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Reducing the Carbon Footprint of Domestic and Commercial Buildings

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Project Report

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Reducing the Carbon Footprint of Domestic and Commercial Buildings
By N T Hayden

This report was written by Nathanael Hayden as the main component of his final year personal project in our BEng programme in Mechanical Engineering. I supervised the work. The aim was to understand what can be achieved with existing building stock, not newly constructed buildings.

The IP of our student projects rests with the student and Nathan is willing for the report to be distributed, providing authorship is properly acknowledged; e.g. as:

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Yours sincerely,

Alan Robins

Alan Robins
Professor of Environmental Fluid Mechanics

Abstract

There is significant evidence that the Earth's climate is warming; this is often referred to as 'global warming' which is having many negative consequences. Climate change is therefore one of the most important issues to be addressed in the modern world. Most climate scientists agree that the main cause of global warming is due to the greenhouse effect. The greenhouse effect is when greenhouse gases in the atmosphere trap the heat radiating from the Earth towards outer space, leading to the increase in the global temperatures. The greenhouse gas CO_2 contributes approximately 70% of the global temperature rise. Therefore, it is essential to reduce the worlds carbon emissions.

In the UK 46% of total CO_2 emissions are from the residential (mainly from fossil fuel heating systems) and electricity generation (mainly from fossil fuel power stations) sectors. Therefore carbon saving technologies have been researched to reduce the carbon emissions generated by these sectors. The technologies analysed include Wind Turbines, PV Solar Panels, Energy Storage, Solar Heating, Micro Combine heat and Power, Heat Pumps, Grid Stabilisation, Insulation and Ventilation systems. The project then analysed two case studies, one on an economically driven rural farm in Hertfordshire and another on an environmentally driven carbon neutral house in Ottawa. Finally, a hypothetical urban home was analysed and suggestions were made for the appropriate carbon saving technologies, which could be used to reduce the carbon emissions and running costs of the home.

The analysis shows that each carbon saving technology has their advantages and disadvantages and their different optimum usage. The technologies that are most suited to low carbon electricity generation in the future are wind turbines and PV solar panels. Wind turbines are generally suitable for grid electricity or for large industrial installations in rural areas and solar panels are suitable for both rural and urban areas. However, since the UK's government tariffs for solar energy have been removed the economic benefits of small-scale PV arrays have been significantly reduced. Nevertheless, as the price of electricity continues to rise and the price of solar panels continues to fall this picture could change in the future and it may again be economically viable to have solar panels on small domestic rooves. The most suitable technology for heating buildings, both environmentally and economically are heat pumps. The environmental benefits of heat pumps are depended on the carbon emissions generated by the electricity generation sector, however as this sector continues to reduce its carbon emissions per kWh, heat pumps are becoming more environmentally beneficial. The economic benefits of heat pumps, however, mostly come from the government tariffs, therefore heat pumps will continue to be used extensively whilst the government tariffs remain.

The farm case study has shown the environmental and economic benefits of carbon saving technologies and the importance of government incentives for businesses, encouraging them to use the technologies. The carbon neutral house in Canada shows how the technologies can work together to remove the net carbon emissions from a dwelling to ensure a greener future. The most suitable carbon saving technologies used in the hypothetical urban home were PV solar panels, a heat pump, and either a hybrid or a fully electric vehicle. The environmental benefits of these technologies were significant. The economic benefits of changing their vehicle and the heat pump were also large however the economic benefit of the PV solar panels were minimal this is due to the removal of the government tariffs of solar panels.

Acknowledgments

I would like to take this opportunity to give my appreciation to the following people for their contributions without which it would have not have been possible to complete this project.

Firstly, I owe a debt of gratitude to my project supervisor Professor Alan Robins for giving me continual support and guidance throughout our frequent meetings and discussions. His advice and comments on draft of the project has been invaluable.

A hearty thanks to Dr Art Hunter for providing very interesting information regarding his carbon neutral property in Ottawa, Canada. The carbon saving project he has completed on his house is truly a glimpse into the future.

My special thanks goes to the farmer Matthew Northern who has provided the data needed for the farm project. He has answered many questions regarding the government tariffs and consumption of both thermal and electricity energy in the various building at his farm in Hertfordshire.

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1. Introduction

1.1 Climate change

The thermal energy that moves through the Earth's atmosphere creates the Earth's weather patterns. The long-term averages of the global weather are called the Earth's climate, therefore changes to the Earth's climate are called climate change.

The climate system receives almost all its energy from the Sun with a small amount coming from the Earth's core. The Earth emits energy into outer space and the difference between the energy emitted and the incoming energy is the Earths energy budget. In the long-term, when the absorbed energy is greater than the emitted energy there is a positive energy budget resulting in the climate warming, if the absorbed energy is less than the emitted energy then there is a negative energy budget leading to the climate cooling.

There is significant evidence that the Earth's climate is warming; this is often referred to as 'global warming' which is having many negative consequences. Climate change therefore is one of the most important issues to be addressed in the modern world.

There are many different factors affecting the Earth's climate and which contribute to global warming. The main three factors are volcanic activity, solar activity and human activity. Both solar and volcanic are out of our control; however, there have been studies completed that suggest that the solar activity has not significantly changed and the effect of volcanic activity is relatively minor, so therefore the climate change over the last century is mainly due to human activity.

Most climate scientists agree that the main cause of global warming today is due to the greenhouse effect. The greenhouse effect is when gases in the atmosphere trap the heat radiating from the Earth towards outer space, reducing the Earth's emitted energy resulting in a positive energy budget leading to the increase in the global temperatures. (NASA, 2019, BYJU's 2019, United nations climate change, 2018)

Figure 1 illustrates the greenhouse effect:

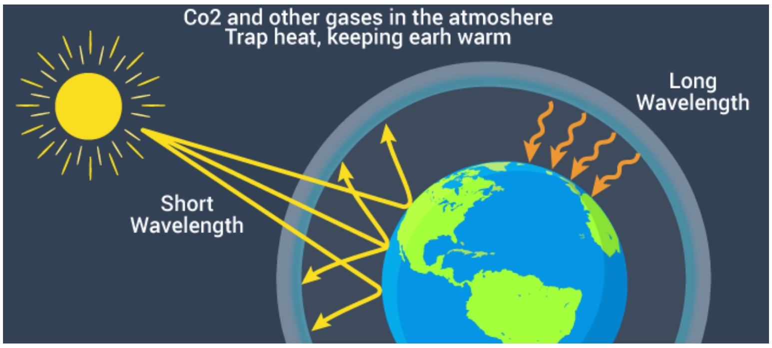

Figure 1: Diagram showing the greenhouse effect (BYJU's 2019)

The gases which contribute the most to the greenhouse effect are called greenhouse gases. The main gases that contribute to the greenhouse effect are methane, CO_2 and water vapour.

Methane is one of the worst greenhouse gases, it contributes the most per tonne to the greenhouse effect. Methane is mainly caused by livestock and biodegrading material, therefore landfills often release a large quantity of methane.

CO_2 is another greenhouse gas however, per tonne of CO_2 released it contributes less to the greenhouse effect than methane. CO_2 is released in large quantities by the combustion of fuels.

Water vapour is the most abundant greenhouse gas, it absorbs infra-red in the same way as CO_2, however it acts as a feedback to the climate. Water vapour increases as the Earth's atmosphere warms, but so does the possibility of clouds and precipitation, therefore water vapour is an important feedback mechanism to the greenhouse effect.

Out of all the greenhouse gases CO_2 contributes approximately 70% of the total global warming, this is because over 80% of the greenhouse gases released is CO_2. It is estimated that the human activity over the last 150 years has raised the concentration of carbon dioxide in the atmosphere from 280 to over 400 parts per million. The full extent of the damage that this will cause is still unknown, but a number of suggestions have been made, these include:

An increase in the average temperature on Earth leading to extreme temperatures in some areas.

The warmer temperatures would cause more evaporation and precipitation which could lead to flooding in some areas and leave other areas very dry, this could result in destroying organisms' habitats.

The higher temperature would cause the oceans to increase in temperature. This would melt some of the remaining glaciers and ice caps, increasing sea level. Also, the ocean water will expand if it warms, further increasing sea levels. This sea level increase could cause low lying areas to be claimed by the sea. The melting ice and the sea claiming more land would dramatically affect low lying coastal communities and also destroy animal habitats leading to the extinction of some species.

However, some crops and other plants may be positively effected by the increased CO_2 levels, and therefore the farming communities would have to adapt to the changing climate.

This large increase in the quantity of CO_2 emitted into the environment is caused by the use of fossil fuels. The use of fossil fuels is not only damaging to the climate, it is also not sustainable. It is estimated that there are 53 years' worth of crude oil reserves if we continue at the current rate of extraction before all the reserves are gone. This shows that even if the fossil fuels were not having a negative effect on the environment it is still essential to move from using them to more sustainable technologies. (ZMEScience, 2018)

To tackle climate change, the UK and 190 other countries drafted the Paris agreement, this came into force at the end of 2016 and set out a number of targets for each country to reduce their carbon emissions. This is to ensure that by 2050 the global average temperature rise is less than 2°C above pre-industrial levels. The UK's target is to reduce greenhouse gas emissions by at least 80% by the year 2050, relative to 1990 levels. The agreement also set out a target for net zero global emissions between 2050-2100. (NASA, 2019, BYJU's 2019, United nations climate change, 2018)

Figure 2 shows how the UK has started to tackle climate change already. The total of greenhouse gases emitted reduced by 44% in the last 38 years. The UK has achieved this by reducing the carbon emissions

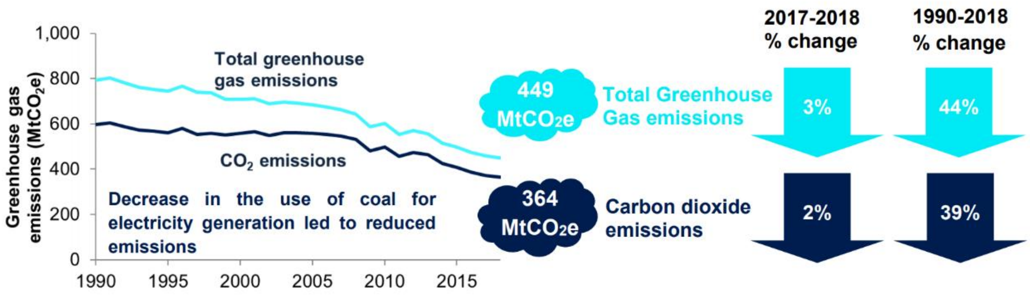

Figure 2: Graph showing the total greenhouse gases released from the UK between 1990 and 2018 (Gov.uk(a) 2018)

particularly in the electricity generation industry. (Gov.uk(a) 2018)

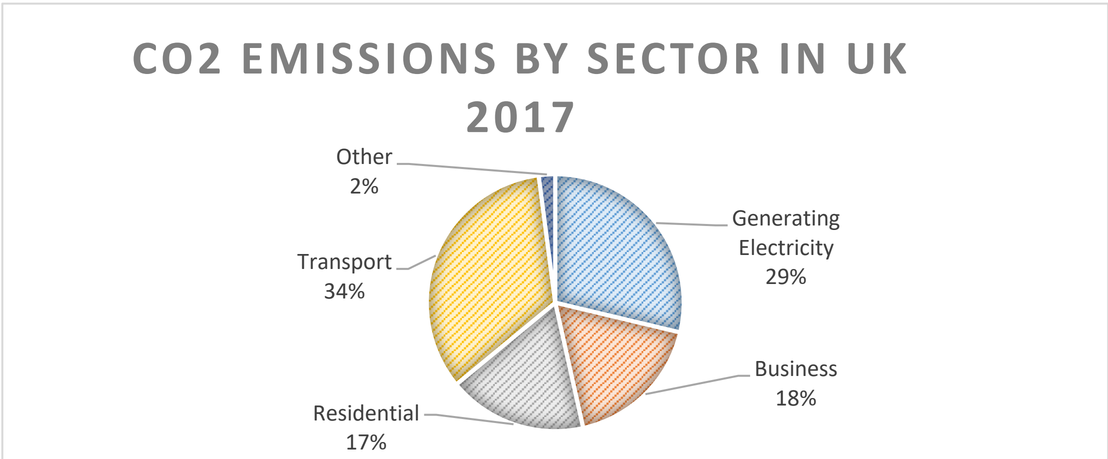

Figure 3: CO_2 emissions by sector in the UK (Gov.uk(a) 2018)

The CO_2 emissions in the UK by each sector is shown in Figure 3. The transport sector contributes to the CO_2 emissions the most, however, and by 2025 the transport sector is expected to reduce its carbon emissions by 20%. This is mainly because of the shift away from the internal combustion engine, towards fully electric vehicles. This shift in the transport sector towards electrification will have a large impact on the electricity generation sector. It is predicted by 2025 the demand on the electricity grid will be 10% higher than the current demand. (Autocar, 2019) (Gov.uk(a) 2018)

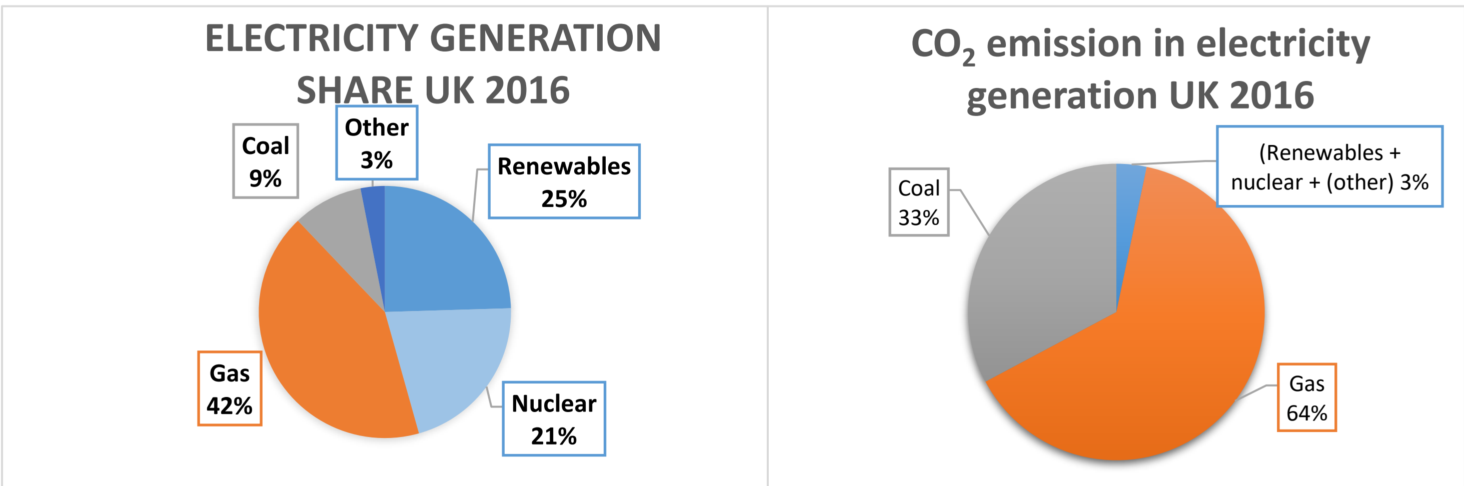

Figure 4: Showing the electricity share in the UK (Left) showing the CO2 emissions from each technology (Right) (Gov.uk 2018)

Eelectricity is generated in the UK by many different technologies, this is called the generation share as seen in Figure 4 (Left):

In Figure 4 (Left) the proportion of electricity generated by the renewables and nuclear makes up 46% of the electricity generation and coal power plants only contribute a 9% share, however, in Figure 4 (Right) the CO_2 released from the renewables and nuclear contribute only 3% of the CO_2 released, compared with coal contributing 33%. This shows that moving towards renewable and nuclear generation technologies can significantly reduce the CO_2 emissions from the electricity generation sector. (Gov.uk(a) 2018)

1.2 Objectives

The overall aim is to review the potential for greenhouse gas emission reductions from dwellings and industrial activities. First, the different available technologies which can reduce the carbon emissions from both the electricity generation and the residential sector and reviewed. The CO_2 emitted from the electricity generation sector is mainly caused by large fossil fuel power stations so this project will be researching alternative carbon saving technologies. The CO_2 emissions from the residential sector is almost all from heating systems and cooking facilities so in this project the different technologies for heating homes will be explored to reduce the carbon emissions from this sector. Some of the technologies which will be discussed move away from fossil fuel-based heating to using electricity to heat homes, this further increases the demand on the electricity generation sector.

Then a number of case studies of buildings that have carbon saving technologies installed will be presented to determine the environmental and economic benefits of the technologies. Finally, a hypothetical urban home will be analysed and suggestions made for appropriate carbon saving technologies which could be used to reduce the carbon emissions and running costs of the home.

