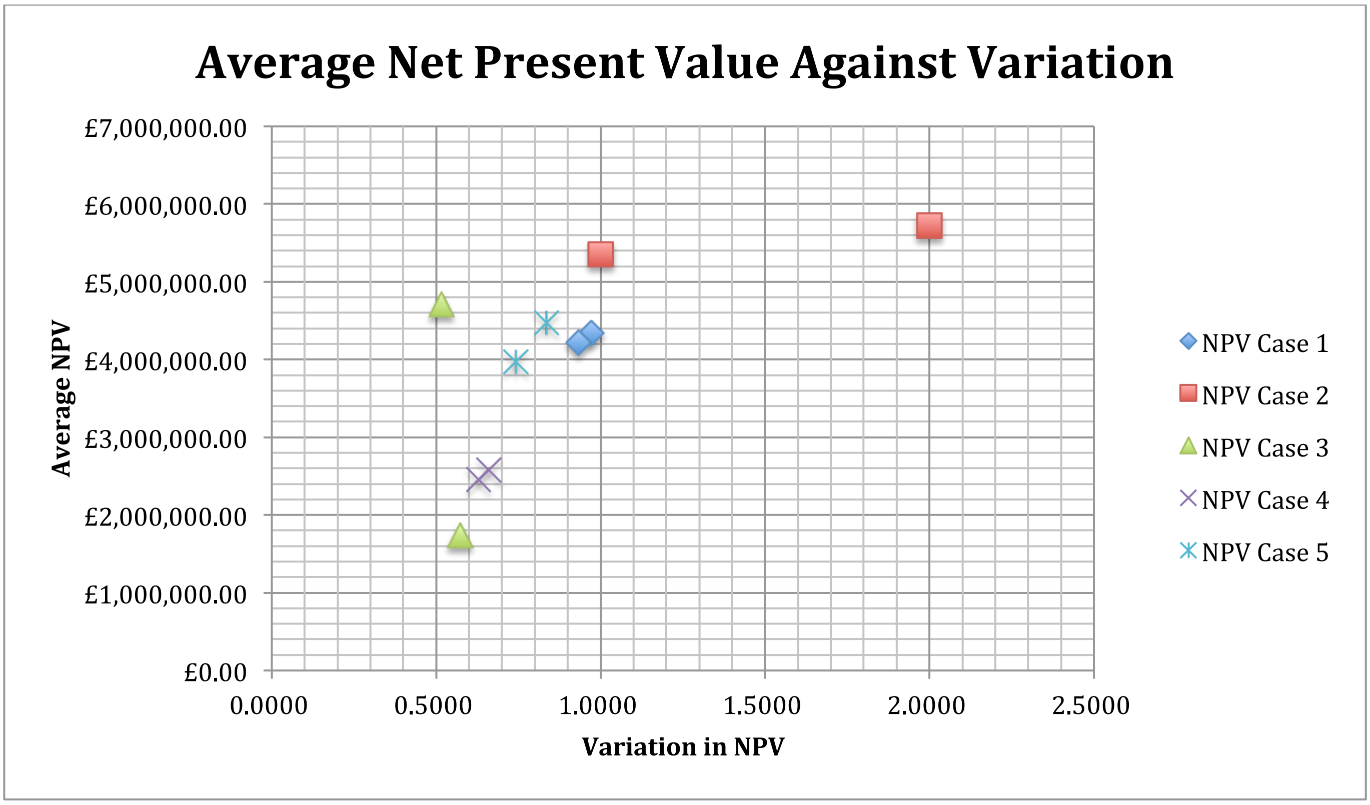

Figure 22, All Cases NPV Against Variance

This chart shows all the schemes with their average NPV plotted against the variation in of NPV observed in the calculations. The greater the variance of NPV the higher the risk involved in carrying out the project allowing the investor to make a judgement on whether this project can be successful. From the results gained it is clear that cases 3 & 4 have the lowest risk and the lowest potential profit, with cases 1, 2 and 5 with the higher variation of NPV but with higher profit. However there is a large variation of NPV between the low and high scenarios of case 2. This large variation of NPV highlights that to the investor that the scheme is high profit but also high risk with a greater chance for variation in the NPV results, there is potential to make greater profit. This analysis shows that cases 1 and 5 will be more reliable investments for a financier as the low and high capital cost assessments are closely related and the variance is not as high case 2.