2. Carbon saving technologies

2.1 Wind Turbines

2.1.1 Wind Power History

In the early development of wind power it was mostly used for milling grain and pumping water, converting wind power into mechanical power. The location of the first windmills is uncertain however there is evidence to suggest that the first windmills and wind pumps had a vertical axes rather than horizontal as they are today. In the 1800s, the use of wind power to mill grain and also to pump water became much more popular in Europe; it peaked around the 1850s when there were around 200,000 windmills- these all had horizontal axes. The first wind turbines capable of producing electricity were developed by Paul La Cour from Demark in 1891. Soon after, in 1922, the Jacobs brothers in America produced the first battery-charging wind turbines. The first megawatt wind turbine was the Smith–Putnam wind turbine installed in the early 1940s. It was the largest wind turbine ever produced until 1979, however it had a blade failure when it had completed 1100 hours. One of the eight-ton blades became unattached from the rotor at a known weak point, at this time there was a lack of materials due to the war so the turbine was dismantled in 1946. (Andreas Sumper, Oriol Gomis-Bellmunt, Francisco Díaz-González 2016) (History 2018)

In the year 2000 offshore wind turbines became a popular option due to the higher and somewhat steadier wind speeds, also the possibility to install larger wind turbines as there are fewer restrictions than on land. The main technology drivers for offshore wind turbines are reliability and availability, the turbines must be reliable as this reduces maintenance costs significantly. One key technical advance was in the drive to the generator. The large ratio gearboxes in the turbine were the main source of reliability issues, therefore the generator was developed to run at low speed reducing the gearbox ratio, which enabled the reliability to be improved. The other technology driver was availability, how long the wind turbine is able to produce electricity when the wind conditions are above the minimum threshold. Things that reduce availability are both scheduled and unscheduled maintenance and turbine shut down due to the wind speed being too high. To increase availability, well designed turbines for the specific operating location and environment are necessary. (Andreas Sumper, Oriol Gomis-Bellmunt, Francisco Díaz-González 2016)

Following the Industrial Revolution, wind power was considered expensive and unreliable compared to the use of fossil fuels and the internal combustion engine. However over the last 20 years wind power has been developed massively. Electricity generation by wind is one of the world's fastest growing renewable energy technologies, despite the high cost and low level of government subsidies. It is estimated that at the end of 2017 the amount of installed wind power worldwide was

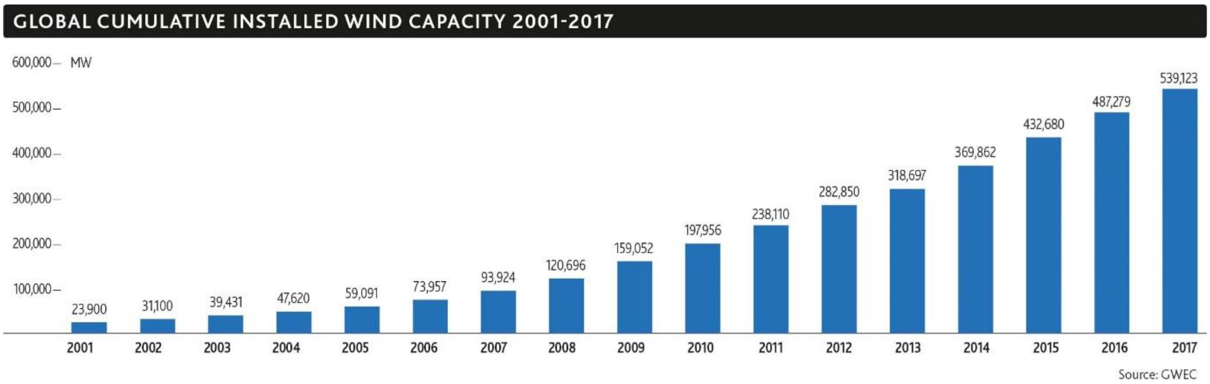

Figure 5: Global Installed Wind Capacity 2001-2017 (Global wind energy council, 2018)

around 539 gigawatts. During 2017 alone, more than 52 GW of wind power was installed based on the information of the Global Wind Energy Council. Figure 5 shows the cumulative global wind power installed capacity. (Andreas Sumper, Oriol Gomis-Bellmunt, Francisco Díaz-González 2016) (Global wind energy council, 2018)

2.1.2 Technology

The dominant concept design for wind turbines is shown in Figure 6, the well-known horizontal-axes turbine with a three-bladed rotor. The blades are connected to the rotor which is comprised of the

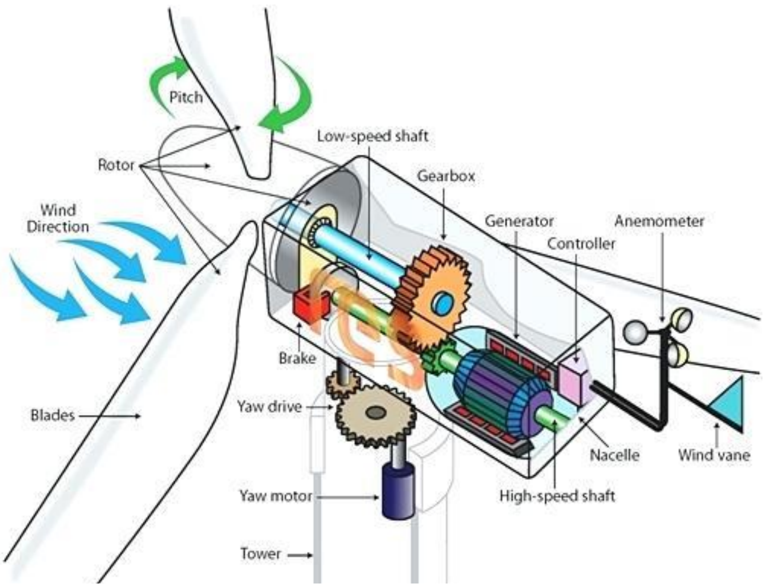

Figure 6: Diagram showing a wind turbine design. (Noupoort Wind Farm, 2017)

hub and low speed shaft, the blades capture energy from the wind and thus rotate the low speed shaft which then rotates the gears in the gearbox. The gearbox increases the rotational speed transferring the power to the high speed shaft which is connected to the generator, the generator converts the mechanical power into electricity. In some turbines the generator is modified so that the rotor has the same speed as the electrical generator, therefore the gearbox is removed reducing the complexity of the mechanics of the turbine, thus reducing maintenance costs. The pitch system allows the controller of the turbine to limit the incoming power from the wind by changing the blade angle, this is necessary in order to keep the machine within its power limits and increase the availability of the turbine. (Chaouki Ghenai, 2012)

Wind turbines are located both onshore and offshore. The main difference between them is the support structure. Onshore wind turbines are installed on a concrete basement, whereas offshore wind turbines are supported using two different methods, a floating structure which is tethered to the seabed or a structure which is directly attached to the seabed.

Figure 7 shows the different types of structures used to support offshore wind turbines:

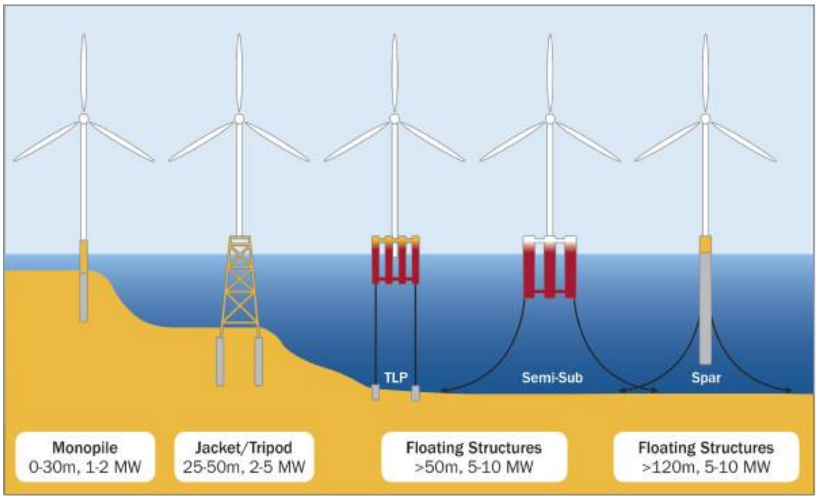

Figure 7: Diagram showing the different types of supports for offshore wind turbines (Helen Bailey, Kate L Brookes, Paul M Thompson, 2014)

The diagram shows that as the sea gets deeper the support for the wind turbine changes. It is better to have a floating wind turbine compared to having the structure directly attached to the ground in deeper water, the large range of possible depths that wind turbines can be located in allows the location of the turbines to be where there is the highest mean wind speed for maximum electricity generation. A benefit of the wind turbine being far out at sea is that the turbine has fewer effects on humans as they are further away from people's dwellings so the noise pollution and the view pollution are less of an issue. (Helen Bailey, Kate L Brookes, Paul M Thompson, 2014)

2.1.3 Positives of Wind Power

The main benefit is that the carbon footprint per kilowatt hour for the life cycle of a wind turbine is much less than traditional methods of electricity production. The life cycle carbon footprint for a coal powered power station is approximately 1000g CO_2/KWh depending on size and efficiency, whereas the lifecycle efficiency for a wind turbine is approximately 12g CO_2/KWh. The reduction in carbon footprint is therefore very significant, wind turbines produce around 1.2% of the life cycle carbon footprint compared to a coal fired power station. This is a large benefit of wind power compared with conventional electricity production methods. The life cycle assessment evaluates all the carbon dioxide emissions throughout the life of the product, therefore the manufacturing, installation, use, maintenance and disposal/recycling are all taken into consideration. Almost all of a wind turbine's carbon emissions are released when manufacturing and installing the turbine, no actual carbon is released when the turbine is in operation whereas for the coal fired power station most of the carbon is released during use i.e. burning the coal.(NREL, 2018)

Another advantage is that it is sustainable, as the wind is produced by the heating of the atmosphere by the Sun, the rotation of the Earth, and other factors the wind is an endless source of energy. For as long as the Sun shines there will be energy in the wind.

Furthermore wind energy is, if the turbines are located in an appropriate location, cost effective. Studies have shown that, in the UK onshore wind turbines are the cheapest form of electricity production, this is due to new rules put on fossil fuel power stations regarding their carbon emissions.

Another advantage of wind power over solar energy is that the physical footprint of a wind turbine is small compared to the equivalent power coverage of a solar farm etc. This is a large benefit as not a large amount of land becomes unusable due to the renewable energy source. (Kohilo, 2018)

2.1.4 Negatives of Wind Power

Some of the possible negatives of wind energy are that they are not as predictable as other renewable energy resources like hydroelectric and tidal power, therefore if the grid had a large proportion of the total energy produced by wind power further infrastructure would be needed to maintain stability within the grid. This could be done using large energy storage technologies. The exact proportion of the grid that is necessary before large scale energy storage is necessary depends on the other technologies used in the electricity generation share, for example if the grid has a high proportion of nuclear power plants and also a high proportion of wind power then large scale energy storage is essential to remove the peaks and troughs between supply and demand, however if an electricity grid has a high proportion of electricity generated by gas turbine power stations, energy storage is not such an issue as gas power plants have a short start up time.

Another disadvantage is that often the most suitable place for wind turbines are in remote locations, this means that the power is produced a long way from where the power is required. This results in a large amount of infrastructure needed to transmit the power into electricity-demanding places, for example cities. This presents a significant infrastructure cost as well as a significant loss of electricity in transmission.

Although wind turbines produce no greenhouses gases when they are operating there are some concerns over the noise produced by the rotating blades and the visual impacts. Development of the rotor blades have been done to reduce the noise pollution reducing this issue.

Other issues with wind turbines are that they can damage the local wildlife, there are reports to suggest that the rotating blades can hit flying birds etc., to reduce this issue wind turbines are placed in a location where the wildlife damage is minimalised. (Kohilo, 2018)

2.2 PV Solar Panels

2.2.1 PV Solar Panels History

The basic principle of PV (photovoltaic) solar panels is to convert light energy to electricity. In 1839 the photovoltaic effect was discovered by a French physicist named Alexandre-Edmond Becquerel and the first solar panel was made in 1883 by Charles Fritts. The panel was made from selenium wafers. No further development of solar panels occurred until Albert Einstein provided the theory of the photoelectric effect which helped establish the solar panel theory for future development. In 1954 in the US bell labs the photoelectric properties of silicon were discovered. A solar panel was then developed that had an efficiency of 6%, this was the start of solar power as we know it today. In 1958 the Americans launched a satellite which was solar powered; this satellite is the oldest satellite still in orbit today.

Further development of solar panels in the late 1950s increased the efficiency to 10%, and then again to 30% in the 1990s.

In 2008 the government feed in tariffs were introduced in the UK, which financially encouraged the technology to be used and to be further developed.

It is estimated that the worldwide solar energy capacity was over 400 GW at the end of 2017 and is expected to be over 500 GW at the end of 2018. Compared with other renewables such as wind power, the world's solar capacity is growing the fastest as the technology improves and the unit cost continues to fall. (Solar Share, 2016) (Labouret, Anne; Villoz, Michel, 2010)

2.2.2 Technology

Solar cells, commonly called 'photovoltaic cells' are a device that converts light into electricity. The photovoltaic effect occurs in most semiconductors when they absorb a photon which excites an electron in the material which then is extracted into an electrical circuit to generate a current. (Ossila, 2018)

The Cell's Semiconductor

The main part of the solar cell is the semiconductor, this is where the light energy is converted into electricity. The electron level structure of a semiconductor is unique compared to other types of materials which makes it suitable to use in solar panels. Electrons in an atom are in the shells or bands of the host atom, there are many band levels each with increasing electron energy when moving further from the nucleus of the atom. The highest electron energy filled band is called the

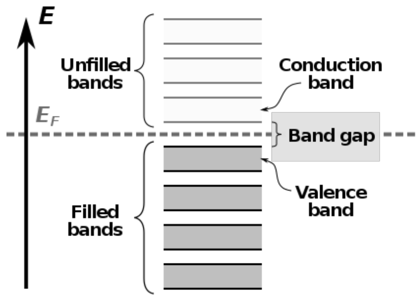

Figure 8: Diagram showing electron energy bands (Wikipedia, 2018)

valence band. The lowest electron energy unfilled band is called the conduction band (see Figure 8). (Ossila, 2018)

The energy difference between the valence band and the conduction band is called the band gap. In a conductive material there is no band gap as the valence band is not filled completely allowing the electrons to move freely through the material, this occurs in metals and enables them to conduct electricity. An insulator however has a very large band gap that results in electrons needing a very large amount of energy to jump to the conduction band which is unlikely to occur, this prohibits the flow of electrons and therefore is a good insulator of electricity. Semiconductors have a relatively small band gap resulting in some electrons being able to jump to the conduction band if given enough energy.

Figure 9 shows a diagram of the band gap between different types of materials.

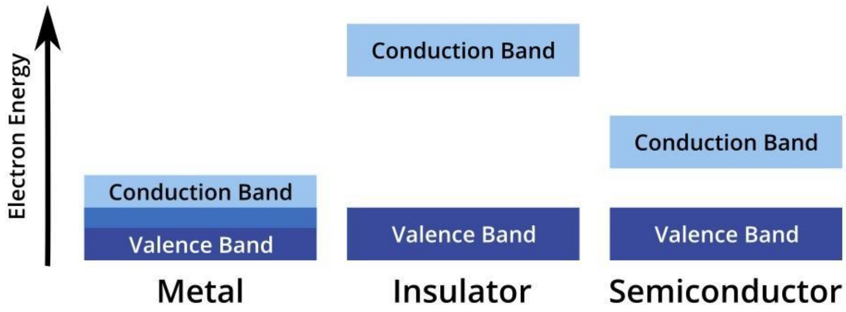

Figure 9: Diagram showing different band gaps between different types of materials (Ossila, 2018)

This small band gap in a semiconductor can be used to generate electricity from light. When photons of light hit the semiconductor material they interact with electrons in the valence band. If the energy given to the electrons is greater than the band gap the electrons jump from the valence band into the conduction band. This process is called excitation. As the electrons are now in the conduction band there are holes in the valence band. This results in the bands having opposite charges resulting in the excited electrons and the holes being coulombically bound. This has to be split before the electron charge can be used, the energy required to do this depends on the dielectric constant of the material. If the dielectric constant for a material is high there is low binding energy between the charges in the semiconductor and therefore the bonds can be broken at ambient temperatures. Once the charges between the electrons and the holes are broken the free charges diffuse into the electrodes of the cell where they are collected. This occurs due to an applied electric field in the semiconductor. This electric field is caused by the relative energy levels from the materials that make up the cell and is dependent on the semiconductive material used. For inorganic semiconductors like silicon the material is doped; i.e. other materials are added to create regions of high (n-type) and low (p-type) electron density, which creates the electric field in the semiconductor. (Labouret, Anne; Villoz, Michel, 2010) (Ossila, 2018) (Leonid A. Kosyachenko, 2015)

As explained above, the band gap is very important for a solar cell to work as the band gap determines how much energy the electrons need to jump to the next band. If the energy given to the electron by the photon is greater than the band gap then the photon will be absorbed, any energy in excess of the band gap energy will move the electron to the bands above the conductive band. The electron will then relax and fall back to the conduction band resulting in a loss of excess energy. If the energy given to the electron is less than the band gap energy then the electron will not move up to the conduction band and the energy is lost. It is therefore critical that the band gap is designed for the specific application as it is a compromise between the two extremes. As Sunlight photons interact with the electrons in the semiconductor they give the electrons a large variety of energies. It is an impossibility to collect all the available power from the Sun and convert it to electricity due to the fixed band gaps. Therefore the maximum efficiency of a single p-n junction (single semiconductive layer) is approximately 33.7%. However, multiple layers of p-n junctions can result in much higher efficiencies. The theoretical limit of efficiency for an infinite number of p-n junctions with Sunlight in the perfect position is approximately 86%; therefore the efficiency of solar panels should increase when multiple p-n junctions are used as they capture more energy from excited electrons. (Labouret, Anne; Villoz, Michel, 2010) (Ossila, 2018) (Leonid A. Kosyachenko, 2015)

2.2.3 Types of Solar Cells

Silicon solar cells

Silicon solar cells were the first panels to reach the commercial market, and with a peak efficiency of 25.3%, the majority of solar panels use silicon as the active material. The band gap of silicon is 1.1ev which is below the optimum - therefore some energy is lost due to the electrons moving to higher energy bands. Also the absorption efficiency is relatively low, which is compensated by a thick layer of silicon being used to capture the photons. (Ossila, 2018)

Cadmium Telluride as semiconductive material

Cadmium Telluride panels are thinner than silicon panels with good absorption due to the band gap being around 1.44ev, they have a peak efficiency of 22.1%. The panels are also flexible which can be beneficial in some applications. The cost of cadmium telluride panels is also relatively low resulting in payback times being less than silicon panels despite the lower efficiency. The negatives of using cadmium telluride in solar panels is that it is highly toxic and very rare, which would limit large scale production of solar panels using this semiconductive material. (Ossila, 2018)

Gallium Arsenide

Gallium arsenide has high performances as the active material in solar panels resulting in a high efficiency of up to 28.8% due to its favourable band gap of 1.43 ev. Also the electro transport properties of gallium arsenide are superior to silicon. However, gallium arsenide is very expensive to produce and has to have a high material purity. This active material in solar panels is normally limited to space exploration and satellites. (Ossila, 2018)

2.2.4 Positives of Solar Panels

The advantage of solar energy is that it is renewable, as long as the Sun shines there will be the possibility of harnessing the energy it produces and generate electricity. The life cycle assessment carbon footprint for a solar panel is approximately 48 g CO_2/KWh, this compared to the life cycle assessment for a fossil fuel PowerStation which is approximately 1000 g CO_2/KWh. Therefore solar panels are significantly better for the environment than traditional methods of electricity generation.

Another advantage of solar panels is the panel price has reduced significantly over the last few years mainly due to the large demand driven by government tariffs. However the government tariffs finish in March 2019. As the price of panels have dropped significantly it will still be economically viable to install solar panels without the government tariffs if a large proportion of the generated electricity is used on site and not exported back into the grid.

Solar panels have no moving parts and have a long service life, often manufacturers will offer a 20-25 year guarantee. Also the maintenance costs are very minimal, most of the costs are to keep the panels clean, how often this has to be done very much depends on the environment that the panels are subjected to, however for most applications a clean every two years is sufficient. The inverter can go wrong and may need replacing but has a very minimal maintenance cost compared with other renewable energy sources.

Compared with other renewable schemes, solar panels can be put almost anywhere including in cities, this is a large benefit as most renewable schemes require large areas of free space whereas solar panels can just be put on the roofs of buildings. (World Nuclear Association, 2016) (Energy informative, 2014) (Green Match(a), 2018)

2.2.5 Negatives of Solar Panels

One of the largest drawbacks of solar panels is that they only work when the Sun shines, this is an issue as particularly in the winter months where there are few daylight hours or on an overcast day there is only a small amount of energy produced. These means that, like most renewables there needs to be an external backup. This can be in the form of a diesel generator or an energy storage system to level the peaks and troughs in the energy production and usage when running from an unreliable energy resource. Also as seen in Figure 10 the average radiation from the Sun per year is different for different parts of the UK, this would therefore have to be considered when installing solar panels.

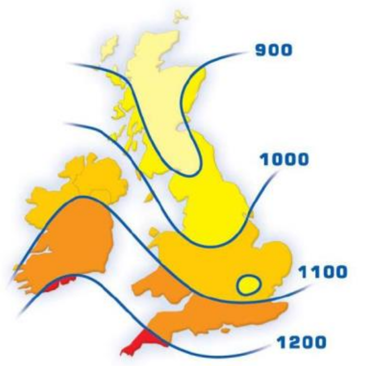

Figure 10: Average number of kWh of light energy per metre squared in the UK (Stickings plumb heat, 2018)

Another disadvantage is that although solar panels can be put on already existing structures (houses etc.), larger scale solar systems require a great deal of space, between 3.5-10 acres per MWh. This is a significant area which could lead to land degradation and habitat loss for wildlife.

The initial cost of solar panels is high compared with fossil fuel alternatives with the same capacity; however the cost per unit is significantly less than other renewable schemes like hydroelectric plant and wind power making it much more affordable for home owners for domestic use. (Green Match(a), 2018) (Stickings plumb heat, 2018)

2.3 Energy Storage

As renewable energy sources become a larger proportion of the energy in the grid there is an increasing demand for suitable energy storage infrastructure which will even out the peaks and troughs in electricity demand and supply. This is because most renewable power sources are not able to supply a constant electricity output as they rely on natural power which is not constant. For example, wind and solar energy have times they can produce electricity and times they are not able to. Therefore suitable energy storage is essential for supplying a reliable grid which uses a high percentage of renewable power. For the purposes of this project the only energy storage mechanism that will be considered in detail is the battery storage technology, this is because battery storage is the most suitable for an individual building, as the other storage technologies like hydro pump storage are on a much larger scale and therefore will not be considered in detail for this project.

2.3.1 Battery Energy Storage

A battery is an energy storage system which converts electrical energy into potential chemical energy when charging, and converts chemical energy into electrical energy while discharging. Batteries work on the principle of reduction and oxidation reactions (redox reactions). A reduction reaction allows the component involved to gain electrons whereas an oxidation reaction allows the component to lose electrons. These reactions produce new electrochemically active substances, ions with an electric charge. Battery cells provide the conditions needed for the redox reactions to occur, which generates a flow of ions between the anode and the cathode. This flow is conducted through a circuit, one part being the battery itself, this is when the ions flow between the components of the battery, and the other part is the system that the battery is connected to, which can be either a load (which discharges the battery) or an external energy source (which charges the battery).

The main battery cell contains electrodes, two pairs of electrochemically active substances, an electrolyte, a separator and a container which the components are fixed to. Each part of the cell is expanded on below. (Andreas Sumper, Oriol Gomis-Bellmunt, Francisco Díaz-González, 2016)

The Electrodes

A battery has two electrodes, the anode and the cathode. When the battery is discharging, oxidation occurs on the anode, which captures the electrons lost by the cathode and the electrons flow out of the anode into the device which the battery is connected to; the anode is the negative terminal of the battery. The cathode is the positive electrode and reduction reactions occur at the cathode during discharge. (Andreas Sumper, Oriol Gomis-Bellmunt, Francisco Díaz-González, 2016)

Two pairs of electrochemically active substances

The pairs of electrochemically active substances are used to create the oxidation and the reduction reaction in the anode and cathode respectively. There is one type of pair in the anode region and another type of pair in the cathode region, as seen in Figure 11 these play an important role to make the battery function for the movement of electrons. (Andreas Sumper, Oriol Gomis-Bellmunt, Francisco Díaz-González, 2016)

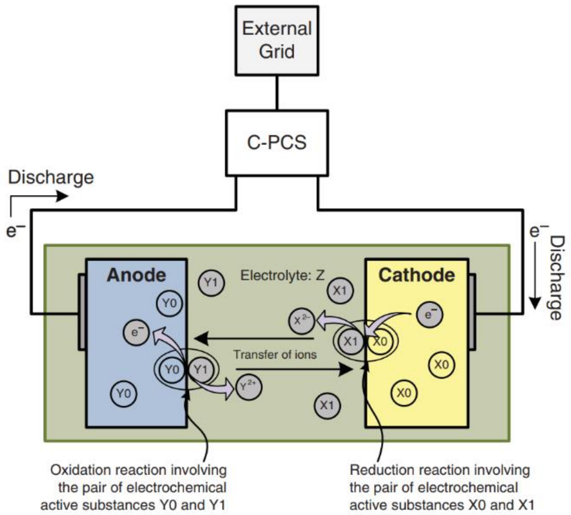

Figure 11: Diagram showing the basic principles of a battery cell (Andreas Sumper, Oriol Gomis-Bellmunt, Francisco Díaz-González, 2016)

The Electrolyte

The electrolyte in the battery cell is the catalase which helps the movement of ions from the cathode to the anode and vice versa, the electrolyte can be either a solid or a liquid and is an electrical insulating substance so as to not short circuit the battery. (Andreas Sumper, Oriol Gomis-Bellmunt, Francisco Díaz-González, 2016)

The Separator

The separator in the battery avoids direct contact between the active substances in the anode and cathode regions, the separator still allows the movement of ions but not of the active substances.

The separator is important as without it the battery would have an internal short, the small amount of charge that passes through the separator is self-discharge which needs to be avoided. (Andreas Sumper, Oriol Gomis-Bellmunt, Francisco Díaz-González, 2016)

The Container

Batteries normally contain several cells, which can either be in parallel or series depending on the desired output voltage, the container is used to keep them in a compact and isolated environment. (Andreas Sumper, Oriol Gomis-Bellmunt, Francisco Díaz-González, 2016)

2.3.2 Lead Acid Batteries

Lead acid batteries have been developed and used for the last 140 years, they are constructed with several lead plates which are arranged in parallel to each other, the cathode plates are coated with lead dioxide and the anode plates are porous lead, these plates are immersed in sulphuric acid which is the electrolyte. When the battery is discharged the lead anode reacts with the sulphuric acid converting to lead sulphate, this releases excess electrons. These electrons then pass out of the battery and through to the load on the battery and return to the cathode. The electrons then along with the sulphuric acid react with the lead dioxide and form lead sulphate. Water is also produced in this process. The potential difference between the anode and the cathode in this process is around 2.04V therefore six cells are used in series to produce a 12V battery. (Andreas Sumper, Oriol Gomis-Bellmunt, Francisco Díaz-González, 2016)

Lead Acid Battery Degeneration

A lead acid battery when it is charged and discharged has a build-up of lead sulphate crystals forming which cannot be reversed which reduces the capacity of the battery, this is called sulphating. These effects are accelerated if the battery is deprived of a periodic full charge process, if the battery is not excised (charged and discharged) for a long time, sulphation also occurs when the battery is discharged until it contains very little energy so this is not recommended. Also issues occur when the battery is overcharged which results in the water in the electrolyte forming hydrogen which is very flammable and could be dangerous. (Andreas Sumper, Oriol Gomis-Bellmunt, Francisco Díaz-González, 2016)

Lead Acid Battery Recycling

Lead acid batteries are recycled by first breaking them up into little pieces. The parts are put into a vat which splits the parts into different categories: plastic, lead and sulphuric acid.

The plastic parts are washed, blow dried and melted together into a liquid. The molten plastic is put through an extruder which converts it into pellets, these pellets are sent back to the battery case manufacturing plant to be reused.

The lead parts are put into a smelting furnace which purifies the lead, the molten metal is then poured into ingots. These ingots are then sent back to the battery manufacturers.

The sulphuric acid is either neutralised with an alkaline substance and then put back into the water system or, it is converted into sodium sulphate and used in washing detergent etc. (Battery solutions, 2018)

Advantages of Lead Acid Batteries

Lead acid batteries are approximately £65 per kWh, this is relatively inexpensive compared with other battery technologies.

Lead acid batteries also have a high cycle efficiency of up to 95%.

Due to the well-established recycling process that lead acid batteries undergo at the end of their life, and the fact that the materials separate relatively easily, the recycling process is not damaging to the environment as other battery technologies. It is estimated that 98% of the battery is recycled.

Negatives of Lead Acid Batteries

For the reasons discussed above lead acid batteries have a very poor cycle life, the battery will do between 200-1800 cycles (depending on the cycle depth) before the battery needs replacing, this is poor compared to other battery technologies.

Also lead acid batteries have a poor energy density of between 60-110 KWh/m^3, this is poor compared to other battery technologies. The specific energy of lead acid batteries is relatively poor too of between 33-42 Wh/kg.

The CO_2 released in producing a lead acid battery is approximately 72KG CO_2/kWh of capacity, this is better than Lithium-ion batteries but not as good as some other technologies.

Due to the poor cycle life of lead acid batteries they are rarely used for energy storage. (Kanchanapiya, Premrudee & Jantima, (2013)

2.3.3 Lithium-ion Batteries

Lithium-ion batteries are used for many different applications including phones, laptops, electric cars, and also used on a large-scale storage to complement renewable energy schemes.

Like all batteries, Lithium-ion batteries have an anode and a cathode which are the positive and negative parts of the battery. The active materials in the negative electron (anode) are mainly carbon in the form of graphite with some lithium atoms. The positive electron (cathode) is lithium metal oxide in the form of lithium cobalt, the electrolyte contains lithium based dissolved salts. The separator used is normally a porous substance made of polyethylene or polypropylene.

When a Lithium-ion battery is charging the Lithium-ions are extracted from the cathode and travel across to the anode and are there imbedded in the graphite. This movement of ions causes an electric current to be drawn from the power supply, then once the battery is charged there is a potential difference between the anode and the cathode, the potential difference is approximately 3.7 V when there is no load on the battery this is the voltage across one cell, multiple cells can be used in series to increase the battery output voltage. (Andreas Sumper, Oriol Gomis-Bellmunt, Francisco Díaz-González, 2016)

Lithium-ion Degradation

Lithium-ion batteries degrade as the finely structured nanomaterials coarsen on the anode and the cathode of the battery reducing capacity - also studies have shown that some of the Lithium-ions become trapped in the graphite of the anode which results in the concentration of Lithium-ions reducing around the cathode resulting in a reduction of capacity. (Battery University,(a) 2018)

The degradation of a Lithium-ion battery largely depended on the depth of cycle of the battery. As seen in Table 1 the depth of cycle has a large impact on the number of cycles until the battery capacity reduces to 70% of the original capacity. (Battery University,(b) 2018)

Table 1: Depth of cycle compared with the number of discharge cycles before the battery capacity drops to 70% (Battery University (b), 2018)

Depth of discharge	Discharge cycles (NMC / LiPO4)
100% DoD	~300 / 600
80% DoD	~400 / 900
60% DoD	~600 / 1,500
40% DoD	~1,000 / 3,000
20% DoD	~2,000 / 9,000
10% DoD	~6,000 / 15,000

This graph would suggest that for the same application a larger battery which is not exercised as deeply would last significantly longer than a battery which had 100% depth of cycle every time it was used. This is an imported consideration when choosing a specific battery capacity for an application. (Battery University,(b) 2018)

Large Lithium-ion Energy Storage Schemes

In South Australia Tesla has installed a 100 megawatt battery which will help to stabilize the grid. The grid is unstable as there is a large amount of renewable energy scheme which are causing both high and low peaks in power that can lead to an entire state losing power. Therefore the power network needed a energy storage scheme. The 100MWh battery cost approximately £50.5 million; however due to the highly unstable electricity grid the battery is able to effectively sell electricity at a high price and buy at a low price, which means there is significant financial benefits to the system. It is estimated that the battery will create a revenue of £15 million each year. (Fred Lambert, 2018)

Lithium-ion Battery Recycling

Lithium-ion batteries are much more difficult to recycle compared with other battery technologies, recycling plants are able to reduce the waste from old batteries by producing an alloy which is refined into cobalt, nickel and other metals, the cobalt (highest value material in the battery) is used to make lithium cobalt oxide which can be put back into manufacturing new batteries, which is not only better for the environment but also has a financial incentive due to the high valued metal.

The by-products of this process produce an environmentally friendly slag which goes into the cement industry, it is used as a raw material avoiding thermal processing which reduces the CO_2 emissions.

This process of recycling Lithium-ion batteries therefore is not a closed loop and a large proportion of new batteries do not contain a high proportion of recycled materials. This is one of the issues with Lithium-ion batteries. (Tesla, 2011)

Advantages of Lithium-ion Batteries

A benefit of Lithium-ion batteries is that they have a high energy density of between 170-300 KWh/m^3 which is much higher than lead acid batteries.

Also Lithium-ion batteries have a high specific energy of around 75-125Wh/kg this makes them suitable for portable devices.

Lithium-ion batteries also have a high charge and discharge capacity and have a cycle efficiency of approximately 78%.

Disadvantages

The Lithium-ion battery has a high cost compared with other technologies of 145 £/KWh.

Manufacturing Lithium-ion batteries is a very energy consuming process, this combined with the other processes involved in Lithium-ion battery production releases approximately 150-200 kg CO_2/ kWh of capacity. This is relatively high compared to other battery technologies.

The Lithium-ion batteries have electrolytes that are very flammable, this raises some safety and environmental issues of using Lithium-ion batteries.