5.5. Implement Decision

Finally, it is necessary to take into consideration all of the data that has been evaluated in this methodology; the merit analysis, the financial assessment and the sensitivity analysis of the schemes as one. It is important to use this data to find the scheme that is best for to meet the demands of the University of Strathclyde. From the analysis the scenarios that were brought into attention were case 1, 2 and 5. These cases performed well in the financial assessment and in the sensitivity analysis. Case 2 however was shown to be more risk averse so this can be ruled out on the basis that cases 1 and 2 did not have this issue.

Selection can now be carried out between case 1 and case 5. Case 1 utilises only CHP to meet the electricity and thermal demands and Case 5 uses a combination of devices to meet the demands. If the investor were to go for case 1 they would need to rely on fuel such as gas only to produce energy. Case 5 on the other hand does not have this problem and could be considered a better choice due to its ability to benefit from feed in tariffs and a smaller reliance on fuels.

The investor can now make the decision on whether these cases or not to invest in a scheme if it meets their requirements. Through close adherence to the methodology it is possible to take the process of finding an effective investment logically from the outset and ensure that the result is

5.6. Discussion

Through application of the methodology it was possible to take the feasibility of a scheme from start to implementation decision. Through the use of accurate data and demand supply matching it was possible to identify 5 schemes that would fit the needs of the demands effectively.

Implementation of these cases into the tool provided insight into the financial outcomes of implementing these cases as well as addition sensitivity/risk factors. Of the 5 cases selected for investigation it was found that cases 1, 2 and 5 had the greatest potential. Risk assessment of these schemes allowed case 2 to be ruled out of the analysis.

The outcome of this analysis was that the investor could select either case 1 or case 5 for the microgrid to provide energy for the University of Strathclyde. The decision for this however resides with the investor, they can take into account all of the data and analysis provided by the tool and select the outcome that suits their investment needs most closely.

6. Conclusions

6.1. Literature Review Summary

The literature review has pointed towards the important factors that are issues in the development and greater implementation of low carbon hybrid energy system microgrids. The forces that are driving this, the barriers that have the potential to slow development and the current models that are being provided to allow for deeper analysis have been assessed.

From evaluation of the drivers it was found that legislation pushing for reductions in CO2 emissions was causing the drive towards a greater use of low carbon technologies to produce the energy that people need to live. Financial incentives such as FITs and carbon allowance markets incentivised the reduction of carbon emissions. Further to this government efforts to penalise organisations that fail to reduce their emissions. This drive towards renewable energy was pushing towards a greater use of decentralised grid technologies and microgrids that allow consumers to provide for their own energy demands through hybrid energy systems.

Improvements in engineering methods mean that the development of microgrid systems is not only easier but also beneficial to the user. Important developments in this field are the smart grid and the greater use of smart metering that promises to allow for more effective use of energy supply and production.

Barriers to this development are the capital costs involved in setting up schemes, price of fuels, carbon market value and the ability for investors to see good potential for investments. Review pointed that the investor's view of a project played a large part in the chances of a project being invested in.

Current models were also assessed that are being used to assess the feasibility of microgrid sites. Three currently used tools were analysed and their relative merits assessed. A weakness was discovered for the Merit analysis tool was discussed and a need for a greater ability to develop financial and sensitivity/risk analysis outcomes from Merit analysis was identified.

6.1.1. Research Outcomes

A decision making framework was developed that provides a solid process in which an effective decision can be made by investors and engineers alike as to the type of scheme that would fit a site and what financial outcomes can be expected. Methodology provides the direction required to use the tools available correctly to find the best solution for an investor. Framework takes into account the needs of stakeholders when considering a microgrid scheme, in particular the engineering side and the financial investment side. This methodology seeks to streamline the process of decision-making and allow for more effective decisions being made.

A financial decision-aiding tool has also been developed that is used in conjunction with the framework process alongside a demand/supply-matching tool such as Merit. This tool allows the user to assess up to 5 different microgrid projects at a time over 20 years of project life. The tool provides potential investors with the financial data that they need to make good investment decisions when considering microgrids. The tool seeks to improve the decision making of investors through the use of sensitivity analysis, also provides a risk analysis to allow the user to assess the project in terms of profit and variability of risk. Comparisons can be made between up to 5 schemes at a time allowing schemes to be compared against each other. The tool provides the user with the necessary analysis to effectively consider a potential microgrid scheme, providing them with the key data that they need and allowing them to make their own judgement on whether they should invest.

The inherent value of this research is how the methodology is applied to a real situation. A case study on the University of Strathclyde's energy demands and potential to implement a hybrid microgrid energy system is carried out. This study utilises real data that has been collected by half hourly meters and can be seen as accurate representation of the energy consumed in one year. One of the outcomes of this analysis is highlighting two potential schemes that could be implemented at the university, allowing an investor to decide on which scheme would suit best.

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