Lithium-ion batteries also are difficult to recycle at the end of their life, which causes the disposal of them to be damaging to the environment. (Ivl, 2017)

2.3.4 Other Lithium Based Batteries

Lithium-ion batteries have been used for many years and have been developed extensively, however other lithium technologies can potentially offer better specific density at a lower cost. Lithium sulphur is one such potential technology which could supersede Lithium-ion batteries.

The Lithium sulphur batteries are made up of the basic elements of lithium and sulphur. They have a cathode made of carbon sulphur and solid lithium as the anode. The carbon sulphur is obtained as the waste product of refining crude oil and therefore is relatively inexpensive.

During the charging process the Lithium-ions separate from the lithium sulphate at the cathode and attach to the lithium metal at the anode. As the ions leave the cathode only the sulphur remains on the cathode.

The discharging process is the opposite, lithium is dissolved at the negative electrode and produces Lithium-ions, these Lithium-ions move towards the cathode and react with the sulphur, this process releases Lithium polysulfide, and energy is also released. Sulphur has a theoretical capacity which is 10x that of other conventional cathodes, including the cathode in Lithium-ion batteries, therefore a much higher energy density can be achieved by using sulphur as the cathode. (Krunal Patel, 2016) (Dario Borghino, 2009)

The Advantages of Lithium Sulphur Batteries Compared with Lithium-ion

The benefits of lithium sulphur batteries are that they have a potentially much better specific energy and energy density compared with Lithium-ion, possibly up to three times the energy density.

Another benefit is the raw materials are more readily available and therefore cheaper than Lithium-ion batteries, it is estimated that the cost per KWh could be as low as £78/KWh. (Krunal Patel, 2016) (Dario Borghino, 2009)

Disadvantages

The disadvantages are that the technology is not available to make the lithium sulphur batteries have a high cycle life, this therefore makes the technology less useful for large battery storage for renewable schemes and most other battery uses at this point in the technology. However by protecting the electrodes could significantly increase the cycle life of the battery but this is still under development. (Krunal Patel, 2016) (Dario Borghino, 2009)

2.4 Solar Heating

It is estimated that over 70% of energy used in domestic properties is used for space and water heating. The most effective way to reduce the energy required and therefore CO_2 generated for heating buildings is to have suitable thermal insulation (The required insulation levels according to UK building regulations are researched in section 2.8). After suitable thermal insulation levels have been used in the building it is important to consider renewable ways of heating water for central heating systems as well as heating hot water tanks (DHW).

2.4.1 Solar Heating History

Solar heating has been used for many years, the earliest examples of solar water heaters were effectively a box painted black and filled with water, this worked satisfactory when the Sun was shining although at night the water would rapidly lose heat as there was no insulation around the box. In 1909 William Bailey invented a thermosiphon system which uses the natural convection of hot water to circulate the water around the system. The system had a tank on the roof and a collector underneath which enabled the water to stay hot for longer as the collector was insulated. Due to this advancement solar heating became more popular. However due to the Second World War resources became in short supply and the solar heating industry shrank considerably as the systems contained a significant amount of copper and other expensive metals.

Large advances in solar thermal technology was made in the 1970s as the price of oil and gas started to rise and there were growing concerns that fossil fuels were contributing to climate change, this made the solar thermal technology more economically viable and the systems became more popular again, the UK government tariffs came into effect in 2010 supporting the solar thermal heating as well as other renewable technologies. These also encouraged the solar heating technology to be developed and used more extensively. (The renewable energy hub uk (a),2018) (The renwable energy centre,(b) 2018)

2.4.2 Technology

Solar Water Heating uses the radiation from the Sun to heat the water in central heating systems and hot water tanks. As central heating systems have the most demand when the Sun is weakest (in the winter) it is necessary to have another method of heating water to back up the solar system.

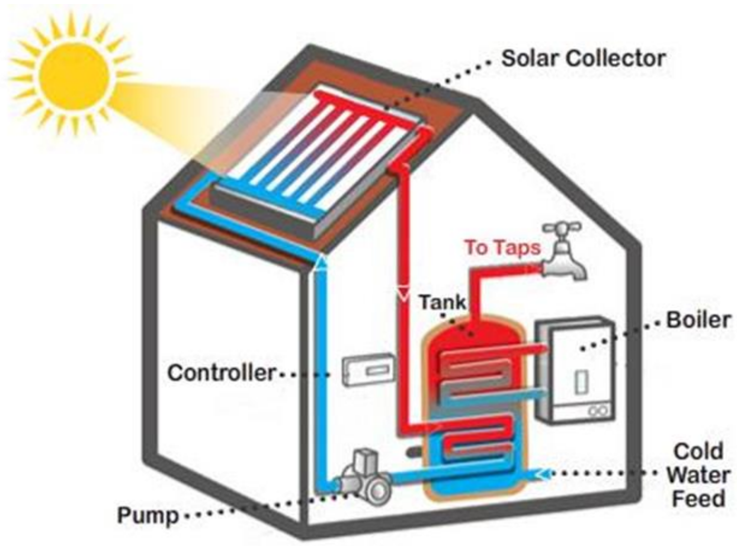

Figure 12: Diagarm showing how a solar heating system works (BK101,2018)

Therefore solar heating systems can only partly contribute to the heating energy requirements. However in the summer when swimming pools etc. are in peak demand the solar heating is also at a peak supply so the energy can be used effectively.

A basic system diagram is shown in Figure 12. If the system is an appropriate size for the demand it can provide over 40% of the total heat energy required throughout the year.

There are two main technologies used for the roof part of a solar heating systems, they are Flat Plate Collectors and Evacuated Tube Collectors. (The renwable energy centre, 2018) (BK101,2018)

2.4.3 Flat Plate Collectors

Flat plate collectors work by having a flow of fluid (normally water) passing through pipes which are integrated into a back plate. As the solar radiation comes through the glass sheet it is absorbed by

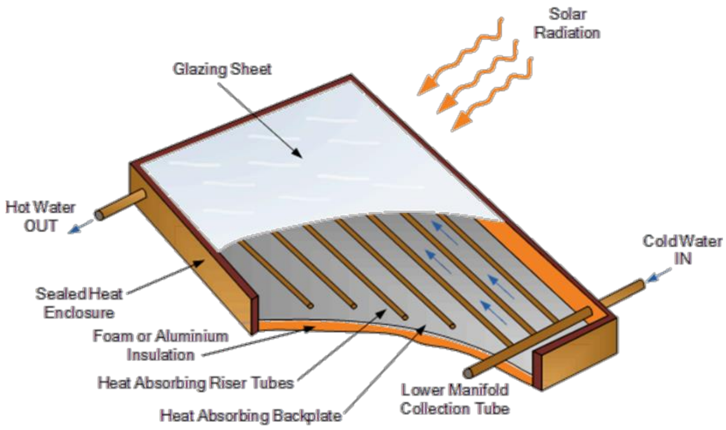

Figure 13: Diagram showing the different parts of a Flat Plate collector
(Alternative Energy tutorials, 2018)

the back plate, this causes the back plate to heat up which in turn heats the fluid in the pipes up. Therefore the fluid flowing through the panel is heated and returns to the cylinder. Insulation is placed under the back plate to prevent heat transfer through the back of the panel, the glass on the front traps the air inside the panel to prevent the flow of air cooling the back plate down it has the effect of working like a greenhouse. As seen in Figure 13. (Alternative Energy tutorials, 2018)

2.4.4 Evacuated Tube Collectors

Evacuated tube collectors consist of two glass tubes one inside the other with a vacuum in between. The outer tube is made of borosilicate glass which is low in iron allowing 98% of light energy to pass through. The second glass tube has a coating to absorb the radiation and withstand temperatures up to 300°C without detreating. This absorbed radiation is transferred as heat to the fluid within the tube. The fluid inside the inner tube depends on the system. (Northern Lights Solar Solutions, 2018) (SLT Energy, 2014)

For open collector systems the water flows directly into the inner tube and is heated. Thermosiphon causes the hot water to rise to the top replaced by the cooler water. A manifold at the top of the

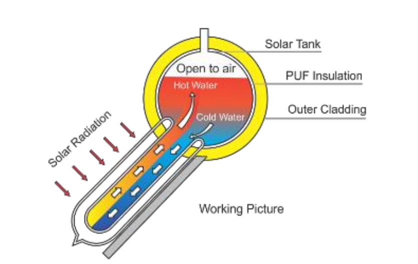

Figure 14: Diagram showing an open tube collector *(SLT Energy, 2014)*

tube connects the multiple vacuum tubes together and therefore heats the water in the hot water tank. See Figure 14. (Northern Lights Solar Solutions, 2018) (SLT Energy, 2014)

For closed collector systems instead of water passing through the inner tube a hollow copper pipe is inserted through the length of the tube which contains a liquid that is used as a transfer medium: see Figure 15. The inner tube is at low pressure which cause the fluid to vaporise at low

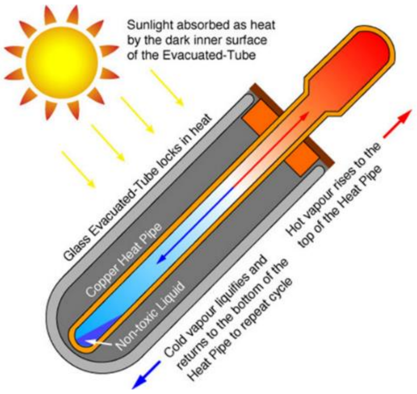

Figure 15: Diagram showing a closed Collector system (*Silicon Solar 2018)*

temperatures approximately 30°C. This vapour rises to the top of the tube to the condenser bulb at the top of the chamber. In the condenser bulb the vapour is cooled back to a fluid. The copper pipe is used as it aids the transfer of heat up the tube. The condenser bulb is inside a heat exchanger to transfer the heat from the bulb into the water system. This process has a high efficiency of around 94%, it is expensive but widely used.

Comparison of the Different Technologies

Flat plate collectors can be more easily integrated into the roof fabric and have a lower profile than evacuated tubes whereas Evacuated Tube Collectors are more efficient but are larger set up and do not blend into the existing roof which makes the technology less favourable if aesthetics are an issue. (Northern Lights Solar Solutions, 2018)

Advantages

The advantage of a solar heating system is that the efficiency of the system is much greater than a solar PV system and therefore requires a smaller surface area for the same energy output. Per year the average output of a PV solar system is between 160-170 KWh/m² whereas a solar heating system is between 300-510 KWh/m². (The renewable energy hub uk(b) ,2018)

Another advantage is that, like PV solar panels the energy produced is green energy, once installed it creates no greenhouse gases when in operation.

Solar heating panels have no moving parts so have a long service life, the life expectancy is over 20 years, they have been known to last over 30 years.

Another advantage is they are less expensive than PV panels per kw capacity for domestic installations. (Green power technology, 2015)

Disadvantages

The disadvantage of solar heating is that the time when it produces the most thermal power is at a time when the least hot water is required in the domestic home and vice-versa. The system therefore requires another heat source to fully satisfy the heat demand.

The maintenance costs are greater than solar PV, it is recommended to check the pump and anti-freeze relatively frequently to check the system is preforming optimally. The panels will need a clean every few years to enable the light to pass into the panel easily. Some of the other parts of the system including pumps have a shorter service life than the panels, however, they are relatively inexpensive components to change.

Depending on the system an additional water tank has to be fitted inside which requires space inside the house. (Green power technology, 2015)

2.5 Micro Combined Heat and Power

Micro combined heat and power has an environmental and economic benefit as electricity generation is a by-product of an existing thermal load. In traditional electricity generation at a power station a large proportion of the energy consumed is lost as heat, this is due to the inefficiencies involved in converting chemical energy into electrical energy. Therefore power stations are frequently placed near rivers, lakes and the sea so the waste heat from the power station can be disposed of in heating the water. Due to the Carnot's theorem the maximum efficiency of a heat engine (which almost all traditional power stations are) is given by Equation 1:

$$Maximum\ posible\ efficiency = 1 - \frac{T_C}{T_H} \tag{1}$$

Where T_C is the air temperature (normally ambient temperature) and T_H is the temperature that the gas is raised to during the cycle. For a normal natural gas turbine the maximum efficiency is shown in Equation 2:

$$Maximum\ posible\ efficiency\ \% = \left(1 - \frac{294K}{1533}\right) \times 100 = 80.8\% \tag{2}$$

This is the maximum theoretical efficiency, the actual efficiency of a gas turbine power station is less than 60%, therefore there are large losses in electricity production and almost all the energy losses are lost as heat.

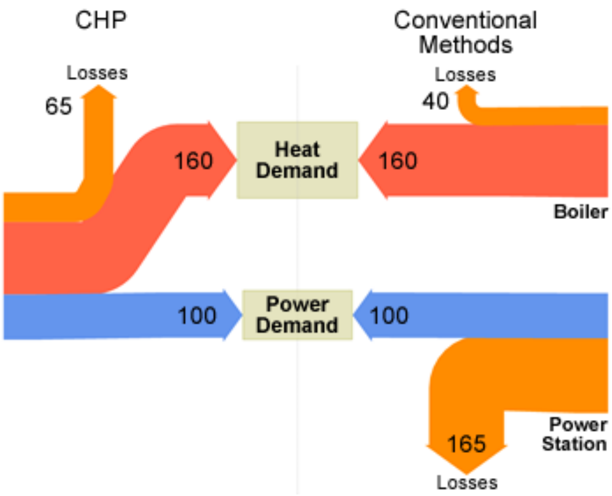

Figure 16: Sankey Diagram showing a typical combined heat and power technology. (Sankey Diagrams 2009)

Combined heat and power schemes are used to satisfy a thermal and electrical load. The Sankey diagram in Figure 16 shows that by having a combined heat and power scheme the overall efficiency of the combined system is increased.

The difference between combined heat and power technologies compared to the previous renewable energy schemes is that CHP technologies only increase the efficiency of the system whereas previous energy sources are completely renewable and therefore emit no CO_2 when in operation.

This project will be considering micro-CHP systems as these are the most relevant for domestic use.

The energy output for different CHP technologies compared with gas boiler is shown in Figure 17.

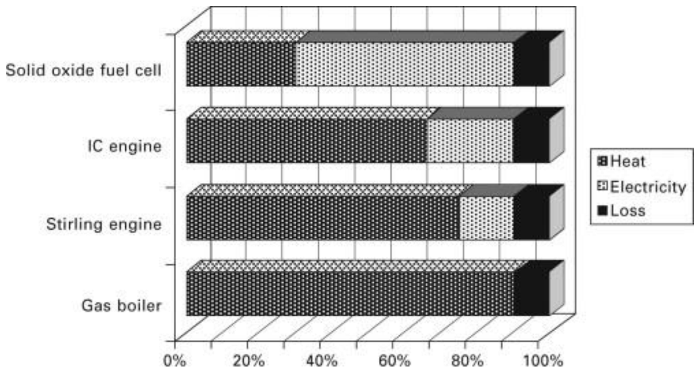

Figure 17: Diagram showing the energy output proportion of fuel inputted into verious CHP technoigies and also a traditional gas boiler (J.Harrison, 2011)

The fuel cell and internal combustion engine CHP technologies will be analysed in this report as they are the most suited for domestic and commercial buildings. (Sankey Diagrams 2009) (Harikishan Ellamla, Iain Staffell Piotr Bujlo, Bruno G.Pollet, Sivakumar Pasupathi, 2015) (Energy.Gov 2019)

2.5.1 Internal Combustion Engines

Natural gas internal combustion engines inject the fuel and air into the cylinders where the combustion takes place. This combustion results in a temperature and pressure change which acts on the piston and then through the crank shaft to produce useful mechanical work. This technology has been used for many years in both stationary and automotive applications. In a CHP system the mechanical power at the crank shaft would be used to rotate a generator which would then generate electricity. The efficiency of converting chemical energy into electricity is approximately 25%, 67% of the remaining chemical energy is converted into useful heat which is used for a thermal load. This makes a total combined efficiency of 92% which is comparable to the efficiency of a condenser boiler. The issues with internal combustion engines are that they have high noise and vibration levels as well as a high service requirement which makes them less attractive compared to other CHP technologies. However, internal combustion CHP units are widely used particularly in the Japanese market for which they have sold over 100,000 units. (J.Harrison, 2011) (The Renewable energy Hub (c) 2018)

2.5.2 Fuel Cell

Another CHP technology is using fuel cells to convert chemical energy into electricity and heat energy. This requires no mechanical drive or generator which makes the process low noise and no vibrations which makes it suitable for domestic use.

Technology

Fuel cells take advantage of generating electricity from a chemical reaction between two input gases, usually hydrogen and oxygen and therefore the losses associated with converting chemical energy first into mechanical energy and then to electrical energy is bypassed. The basic theory behind fuel cells is shown in Figure 18.

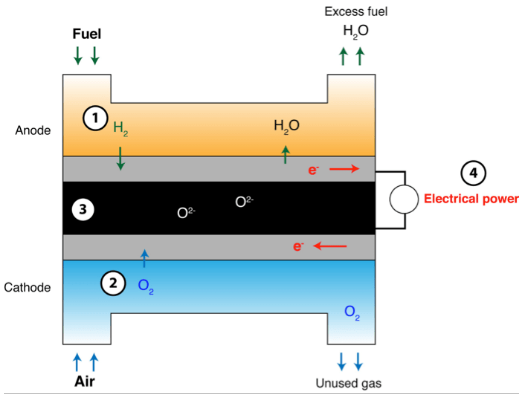

Figure 18: Diagram showing how fuel cells work. *(Harvard University, 2015)*

The diagram shows that the fuel (hydrogen) (1) flows across the anode of the fuel cell and air (2) flows over the cathode, the hydrogen and oxygen out of the air combine across the separator (3) which induces a flow of electrons. This generates the electrical power (4). Hydrogen gas however is not readily available and has to be made, this is often done by reacting methane and pressurised steam at high temperatures forming hydrogen and carbon monoxide or carbon dioxide. However, this process requires a large amount of energy reducing the efficiency of the overall fuel cell technology. The issue with fuel cells used for domestic heating is that in order for the fuel cell to work effectively for a long service life the fuel cell cannot be frequently turned on and off, also they have a start-up time of 0.5h-20h depending on the technology used, therefore FCCHP system are used only for domestic hot water heating systems as hot water is required throughout the year.

Therefore to fully satisfy the heating demand FCCHP systems have to work in conjunction with a traditional boiler or another technology. This also means that the output electrical energy of the fuel cell is constant as well, therefore it is essential that the domestic home is either connected to the electricity grid or has an energy storage system for the peaks and troughs in energy usage. (J.Harrison, 2011)

Polymer Electrolyte Membrane Fuel Cells (PEMFC)

The polymer electrolyte membrane fuel cell has the same design as the fuel cell shown in Figure 18 and work to a high efficiency. However, the main disadvantage of polymer electrolyte membrane fuel cells for domestic use is that it requires nearly pure hydrogen as fuel. As most domestic homes have mains natural gas the technology relies on an efficient way of converting natural gas into hydrogen. A possible set up is shown in Figure 19. The diagram in Figure 19 shows two ways of

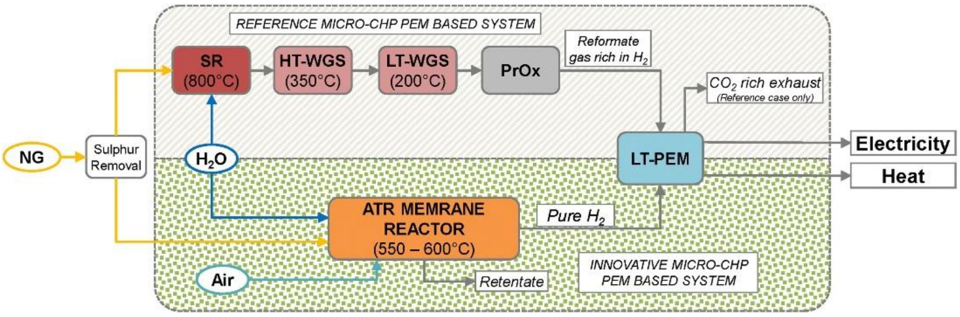

Figure 19: Diagram showing the two ways natural gas can be used to directly generate electricity without going through a combustion process (Gioele Di Marcoberardino, Giampaolo Manzolini, Cécile Guignard, Violaine Magaud, 2018)

converting natural gas into hydrogen. The top path consists of four parts, the steam reformer (SR), a low and high water gas shift (WGS) and a preferential oxidizer (PrOx). The steam reformer (SR) is a chemical synthesis for producing hydrogen and carbon monoxide from natural gas and water, this occurs by reacting high pressure and temperature steam with methane in the presence of a nickel catalyst. The water gas shift (WGS) reactors convert carbon monoxide and water into carbon dioxide and hydrogen, the preferential oxidizer (PrOx) removes the remaining carbon monoxide out of the hydrogen fuel.

The other way of converting natural gas into hydrogen is by using an Autothermal reforming (ATR) membrane reactor. In the ATR the heat needed to reform the reactions is supplied by the combustion of a small proportion of natural gas. The overall chemical reaction taking place in the ATR includes total oxidation, steam reforming and water gas shift. This then creates the pure hydrogen which is inputted into the low temperature polymer electrolyte membrane fuel cell.

As seen in the diagram the hydrogen is then used in the fuel cell to generate electricity and heat which can be used in the domestic home. This technology has a high initial expense and has the potential to have high maintenance costs if the fuel is not as pure as expected, therefore PEMFCs are not widely used in domestic homes (Vladimir Volkov, Angelo Basile, Natalia Orekhova, José Sanchez-Marcano, 2012) (J.Harrison, 2011) (Gioele Di Marcoberardino, Giampaolo Manzolini, Cécile Guignard, Violaine Magaud, 2018)

Solid Oxide Fuel Cells

Solid Oxide fuel cells are different to most other fuel cells as the separator is made of solid ceramic. The fuel cell is therefore able to operate at temperatures above 700°C. This allows hydrogen to be produced internally to the fuel cell, i.e. in the anode region. Figure 20 shows a solid oxide fuel cell system supplying a home.

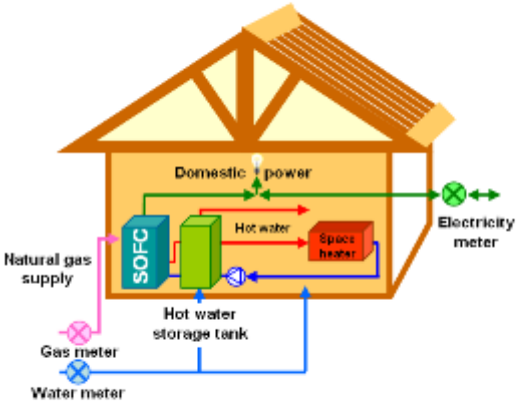

Figure 20: Diagram showing a solid oxide fuel cell supplying a domestic home. *(Power to the People, 2006)*

The input fuel at the anode can be common fuels like natural gas and still return a 60% electrical efficiency, most of the remaining energy is used to satisfy the heat demand in the home and therefore the system has a combined efficiency of up to 90%. Solid oxide fuel cells are therefore much more attractive than other fuel cell technologies. The exhaust gases from the solid oxide fuel cell is primarily carbon dioxide and water. This fuel cell technology is therefore proving to be suitable for the use in both domestic and commercial buildings. (J.Harrison, 2011)

Advantages of Fuel Cells

The main advantage of fuel cells for heating buildings is that the total CO_2 emissions are less than using conventional grid electricity and a natural gas boiler for hot water and space heating. The other benefit of the fuel cell technology is that they are very low noise, low vibrations and they are relatively small making them suitable for use inside domestic buildings. The large benefit of CHP technologies is that they increase the efficiency of the electricity and heat demands of the building by approximately 30% and therefore approximately 30% of the CO_2 is released compared to traditional heating and electricity generation technologies. (J.Harrison, 2011)

Disadvantages of Fuel Cells

If natural gas is used to generate the hydrogen needed to run the fuel cell the process still emits CO_2. As the UK grid continues to reduce the carbon emissions per kWh, the reduction in CO_2 emissions due to the CHP system becomes less significant.

The initial cost of the fuel cell is greater than conventional heating however due to the electricity produced the investment pays off after a few years of operation.

Due to the internal damage and the slow start up times fuel cells cannot be switched on and off regularly. Therefore most fuel cells are almost never turned off. This results in the fuel cell outputting the same amount of thermal and electrical energy all year round, this is an issue as very few thermal loads are needed all year round, therefore a fuel cell with only a few KW are used which heats the hot water in the building. Another heating technology is therefore needed to fulfil all the domestic home's heating needs resulting in two systems leading to more servicing and more initial expense. (Vladimir Volkov, Angelo Basile, Natalia Orekhova, José Sanchez-Marcano, 2012) (J.Harrison, 2011) (Gioele Di Marcoberardino, Giampaolo Manzolini, Cécile Guignard, Violaine Magaud, 2018) (J.Harrison, 2011)

Disadvantage of CHP in General

Most of the CHP technologies that have been discussed are powered by fossil fuels which, due to their carbon releasing nature are harmful to the environment. Also if fossil fuels are used to power the systems which generates both heat and electricity the local emissions from the building will be higher as it is generating electricity as well as heat rather than the electricity being generated at a power station a long distance away. Therefore, in an urban area if domestic and commercial buildings all had CHP systems installed the concentration of CO_2 locally would be higher than traditional methods therefore CHP is a good technology for an efficiency of fossil fuel usage but cannot offer the solution to zero carbon future. (J.Harrison, 2011)(The Renewable energy Hub (c) 2018)

2.6 Heat Pumps

As mentioned in the solar heating study it is estimated that over 70% of energy used in a domestic property is used in space and water heating, therefore it is important to look at technologies which can satisfy this heat load with a reduction in the carbon footprint. A heat pump is based on a reverse Carnot thermodynamic cycle, which requires a drive energy (compressor) and produces thermal energy. It works by taking the thermal energy out of a low temperature heat source into a high temperature heat load, it consumes energy to produce this thermal effort. There are many different types of heat sources, these include, a gas (outside air/ventilation systems etc.), a liquid (pond, the sea, lake, ground water, etc.) or just the ground. The heat pump yields thermal energy at higher temperatures which is useful for a range of different applications including, space heating and water heating for both domestic hot water tanks and also for heating swimming pools etc. (The Renewable energy hub, (d) 2019)

2.6.1 Heat Pumps History

Geothermal power has been used since ancient times in the form of using the heat from hot springs however, heat pumps and artificial refrigeration was demonstrated by William Cullen in 1748 which marks the beginning of the heat pump as a scientific principle. Later Lord Kelvin further developed the scientific concept in 1852. Peter von Rittinger built the first air source heat pump system which was completed in 1857. From this invention Robert C Webber developed the first ground source heat pump in the late 1940s, after he saw that the ground source heat pump was working effectively he designed and made a much larger heat pump system to provide enough heat for his house. In recent years heat pumps have become significantly more efficient and cost effective. (The Renewable energy hub, (d) 2019)

2.6.2 Technology

The theory behind a heat pump system is the same as for a refrigerator system, Figure 21 shows a heat pump cycle diagram.

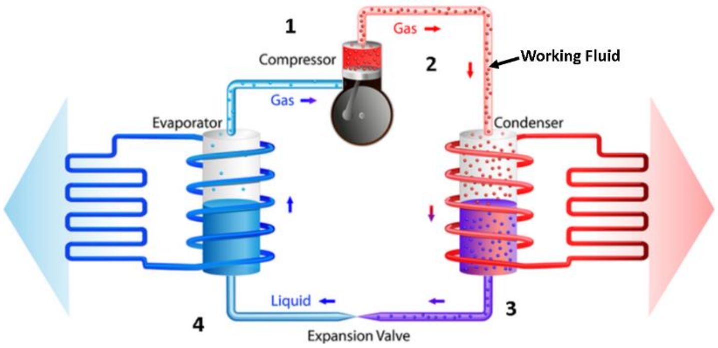

Figure 21: Diagram showing the heat pump cycle (Alaska Power and Telephone Company, 2019)

Figure 21 shows the heat pump cycle, a description as to the role of each component part in the cycle is given below:

Stage 1-2, this is where the working fluid is compressed by a compressor, the temperature and pressure both increase significantly, converting the working fluid to a hot gas.

Stage 2-3, the working fluid then passes through a condenser which both reduces the temperature and changes the state of the working fluid therefore thermal energy is released. When heating the building this thermal energy is released into the building.

Stage 3-4, the expansion valve allows the working fluid to expand and therefore the temperature and pressure reduces.

Stage 4-1, the evaporator has the low temperature and pressure flowing through it therefore thermal energy is absorbed. When heating a building the thermal energy is absorbed from the heat source. (The Renewable energy hub, (d) 2019) (Alaska Power and Telephone Company, 2019)

Coefficient of performance

The coefficient of performance is an important value which relates to the output thermal energy compared to the input of work/electricity, the diagram in Figure 22 shows the thermodynamic theory.

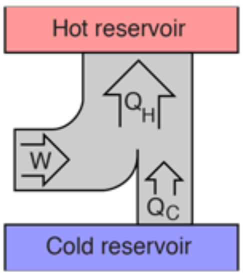

Figure 22: Heat Pump Thermodynamics (Hyper Physics, 2019)

$$Coefficient\ of\ performance(COP) = \frac{Q_H}{W} \quad (3)$$

Where Q_H is the thermal energy of the working fluid passing into the hot reservoir and W is the work/electricity (assuming lossless motor) input. (Hyper Physics, 2019)

Therefore the higher the COP the higher the work input is multiplied to give a larger thermal energy passing into the hot reservoir or the heat load.

The COP is affected significantly by the temperature difference between the hot and cold reservoir. The graph in Figure 23 shows how for a low heat source temperature the COP is much lower for the same output temperature. Therefore to maximise the efficiency and effectiveness of heat pumps the difference between the hot and cold reservoirs is to be kept to a minimum. The necessary temperature differences can be minimised by increasing the surface area of thermal transfer within the building, this can be achieved by heating methods such as underfloor heating and larger radiators. A lower required temperature results in a smaller temperature difference and therefore a higher efficiency and effectiveness of the heat pump.

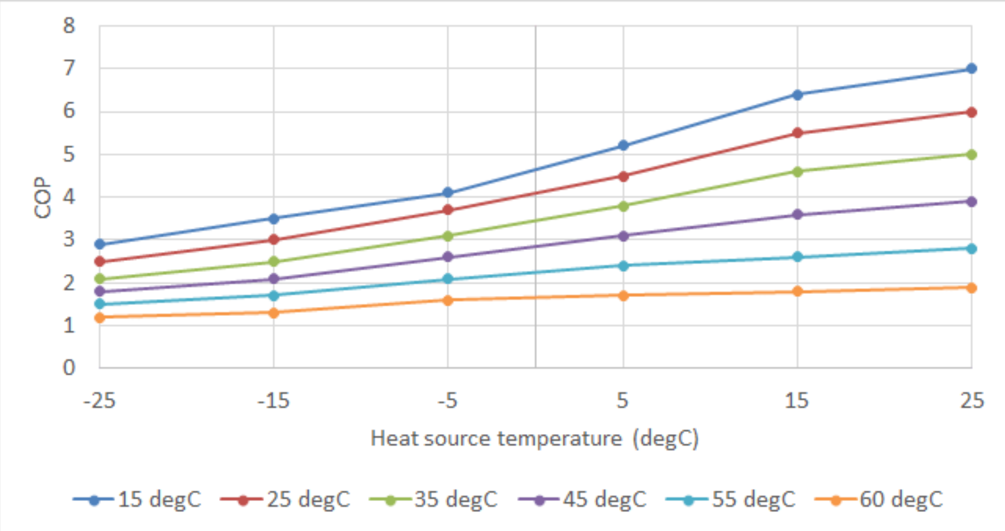

Figure 23: COP compared with the heat source temperature depending on the desired output temperature (Janne Hirvonen and Kai Sirén, 2017)

The indirect carbon emissions of heating buildings using heat pumps varies significantly depending on how the electricity used in the compressor is generated however for this analysis the average carbon emission per kWh from the National Grid will be assumed. The average coefficient of performance over a year for heat pumps heating buildings in the UK is between 2.9 and 4.8 (depending on the heat source etc.). These heat pumps are consuming electricity which, in the UK in 2018 had an average carbon footprint of 283 g CO_2/KWh of electricity. The heat pumps were using this electricity and generating between 2.9 - 4.8 KWh of heat per KWh of electricity. The actual carbon footprint per KWh of heat generated by the heat pump is between 59 and 98 g CO_2/KWh of heat. The average gas boiler generates approximately 220 g CO_2/KWh of heat, therefore the carbon emissions for heat pumps are less than half that of traditional methods of heating. However this value relates to the carbon emissions when in operation and is not including the CO_2 released in the life cycle of each technology. (The Renewable energy hub, (d) 2019) (Iain Staffell, Dan Brett, Nigel Brandon, Adam Hawkes, 2012) (Gov.UK(b), 2018)

2.6.3 Government Tariffs on Heat Pumps

One of the main reasons heat pumps are becoming more frequently used to heat buildings is that there are substantial government tariffs to give a financial incentive to use heat pump technology.

Table 2: Government tariffs for different heat pump technologies. (Ofgem (a) 2018)

Applications submitted	Biomass boilers and stoves (p/kWh)	Air source heat pumps (p/kWh)	Ground source heat pumps (p/kWh)
01/01/2018 - 31/03/2018	6.54p	10.18p	19.86p
01/04/2018 - 30/06/2018	6.74p	10.49p	20.46p
01/07/2018 - 30/09/2018	6.74p	10.49p	20.46p

Table 2 shows the government tariffs for different heat pump technologies making the technologies financially beneficial. (Ofgem (a) 2018)

2.6.4 Advantages of Heat Pumps

Reduction in carbon emissions compared with traditional heating methods.

As they run on electricity and no combustion takes place, therefore they are safer than traditional combustion heating methods, also all the CO_2 produced is indirect CO_2, therefore there are no local emissions and therefore better local air quality compared to traditional heating methods.

Less energy is consumed to satisfy the same heating demands as most of the thermal energy is extracted from the atmosphere.

Little maintenance is needed to keep them working correctly as they have few moving parts.

Can be economically beneficial depending on government tariffs and fuel prices.

The technology can be used as air cooling when required. (The Renewable energy hub, (d) 2019)

Disadvantages of Heat Pumps Compared to Traditional Heating Technologies

High initial cost for heat pump and installation.

Still indirectly emits CO_2 as the electricity generation sector is not carbon free.

If the heat source temperature drops too low it is necessary to have an additional technology to continue to satisfy the heat load demand resulting in higher cost and larger space in the building needed.

Similar noise level to an air conditioning unit which can be an issue if operating for long periods of time. (The Renewable energy hub, (d) 2019)

2.6.5 Types of Heat Pumps

There are three main different types of heat pumps which have their advantages and disadvantages depending on the application. These three are Air source heat pumps, Ground source heat pumps, and Water source heat pumps.

2.6.6 Air Source Heat Pumps (ASHP)

An Air Source Heat Pump (ASHP) creates a flow of air from the outside atmosphere through a finned heat exchanger (Evaporator) which reduces the temperature of the air and thus increases the thermal energy of the working fluid. Then, using a compressor mechanism the pressure and temperature of the working fluid is increased. Inside the building the heated working fluid can either be put through a water heat exchanger or an air heat exchanger. A water heat exchanger is used to heat water to work with radiators and underfloor heating systems for space heating or to heat domestic hot water tanks. An air heat exchanger produces a flow of warm air that can be used to heat rooms and is circulated by fans. The ASHP unit is relatively compact and is a self-contained unit, therefore it is relatively easily fitted to an existing or new building. (The Renewable energy hub, (d) 2019)

Advantages of Air Source Heat Pumps

Relatively inexpensive to fit compared with other types of heat pumps. Also significant government tariffs which could make the technology financially advantageous.

They are suitable in almost any location, either urban or rural, this is because they work anywhere there is access to the atmosphere.

Relatively high COP. Average COP value between 2.9-3.5 yielding between 83-98 g CO_2/KWh of heat which is significantly better than traditional gas boilers. (The Renewable energy hub, (d) 2019)(Iain Staffell, Dan Brett, Nigel Brandon, Adam Hawkes, 2012)

Disadvantages of Air Source Heat Pumps

Because the heat pump is using the atmosphere as the heat source the temperature can vary significantly during a year. The coefficient of performance is low at low outside temperatures, therefore the maximum heat outputted from the same size heat pump is significantly reduced at low temperature. The heat demand is also greater at lower outside temperatures therefore an additional heat source technology is sometimes needed.

They have a relatively slow response time, they take a while to warm up compared with traditional gas boilers. (The Renewable energy hub, (d) 2019)

2.6.7 Ground Source Heat Pumps (GSHPs)

A ground source heat pump is the same as an air source heat pump except the thermal energy is extracted from the ground as opposed to extracting thermal energy from the atmosphere. There are a number of different methods used to extract the thermal energy from the ground. The most common way is by digging a series of pipes approximately two metres below the surface which have a mixture of water and antifreeze flowing through them, this is called the ground loop as seen in

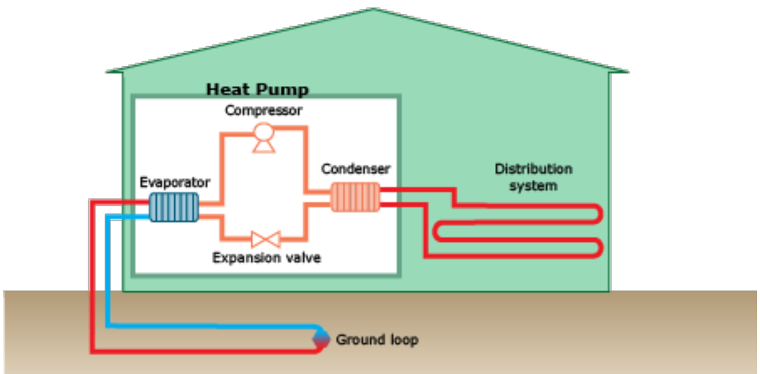

Figure 24: Diagram showing a ground source heat pump setup. (Basix 2019)

Figure 24. The fluid from this ground loop is circulated through a heat exchanger which extracts thermal energy out of the fluid which then continues to flow back into the ground to reheat. This is the evaporator part of the heat pump cycle, the next stages of the system are exactly the same as the ASHP technology. (The Renewable energy hub, (d) 2019) (Basix 2019)

Advantages of Ground Source Heat Pumps (GSHPs)

The benefits of a GSHP is that the temperature of the returning ground loop fluid is more stable than for a ASHP, this is due to the high specific heat capacity of the ground and the large volume the loop covers resulting in the outside temperature having a delayed effect on the ground temperature. Therefore GSHPs have a higher average coefficient of performance than ASHPs. GSHPs have an average COP in the UK of between 3.9-4.8. Therefore they have lower carbon emissions per KWh as they consume less electricity for a given heat load, they emit between 59 and 73 g CO_2/ KWh on average using the 2018 electricity emissions figures. (Iain Staffell, Dan Brett, Nigel Brandon, Adam Hawkes, 2012)

As the temperature of the ground stays relatively stable even at extreme atmosphere temperatures the heat pump is able to constantly work at high COP values, therefore if the size of the GSHP set up is proportionate to the size of the building the heat pump should be able to satisfy demand all year round without the need for an additional heating methods therefore reducing the initial cost. (The Renewable energy hub, (d) 2019) (Basix 2018)

Disadvantages of Ground Source Heat Pumps

GSHPs are expensive to install as they require long trenches to be dug to put the ground loops in therefore commonly more expensive than ASHPs.

Need a large amount of space which is unoccupied by other buildings to enable the ground loop to be put in, this makes them unsuitable for individual flats and apartments in urban areas. (The Renewable energy hub, (d) 2019)

2.6.8 Water Source Heat Pumps

A water source heat pump works on a similar principle to both ASHPs and GSHPs, however the water source heat pumps extract thermal energy out of a body of water, for example a lake, river or the sea. A series of pipework is submerged into the body of water which is used to extract the heat out of the water, much like the ground loop in the GSHP setup. (The Green age, 2019) (The Renewable energy hub, (d) 2019)

Advantages of Water Source Heat Pumps

As water has a higher heat transfer rate than the ground a shorter length of pipework is needed making the system potentially less expensive than a GSHP.

Water has a very high specific heat capacity, therefore the water source temperature is relatively stable and almost always above $0°C$ therefore the average COP is similar to that of GSHP however, this can vary significantly depending on the water source. (The Green age, 2019) (The Renewable energy hub, (d) 2019)

Disadvantages of Water Source Heat Pumps

The disadvantage of a water source heat pump is that it requires a large body of water to extract the heat from, most of the buildings in the UK do not have access to a large body of water and therefore this technology is only suitable for a small proportion of buildings in the UK. (The Green age, 2019) (The Renewable energy hub, (d) 2019)

2.7 Using Electric Vehicles to Stabilise the Grid

As discussed earlier in the battery storage section there is an increasing demand for suitable energy storage infrastructure as renewable energy sources begin to have a larger share of the energy in the grid. This energy storage will even out the peaks and troughs in electricity demand and supply.

Previously discussed in this dissertation was the use of large battery packs which are installed in domestic homes and also on a commercial scale for grid stability, however, these are expensive to purchase and take up space in domestic homes.

It is estimated that with the increasing proportion of renewable energies used in the electricity generation sector the UK requires an increase of 13 GWh of energy grid storage by 2030. However, the predicted number of EVs on the road by 2030 is approximately 10 million and it could be possible to use the EV's batteries to stabilise the grid.

The diagram in Figure 25 shows how the transfer of electrical energy could work between the EVs battery and the grid:

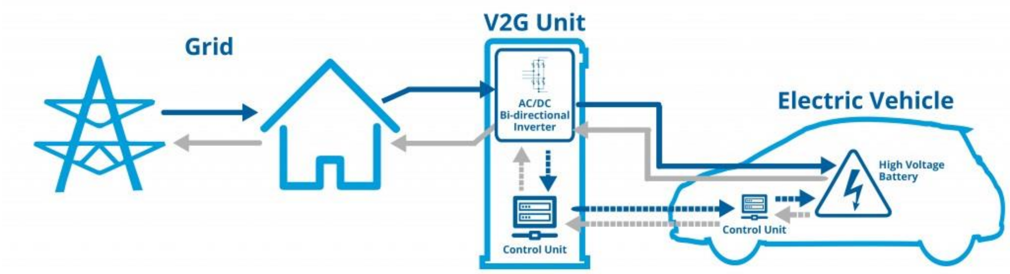

Figure 25: Diagram showing how bi-directional charging would work. (Cenex, 2019)

It is estimated that the average EV sold in 2028 will have a 100KWh battery resulting in the average battery pack size of the 10 million EV in the UK being approximately 60-70KWh. If only a quarter of the EV in the UK were available to be used for energy storage (i.e. connected to a bi-directional charger and the owner has authorised the use of the battery for grid stability), only 5.2KWh of the battery capacity from each EV would be used. This corresponds to less than 10% of the total battery capacity. Therefore the possibility of using the batteries which are in electric vehicles to stabilise the grid could have a large impact on how energy storage issues are overcome in the future. (Clean technica, 2018) (Carbon Brief, 2018) (edie.net ,2019)

2.7.1 Smart Grid

To enable EVs to stabilise the grid the bi-directional charger needs to be controlled in relation to the peaks and troughs in electricity supply and demand. The smart grid is where there is live communication with the energy supplier and consumer resulting in a fluctuating price per unit of electricity depending on the supply and demand. The greater the demand the higher the price and when there is an energy surplus then cost per unit of electricity is reduced. By the fluctuating electricity price the bi-directional charger would know when to charge up the battery and when to discharge back into the grid, thus helping to stabilise the grid. (Electrical Concepts, 2016) (Energy.gov, 2019)

2.7.2 EV Chargers

The customer has overall control whether their car is charged or discharged depending on their driving needs, however the average commute for workers using cars in the UK is approximately 9.9 miles. If the average battery capacity is between 60-70 KWh which corresponds to approximately 200 miles of range there is adequate capacity to stabilise the grid with a bidirectional charger on the average working day. The benefit to the customer if their EV is stabilising the grid is that they get paid the difference between what the EV has sold the electricity for at peak demand (high price) and charged up at low demand (low price). It has been predicted that the cost of the UK installing 13GWh of electrical storage would cost approximately £6 billion, there is the possibility that this money could be spent on rewarding customers which use their EV to help stabilise the grid as the electricity storage infrastructure is not necessary.

Without the government tariffs rewarding customers who stabilise the grid, the difference in price would still be a financial incentive. For example, if similar rates for economy 7 (fixed low and high rates depending on the time) were used and 20KWh of the battery capacity was charged in low demand (6.27p per KWh) and discharged back into the grid at high demand (17.47p per KWh) the EV owner would generate approximately £2.24 per cycle, this would accumulate up to £817 per year (one cycle every day). Also an occasional shallow depth cycle for most battery technologies can prolong the life span of the battery and therefore the degradation of the battery due to stabilising the grid would be minimal. (Clean technica, 2018) (edie.net, 2019) (Cenex, 2019) (Choose, 2017)

2.7.3 Smart Appliances

Smart appliances are appliances such as washing machines, dishwashers etc. which are connected to the smart grid and therefore are connected to the live energy price. Smart appliances are able to adjust their run cycle to minimise the energy drawn at high energy prices, the operator could set a time that they would like the cycle to be complete and by predicting the energy price the smart appliance can work out the run cycle to minimise energy cost but still have the cycle completed at the desired time. This is another way that the smart grid can be used to stabilse the grid. (Smart Grid. Gov, 2019)

2.7.4 Advantages of the Smart Grid, EV Bi-directional Chargers and Smart Appliances

The main advantage of the smart grid is that the electricity suppliers have a duty to ensure that there is a stable grid, however the cost to the energy company and also the emissions produced per KWh depends on the method of electricity generation. Therefore the smart grid enables the customer to pay proportionally to what the electricity cost to generate due to the fluctuating electricity price rather than a flat rate which is not a correct representation of what the electricity cost to produce. This encourages consumers to use electricity when the price is low which helps to reduce the peaks and troughs in the energy consumption in the grid. The smart grid also enables EV's bi-directional chargers to further stabilise the grid, this has large financial benefits to both the EV owners and also the energy grid as large energy storage infrastructure has a significant cost associated with it. By expanding the UK's energy storage using EVs allows renewables to have a larger share of the electricity generation in the UK whilst still maintaining a stable grid. Therefore reducing the carbon emissions of the electricity generation sector. (Cenex, 2019)

2.8 Insulation

Previously in this project many different carbon saving technologies which reduce the carbon emissions per unit of energy have been discussed. However there are other ways to reduce the carbon footprint of buildings, one way is to reduce the quantity of energy needed to maintain a desired room temperature by increasing the thermal efficiency of the building, this is done using insulation. As mentioned previously 70% of energy used in domestic homes is for space and water heating, therefore if less energy was required whilst still maintaining the same temperature it would lead to a reduction in energy consumed and therefore a carbon emissions saving. (Energy saving trust,(a) 2019) (The Green age, 2015)

2.8.1 Roof Insulation

It is estimated that in an uninsulated home 25% of heat energy is lost through the roof. Roof insulation can be installed in many different ways depending on the type of roof that the building has, in a typical house the roof would be insulated either on the loft floor which is above the ceiling on the highest floor or insulated between the roof rafters. (Energy saving trust, (a) 2019)

The building regulations in England state that a minimum of 270mm of mineral wool is needed in new builds and extensions to pass building regulations. In a previously uninsulated loft, 270mm of insulation would cost around £5 per square metre, loft insulation can often be installed relatively simply by the home owner and therefore installation costs are kept to a minimum. A typical uninsulated detached house in the UK would require approximately 36000KWh of space heating during the course of a year, this corresponds to a cost of approximately £1080/year and releases approximately 7900kg CO_2/year using a typical gas boiler. It would cost approximately £400 to insulate the loft up to England's building regulations. It is estimated this would save approximately 7200KWh of heating annually which is a saving of 1500KG of CO_2/year and a space heating bill saving of £216/year, this is therefore very beneficial both environmentally and financially. (Energy saving trust,(a) 2019) (The Green age, 2015)

2.8.2 Wall Insulation

Walls make up a large proportion of the outside surface area of a building, therefore it is important to minimise the heat transfer between the outside and inside of the building to minimise the heat lost. In an uninsulated building 40% of heat is lost through the walls.

There are two main types of walls that are used in buildings, these are solid walls, where there is no gap inside the wall, and also cavity walls where the wall has two layers with a gap or cavity in the middle. Homes which were built before the 1920s in the UK most probably have solid walls. (Energy saving trust, (a) 2019) (The Green age, 2015)

2.8.3 Cavity Walls

In cavity walls the cavity can be filled with insulation which reduces the heat transfer. The cost of cavity wall insulation can vary significantly depending on the materials used, it can cost between £13-£26 per square metre. A typical detached house would cost approximately £725 to insulate the cavity wall. It is estimated this would save approximately 8100KWh of heating annually which is a saving of 1800KG of CO_2/year and a space heating bill saving of £243/year, again a significant environmental and economic saving. (Energy saving trust,(a) 2019) (The Green age, 2015)

2.8.4 Solid Walls

Solid walls can be insulated however they are insulated either on the interior or exterior of the building.

External Insulation

This is when the insulation is put on the outside of the building, this reduces the heat transfer between the inside and outside of the building. The issue with exterior insulation is that planning permission is necessary.

Exterior insulation can cost approximately £100 per square metre. A typical detached house would cost approximately £15,000 to insulate the exterior walls. It is estimated this would save approximately 13,800KWh of heating annually. This corresponds to a saving of 2870KG of CO_2/year and a space heating bill saving of £414/year. (Energy saving trust,(a) 2019) (The Green age, 2016)

Interior insulation

This insulation is put on the inside of the building to reduce the heat transfer through the walls.

In general it is less expensive to install compared with external insulation, interior insulation can cost approximately £60 per square metre. A typical detached house would cost approximately £9,000 to insulate the interior walls. The reduction in energy consumption and therefore the energy and CO_2 saving are the same as for exterior insulation.

The issue with interior insulation is that it can make it more difficult to fix heavy items on the inside walls as the insulation is not as rigid as a traditional wall, and also it reduces the floor area of the building by the thickness of the insulation. (Energy saving trust, (a) 2019) (The Green age, 2016)

2.8.5 Ventilation Systems

Natural ventilation is still the most common method of allowing the change of air within buildings. However, as buildings become more airtight by reducing the air infiltration through cracks and small holes, a ventilation system may need to be put in place to maintain good air quality inside building.

The benefit of a controlled ventilation system compared with uncontrolled natural ventilation is that the rate of air exchange can be reduced if the external temperature is low to reduce the energy lost out of the building. Also the ventilation system can increase air exchange when the building needs cooling when the outside temperature is less than the temperature in the building.

The recommended ventilation of a building is typically 12.7 m^3per hour per person plus 0.5 m^3per hour per m^2 of floor area, therefore for a typical detached house the recommended ventilation flowrate is approximately 150 m^3per hour. (Green Building Advisor, 2013)

There are a number of different types of ventilation systems, these include exhaust, supply, balanced and heat recovery ventilation systems. An exhaust ventilation system where a fan is used to force air out of the building creating a low pressure within the building, there is a flow of air into the building from air ducts. Supply ventilation systems are also used, these force air into the building creating a high pressure within the building resulting in an outflow of air through the passive air ducts. A balanced ventilation controls both the inlet and outlet ducts using fans, the systems avoid the cold air draughts in the winter but are more expensive. Heat recovery or heat exchangers can also be used in ventilation systems.

Heat Recovery Ventilation Systems

Heat recovery ventilation systems use a similar set up to the balanced ventilation system however the ventilation system has a heat exchanger in it which transfers some of the thermal energy out of the outlet air and into the inlet air. The inlet air therefore has more thermal energy than it would otherwise have and therefore less energy is consumed heating the inlet air to the desired temperature within the building.

As discussed in a previous section, in this project air source heat pumps use the outside air as the heat source, however, the heat pump has a greater coefficient of performance when the difference between the desired outlet temperature and source temperature is reduced, therefore some air source heat pumps use the air from the outlet of the ventilation system as the heat source, this reduces the difference between the temperature of the heat source and the desired outlet temperature and therefore increases the coefficient of performance of the heat pump significantly resulting in a higher efficiency.

Another type of building ventilation is to electrically control a buildings air ducts and windows effectively to control the natural ventilation without the use of fans. A control system is used to analyse the environment the building is in, for example the temperature, the wind speed and direction. These factors are used to enable the controlled ventilation of the building. These systems can reduce the need for air conditioning in buildings when the outside temperature is high as by carefully selecting the air ducts used and also the time of the day they are open the temperature of the building can be controlled, however there are limitations to the effectiveness of this system in extreme temperatures. (Home Tips, 2015) (Passivent,2015)

3. Case Studies

A number of case studies have been looked into to show how some of the technologies discussed earlier have been implemented and how it has benefited both environmentally and economically.

3.1 Farm Case Study

Manor Farm in Hertfordshire was used as a case study looking at how a business can used sustainable and carbon reducing technologies to create a return on an investment and also reduce the carbon footprint of the business,

3.1.1 Solar Panels

Manor Farm have 2 solar panel arrays one with a capacity of 25KW and the other a 50KW array.

25KW array

The 25KW array is situated on a large pig barn, the solar array is used to power the facilities used for raising pigs including a ground source heat pump, a ventilation system, a feeding system and water pumps. The solar array has no electricity export meter, however, as the water pumps, ventilation and feeding systems require a large electricity input all day it is approximated for the calculations that all the electricity is used on site and no electricity is exported back into the grid. This results in a large saving in the electricity bill. Yet for the government tariffs it is approximated that for a 25KW array with no export meter the electricity exported into the grid is approximately 50% of the electricity generated and therefore the business is paid an export tariff for half the electricity generated. The solar array therefore has economic and environmental benefits. The specific costings and carbon saving is shown in Table 3

50 KW array

The 50 KW array is situated on a barn roof and is supplying a different meter to the other solar array. This array supplies the other electricity load in the business, this includes a borehole pump (12kw running constantly over the summer), the reservoir pump (50kw pumping water irrigates 50 hectares of potatoes) and the electrical components of 2x 100kw biomass boilers requiring around 7KW of electricity when operating. As this solar array also has no export meter it is approximated for the calculations that 2/3 of the electricity was used in the business, the rest is exported back into the grid. However as this is a 50KW array with no export meter any electricity put into the grid is not paid for. Table 3 shows the tariffs and the electricity generated to date and the forecast over 10 years of the life of the array.

Table 3: Showing the economic and environmental benefits of the solar arrays on the farm

25KW Array													
CO2 saved KgCO2/KWh	0.235												
Average degradation % per year	1		Year										
	Original Terms	**RPI**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total 10 years**
Generation per year KWh			22273	21830	21611	21395	21181	20970	20760	20552	20347	20143	211063
Feed in Tariffs P/KWh	12.13	2.43	12.42	12.73	13.04	13.35	13.68	14.01	14.35	14.70	15.06	15.42	
Export Tariffs P/KWh	4.77	2.43	4.89	5.00	5.13	5.25	5.38	5.51	5.64	5.78	5.92	6.06	
Grid Electricity Cost p/KWh	13	2.43	13.32	13.64	13.97	14.31	14.66	15.01	15.38	15.75	16.14	16.53	
Revenue Generated £			£6,277.34	£6,301.92	£6,390.51	£6,480.34	£6,571.43	£6,663.81	£6,757.48	£6,852.47	£ 6,948.80	£ 7,046.47	£ 66,290.57
CO2 Saved KgCO2			5234.2	5130.0	5078.7	5027.9	4977.6	4927.9	4878.6	4829.8	4781.5	4733.7	49599.8
Initial Outlay	£29,500.00									**Average % Investment**			22%
50KW Array													
			Year										
	Original Terms	**RPI**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total 10 years**
Generation per year KWh			42924	42070	41649	41233	40820	40412	40008	39608	39212	38820	406755
Feed in Tariffs P/KWh	12.13	2.43	12.42	12.73	13.04	13.35	13.68	14.01	14.35	14.70	15.06	15.42	
Export Tariffs P/KWh	0	2.43	0	0	0	0	0	0	0	0	0	0	
Grid Electricity Cost p/KWh	13	2.43	13.32	13.64	13.97	14.31	14.66	15.01	15.38	15.75	16.14	16.53	
Revenue Generated £			£9,143.68	£9,179.49	£9,308.53	£9,439.38	£9,572.07	£9,706.62	£9,843.07	£9,981.43	£10,121.74	£10,264.02	£ 96,560.03
CO2 Saved KgCO2			10087.1	9886.4	9787.5	9689.7	9592.8	9496.8	9401.9	9307.9	9214.8	9122.6	95587.5
Initial Outlay	£ 54,200.00									**Average % Investment**			18%

Key Elements in Table 3

CO_2 saved, measured in Kg CO_2/ KWh is the difference between the life cycle analyses CO_2 emissions from the solar panels compared to the electricity production average carbon footprint per KWh, this value is used to calculate the weight of CO_2 emissions the business is saving when generating electricity via the solar array.

The actual degradation of the solar panels per year is very difficult to measure as the electricity generation of the solar panels is dependent on many factors which are not normally measured, therefore a value of the average degradation of silicon solar panels in the UK was used.

The generation per year is based on the actual value measured for the first 3.5 years, then the data is extrapolated over the 10 years assuming the average degradation of the solar panels.

The Feed in tariffs is the value paid per KWh of electricity generated. This, like all the tariffs increases with the recommended price index.

The Export tariffs is the value paid for exporting electricity to the grid, in the 25KW array 50% of the electricity is assumed to be exported into the grid but for the 50KW array as there is no export meter the electricity exported is assumed to be zero.

The revenue generated is calculated by Equation 4

$$Revenue\ generated(£) = Electricity\ generated \times (Feed\ in\ tariffs + \frac{1}{2}export\ tariffs + (grid\ electricity\ cost \times proportion\ of\ the\ generated\ electricity\ used)) \quad 4$$

Therefore using the initial outlay the average % investment can be calculated.

The CO_2 saved is the KG of CO_2 which the solar panels have saved compared to using the grid electricity.

As the data suggests the two solar arrays are generating large returns on the initial investment, this is important as in order for businesses and home owners to use the carbon saving technologies they must give a significant return.

The reduction in carbon emissions due to these two solar arrays is approximately 14.57 tonnes of CO_2 per year, this is the equivalent of 2.7 hectares of woodland area, therefore theseolar arrays are having a large impact on the reduction of carbon emissions from the electricity generation sector.

However, the forecast of the electricity generation is based on the previous 3.5 years of operation. In the area that the solar panels are placed has experienced a higher proportion of Sunlight than average between 1981-2010. Since 2014 (when the arrays were installed) the average Sunlight hours has been 106.2 % higher than Sunshine average. This would have had a positive impact on the panels causing the forecast to be optimistic about the electricity generated by the panels in the future. However, the average Sunlight hours in the previous few years have been consistently higher than the average between 1981-2010, this could be related to the changing climate giving more extreme weather. (Forestry England, 2019) (Ofgem,(b) 2019)

3.1.2 Heat Pump

The farm used for this case study has a total of 4000 pigs, in the farrowing shed the sows give birth to their piglets, there are approximately 110 sows, and 1000 piglets in this building. An advanced heating and ventilation system is used in this shed to ensure that the pigs are comfortable resulting in healthier pigs. The ventilation system in the shed works by creating a low pressure within the shed which draws the outside air through a series of ducts under the floor. The outlet of these ducts are next to where the sows sit, this ensures the sow is kept cool when in the farrowing shed, the piglets however need to be kept warm so they have underfloor heating pads where they sit, the average temperature of the building is maintained at 21°C. To maintain the necessary temperature difference between where the sow and the piglets sit requires a significant heat input all year round. The exhaust of the ventilation system comprises of a number of ducts each of which have a damper to control the flow rate. All the ducts in the shed come to one large central duct. The exhaust air then flows through a heat exchanger. At the air outlet of the heat exchanger there are a set of large fans which create a low pressure driving the ventilation system. The fans, air duct dampers and underfloor heating pads are all controlled by a central computer to ensure an optimal environment inside the shed.

To heat the underfloor heating pads a 40kW heat pump is used. This is primarily a ground source heat pump although it also takes advantage of the heat exchanger in the ventilation system. This ground source heat pump was authorised in December 2017 and was fully working by May 2018. Figure 26 shows a diagram of the component parts of the heat pump system.

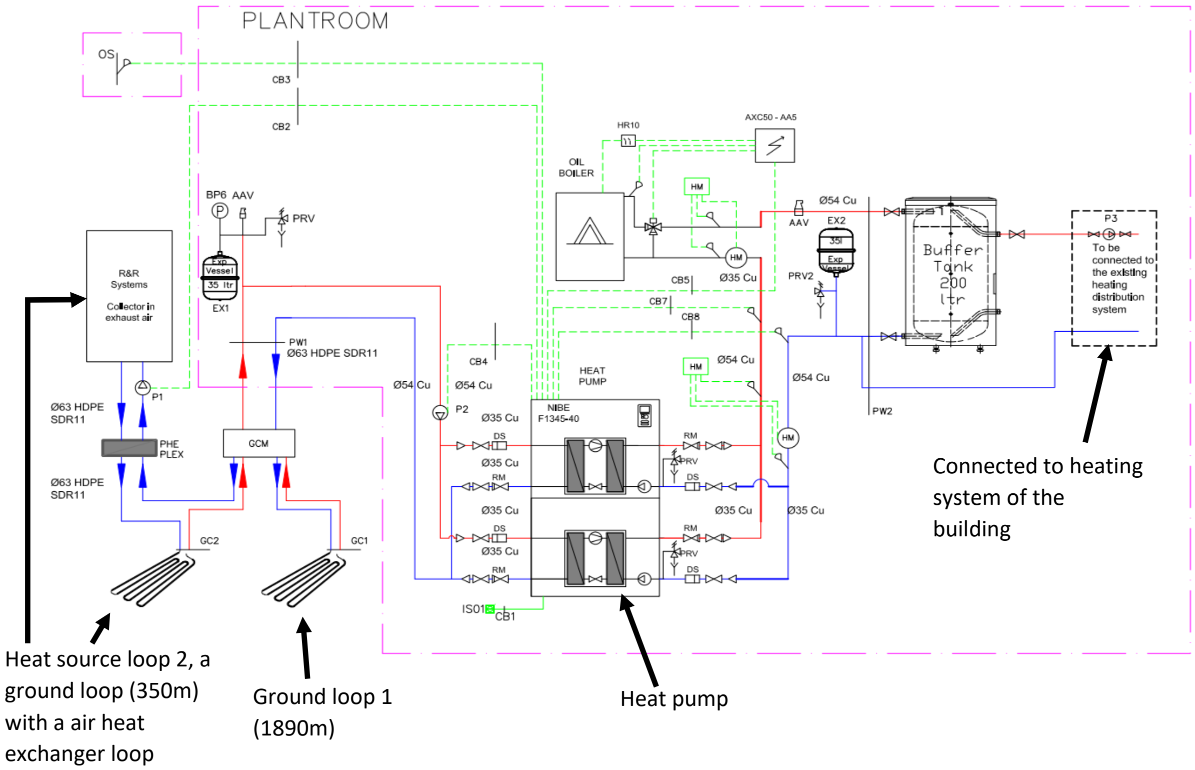

Figure 26: Diagram showing the GSHP system used in the farrowing shed.

The GSHP has two loops, a 1890 M ground loop (ground loop 1) and a 350M ground loop in series with an air heat exchanger loop (heat source loop 2). The two ground loops have a vertical depth of 1.2 m and a width between each loop of 1 m. The temperature of the exhaust air in the ventilation system is around 21°C all year round, the flowrate of air however, varies depending on the difference between the target and the actual temperature of the building but would commonly be around 15,000 m^3/h. The average temperature for this part of the UK is 11°C, the exhaust air heat exchanger is able to fully satisfy the heat source requirements for the heat pump at this outside temperature. So with an outside temperature of 11°C only heat source loop 2 is used. The working fluid flows through the air heat exchanger and then through the 350M ground loop and back into the heat pump. If the fluid at the outlet of the heat exchanger is greater than the temperature of the

Table 4: Showing the environmental and economic benefits of the GSHP used to heat the sow farrowing shed

GSHP Coefficent Of Proformance COP	3.72												
GSHP CO_2 emissions (KG/KWh Heat)	0.0761												
Oil CO_2 emissions (KG/KWh Heat)	0.245												
	Original Terms	**RPI**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total 10 years**
Heat energy required per year (KWh)			183226	183226	183226	183226	183226	183226	183226	183226	183226	183226	1832260
Tier 1 RHI (P/kWh)	9.09	2.43	9.31	9.54	9.77	10.01	10.25	10.50	10.75	11.01	11.28	11.56	
Elegable for Tier 1 (kWh)			52560	52560	52560	52560	52560	52560	52560	52560	52560	52560	
Tier 2 RHI (P/kWh)	2.71	2.43	2.78	2.84	2.91	2.98	3.06	3.13	3.21	3.28	3.36	3.45	
Elegable for Tier 2 (kWh)			130666	130666	130666	130666	130666	130666	130666	130666	130666	130666	
Oil Price (P/kWh)	5.22	2.43	5.35	5.48	5.61	5.75	5.89	6.03	6.18	6.33	6.48	6.64	
Grid Electricity Cost (P/KWh)	14.31	2.43	14.66	15.01	15.38	15.75	16.14	16.53	16.93	17.34	17.76	18.19	
Cost of heating with Oil (£)			£ 9,796.81	£10,034.87	£10,278.72	£10,528.49	£10,784.34	£11,046.40	£11,314.82	£11,589.77	£11,871.41	£12,159.88	£ 109,405.52
Cost of heating with GSHP without RHI (£)			£ 7,219.56	£ 7,395.00	£ 7,574.70	£ 7,758.76	£ 7,947.30	£ 8,140.42	£ 8,338.23	£ 8,540.85	£ 8,748.39	£ 8,960.98	£ 80,624.20
Oil Boiler - GSHP without RHI (£)			£ 2,577.25	£ 2,639.88	£ 2,704.02	£ 2,769.73	£ 2,837.04	£ 2,905.98	£ 2,976.59	£ 3,048.92	£ 3,123.01	£ 3,198.90	£ 28,781.32
Cost of heating with GSHP with RHI (£)			-£ 1,301.33	-£ 1,332.96	-£ 1,365.35	-£ 1,398.53	-£ 1,432.51	-£ 1,467.32	-£ 1,502.98	-£ 1,539.50	-£ 1,576.91	-£ 1,615.23	-£ 14,532.60
Oil Boiler - GSHP with RHI (£)			£11,098.15	£11,367.83	£11,644.07	£11,927.02	£12,216.85	£12,513.72	£12,817.80	£13,129.27	£13,448.31	£13,775.11	£ 123,938.13
CO_2 Saved $KgCO_2$			30951.4	30951.4	30951.4	30951.4	30951.4	30951.4	30951.4	30951.4	30951.4	30951.4	309514.03
Initial Outlay of GSHP	£37,858.00								**Average % Investment**				33%

ground loop (which it would be for outside temperatures above 11℃) the ground will absorb heat from the loop, this is an advantage as the ground has a high specific heat capacity and also can retain heat for a short period of time. If the outside temperature reduces i.e. the difference between day and night, the ventilation system would reduce the air flow and the requirement from the heat source would be greater to maintain the desired temperature inside the building. As the exhaust flow rate reduces the ventilation's heat exchanger would capture less heat energy and therefore the heat exchanger's working fluid outlet temperature would be less than the ground temperature in the ground loop. Therefore, as the working fluid flows through the ground loop the fluid would absorb the heat from the ground increasing temperature at the input of the heat pump. The ground would have a higher than natural temperature as the ventilation heat exchanger has heated the ground when there was an energy surplus. Effectively the ground loop in heat source loop 2 is used as a heat storage rather than a heat source as the ventilation system supplies most of the heat energy. This system is highly beneficial as the heat pump is supplied with a heat source with a higher average temperature resulting in a smaller difference in temperature between the heat source and heat pump output temperature. This corresponds to a higher coefficient of performance resulting in higher efficiencies. Ground loop 1 is also used when the heat demand is high. Table 4 shows the figures for the environmental and financial benefits of using a heat pump to heat the shed rather than an oil boiler.

The table shows the expected values for the heat pump over a period of 10 years. The predictions are based on real figures as the shed was previously heated by an oil boiler for a year so the heat load predictions are relatively accurate.

The coefficient of performance of the heat pump is the standard for the specific heat pump and ground type they are working with, however the calculations were done on a purely ground source heat pump, the positive effects of the heat exchanger in the ventilation system was not considered when calculating the COP. The average COP could therefore be significantly higher.

The average CO_2 emissions per kWh of heat was then calculated for the two options for heating the shed, these are used to calculate the CO_2 saving the GSHP has compared to using the oil burner.

The heat energy required per year was then calculated using the data from the previous year when the shed was heated with an oil boiler which were considered to be relatively constant over the 10 year period.

Tiers 1 and 2 are the government incentives to encourage businesses to use carbon saving technology. Tier 1 has a higher tariff of 9.09 P/kWh which applies to the 'initial heat'. Tier 2 has a tariff of 2.71 P/kWh which applies to the rest. 'Initial heat' is the quantity of heat, in kWh, that would be generated by the GSHP if running at full capacity for 15% of the year (1,314 hours).

The costs associated with the oil and GSHP without the Renewable Heat Incentive (RHI) are the cost of the different fuels to satisfy the heat load, the difference between these values is also shown in the table, the money saved over the 10 year period by having a GSHP compared to a traditional oil boiler is approximately £28,800. The cost of installing the GSHP was £37,858 corresponding to an 8% return on the investment per year. With the servicing and maintenance hassle, and the space that the system takes up, the farm business would have been unlikely to invest in this system had not there been RHI available. It is therefore essential to have the RHI to encourage businesses to use carbon saving technology.

The cost of the GSHP with RHI was then calculated, this shows a negative value because the RHI tariffs are higher than the cost of the electricity to run the heat pump. The difference between the oil boiler and GSHP with RHI was then calculated. This shows a large financial difference of £123,938 between the two heating methods, this corresponds to a 33% return on the initial investment each year which is very significant. This makes the technology financially benefit the business. The specifications for this specific heat pump and ground loop can be found in Appendix A1 and A2.

The reduction in CO_2 emissions by using a GSHP to satisfy the heat demand compared to an oil boiler is also calculated. Approximately 30.9 tonnes of CO_2 are saved each year, this is the equivalent of 5.7 hectares of woodland area which shows the large environmental benefits of carbon saving technologies. Also the indirect emissions from the heat pump are dependent on the carbon emissions from the grid, therefore as the grid reduces the carbon emissions per kWh of electricity generated so the indirect carbon emissions from the heat pump reduce, this is not true of an oil boiler, the oil boiler will increase the carbon emissions per kWh of heat generated as the boiler gets less efficient.

There are many different opinions on whether the government is wise to subsidise green energy as much as they do, however the government have specific targets to meet as outlined in the introduction and therefore they put a damage value of approximately £100 on every tonne of CO_2 released into the atmosphere, therefore they use their resources to encourage carbon saving technologies to be able to meet the climate targets. (Ofgem,(b) 2019) (New York university school of law,2015) (Forestry England, 2019)

3.2 Canadian Carbon Neutral House

A detached net zero carbon emission house near Ottawa in Canada was used as a case study looking at how a rural detached house can use sustainable and carbon reducing technologies. They have been able to reduce their net carbon emissions to zero by using many different technologies, the house has been slowly transformed from a traditionally powered and heated to a fully carbon neutral house. The objectives of this renovation project are very different to the previous case study. The aim of this project was to integrate different technologies to create a carbon neutral home, the financial benefits of the technologies were considered to be relatively unimportant compared to the environmental benefits. Therefore for this project only the environmental benefits will be considered.

The technologies used to reduce the carbon emissions of the home are solar panels, battery storage, an electric vehicle and a ground source heat pump. Also all the cooking facilities etc. within the home are all electrically powered.

3.2.1 Solar Panels

The house has a total capacity of 15kW of PV solar panels, this is the main source of electricity in the home, solar panels are suitable for a carbon neutral house as once they are installed each kWh of electricity they produce emits no carbon emissions. However as discussed earlier the large issue with solar arrays is that they only generate electricity when they are exposed to light radiation, therefore at night and on cloudy days they produce very little electricity. Therefore to have a home which is fully powered by solar power it is necessary to have an energy storage technology.

3.2.2 Tesla PowerWall

The home has three Tesla PowerWalls which have a total of 39kWh of lithium-ion battery storage. This enables the surplus electricity which is not used by the home to go into the battery storage, then when the battery is fully charged the surplus electricity is exported back into the grid. However when the solar panels do not generate any electricity for example at night the batteries supply the house with the stored electricity.

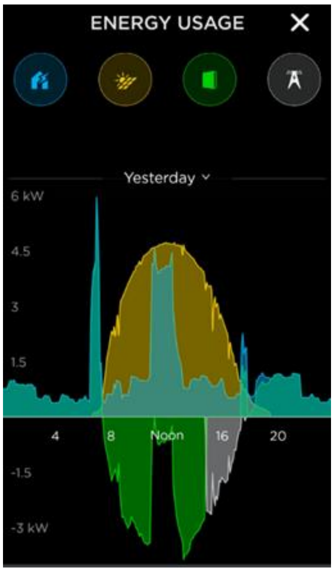

Figure 27: Graph showing the energy transferred on a typical day

Figure 27 shows a diagram of the energy usage on a typical day, in the diagram the energy used in the house is in blue, the solar energy is yellow, the Tesla PowerWall is green and the electricity from the grid is shown in grey.

At the start of the day up until 08:00 the electricity used in the house is completely supplied by the Tesla PowerWall, then, as the Sun rises the solar panels start to supply the electricity for the house. As Figure 27 shows the energy usage from the Tesla battery pack becomes negative, this is because the surplus electricity from the solar array is being used to charge the battery. At approximately 15:00 the battery storage is no longer using the surplus energy from the solar panels, this is due to the batteries being fully charged. The surplus electricity is then exported into the grid. At approximately 18:00 the electricity from the solar panels can no longer sustain the home usage, therefore the battery packs then supply the electricity needed in the home. This shows how the different technologies are working together to ensure the house always has sufficient power but in a self-sufficient way.

In this typical day the carbon emissions from the house would be zero. Also some of the zero carbon electricity was exported back into the grid. However, on some days there is repeatedly an energy deficit between the electricity consumed in the house and the electricity generated from the solar panels. This causes the batteries to run low and therefore electricity is drawn from the grid, this electricity is not carbon free, however as in the typical day in Figure 27 the electricity was exported into the grid is now taken back out the grid, if the total electricity both imported and exported into the grid is the same there is net zero grid power consumed. Therefore this house is a net zero carbon emission house as the total electricity generated by the solar panels is the same as the electricity consumed.

3.2.3 Electric Vehicle

The Mitsubishi EV has a 14 kWh battery and is used for transport, the EV has a range that is suitable for almost all the transport requirements that the home owners have, this means that it is always charged up at the home charge port and therefore emits no carbon as the electricity used in the house is carbon free.

3.2.4 Ground Source Heat Pump

The heating and domestic hot water requirements for the house are supplied by a ground source heat pump, this ground source heat pump has a coiled PVC pipe 2m below the surface. Figure 28 shows the trench the coiled PVC pipe was put into.

Figure 28: Image showing lowering the ground loop into the trench

The ground loop is in Leda Clay. Leda Clay has a very small particle size therefore it packs together very tightly. This makes it have a similar permeability to concrete. The bottom of the trench is below the water table, therefore when the trench had been dug water started to seep into the trench due to the pressure. Once the pipe was laid in the trench it was back filled with sand and then Leda Clay on top, as the permeability of sand is very high the sand soon became waterlogged. Once the water saturated the sand up to the water table there was no pressure difference and therefore no flow of water through the soil, this means that effectively the only heat transfer mechanism between the waterlogged sand and the surrounding clay is conduction. This is a large benefit as the soil can be used for an effective thermal storage.

The heat pump used can also cool the house when the inside temperature is above the desired temperature, in 2018 when there was a prolonged period of high outside temperature the waterlogged sand increased to approximately 17.5℃, this is 5.5℃ above the natural temperature of the ground. Due to the surrounding soil type the saturated sand is expected to retain this elevated temperature for 3-4 months, therefore this thermal energy can be recovered when the outside temperature reduces and the heat pump is reversed back to heating the building and heat energy is needed from the ground loop. This significantly increases the COP of the heat pump, thus increasing the efficiency of the system.

The house is situated in a climate where there is snow on the ground most of the winter, the heat demand in the winter is therefore high which causes the ground loop to rapidly reduce. However what was discovered is that the saturated sand temperature rarely reduces below -0.2℃. This effect is due to the latent heat in the water in the transition between a liquid to a solid. Another technology that is used is a Loopanol heater. In the winter when there is an electricity surplus from the solar arrays instead of exporting the electricity back into the grid the electricity is used to power the loopanol heater which puts thermal energy into the ground loop, this works with the geothermal heat coming from the Earth to heat the sand and ground surrounding the ground loop. If the water in the saturated sand is undergoing the transition between a solid and a liquid the thermal energy put in by the Loopanol heated is almost 100% recoverable by the GSHP as the temperature of the ground loop has a very low change in temperature.

The energy transferred through the carbon neutral home is shown in Figure 29

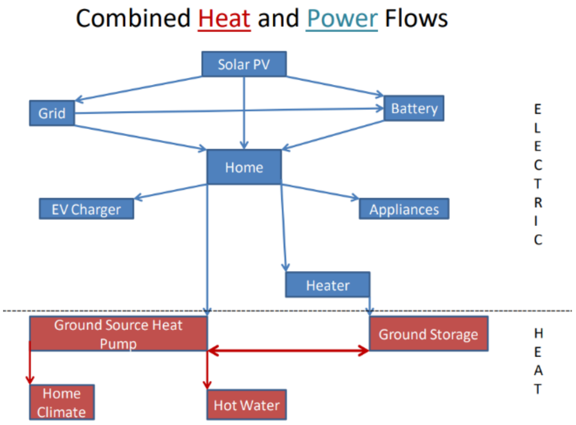

Figure 29: Energy transferred through the carbon neutral house

The diagram shows how all the different technologies are integrated into the system. A computer program has been developed in order to control the systems to ensure that they are running at maximum efficiency, this is essential as the more efficient the system is the less energy is required to run the home.

This case study shows that integrating many different existing technologies together it is possible to make a house which is carbon free. The aim of this project was a personal ambition from the owner to overcome the challenge of a carbon neutral house, however it shows what is possible and as the technologies continue to reduce in price projects like these will become more attractive financially and therefore many more homes will become self-sufficient.

3.3 Hypothetical House in London

The purpose of this section is to suggest carbon saving technologies for a house in an urban area. Each technology will be looked at in terms of its feasibility and its environmental and economic benefits. The hypothetical house being analysed is a 3 bedroom terraced house which is up to building regulations as it has recently been renovated, the home has a condenser gas boiler which supplies the home with space heating via an underfloor heating system and domestic hot water, the cooking facilities are all electric. It is estimated that the home would require 12400 KWh of gas for heating and DHW and consume approximately 4000kWh of electricity per year. This is based on the fact that the property has recently been renovated and therefore is up to specifications with insulation double glazed windows etc. The owner of the house has a vehicle which is a BMW 5 series with a 3L petrol engine. The changes to this average house in London would include placing solar panels on the roof, changing the heating system and changing the owner's vehicle.

3.3.1 Solar Panels

Table 5 shows the environmental and economic benefits of putting solar panels on the roof. This solar array at this size is expected to generate approximately 2500kWh per year, this corresponds to saving approximately 587kg of CO_2 per year which is a large environmental incentive. However as

Table 5: Showing the Financial and environmental benefits of installing solar panels on the roof

3KW Array													
CO2 saved KgCO2/KWh	0.235												
Average degradation % per year	1							**Year**					
	Original Terms	**RPI**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total 10 years**
Generation per year KWh			2500	2450	2426	2401	2377	2354	2330	2307	2284	2261	23690
Grid Electricity Cost P/KWh	15.39	2.43	15.76	16.15	16.54	16.94	17.35	17.77	18.21	18.65	19.10	19.57	
Revenue Generated £			£394.10	£395.64	£401.20	£406.84	£412.56	£418.36	£424.24	£430.21	£ 436.25	£ 442.39	£ 4,161.81
CO2 Saved KgCO2			587.5	575.8	570.1	564.4	558.7	553.1	547.6	542.1	536.7	531.3	5567.3
Initial Outlay	£ 7,000.00										Average % Investment		6%

Table 6: Showing how an ASHP would benefit the house both financially and environmentally

ASHP Coefficient Of Performance COP	3												
ASHP CO2 emissions (KG/KWh Heat)	0.0943												
Gas CO2 emissions (KG/KWh Heat)	0.220												
							Year						
	Original Terms	**RPI**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total 10 years**
Heat energy required per year (KWh)			12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	120000
RHI (P/kWh)	10.71	2.43	10.97	11.24	11.51	11.79	12.08	12.37	12.67	12.98	13.29	13.62	
RHI Per Year			£ 1,316.43	£1,348.42	£ 1,381.19	£ 1,414.75	£ 1,449.13	£ 1,484.34	£ 1,520.41	£ 1,557.36	£ 1,595.20	£ 1,633.96	£ 14,701.19
Gas (P/kWh)	3.50	2.43	3.59	3.67	3.76	3.85	3.95	4.04	4.14	4.24	4.34	4.45	
Grid Electricity Cost (P/KWh)	15.39	2.43	15.76	16.15	16.54	16.94	17.35	17.77	18.21	18.65	19.10	19.57	
Cost of heating with Gas(£)			£ 430.21	£ 440.66	£ 451.37	£ 462.34	£ 473.57	£ 485.08	£ 496.87	£ 508.94	£ 521.31	£ 533.98	£ 4,804.31
Cost of heating with ASHP without RHI (£)			£ 630.56	£ 645.88	£ 661.58	£ 677.65	£ 694.12	£ 710.99	£ 728.26	£ 745.96	£ 764.09	£ 782.65	
Cost of heating with ASHP with RHI (£)			-£ 685.87	-£ 702.54	-£ 719.61	-£ 737.10	-£ 755.01	-£ 773.35	-£ 792.15	-£ 811.40	-£ 831.11	-£ 851.31	-£ 7,659.44
Gas Boiler - ASHP with RHI (£)			£ 1,116.08	£1,143.20	£ 1,170.98	£ 1,199.43	£ 1,228.58	£ 1,258.43	£ 1,289.01	£ 1,320.34	£ 1,352.42	£ 1,385.28	£ 12,463.75
CO2 Saved KgCO2			1508	1508	1508	1508	1508	1508	1508	1508	1508	1508	15080
Initial Outlay of ASHP	£ 8,000.00									Average % Investment			16%

there are no government tariffs the only way the solar panels can be economically beneficial to the property owner is that it reduces the quantity of electricity having to be drawn from the grid and therefore reduces the electricity bill. On this small array there would be no payment for the electricity generated surplus to the house requirements but if the occupants of the house used their appliances at the times when electricity is being generated by the panels then very little would be exported back into the grid and the owners would be getting the most benefit from their investment. The return on the investment of £7000 for the panels would be approximately 6%, which is relatively low compared with other investments, especially as the panels are guaranteed for only 20 years.

3.3.2 Heating Technology

There are two feasible carbon saving alternatives to the gas boiler which is used for the space heating and DHW. The first is to install a solar heating array on the roof generating sufficient heat energy for the household needs. The other is fitting an air source heat pump. Solar heating panels are approximately three times more efficient than PV solar panels, therefore generate three times as much energy per square metre. However an ASHP has a COP of approximately three, if the PV solar array was powering an ASHP it would return as much heat energy as the same sized solar heating panels. Also an ASHP is able to supply the home with sufficient heat energy for 95% of the time (may need some assistance during a cold winter) whereas solar heating panels can only generate 40% of the heating needs of the home, therefore for this home an ASHP is the most favourable technology to satisfy its heat demands.

Table 5 shows the financial and economic benefits of the heat pump. As the table shows, without the government incentives (RHI) it would be less expensive to continue with the gas boiler than transfer to an ASHP. However the carbon dioxide emissions from the heat pump compared with the gas boiler saves approximately 1508 kg of CO_2 per year, therefore transferring from a gas boiler to an ASHP is significantly better for the environment. When the RHI tariffs are included the cost of heating the home is approximately -£685, which means that the owner is effectively paid to heat their home. When the incentives are included in the calculations the difference in heating costs are approximately £1100 per year this corresponds to an investment of 16% which is significant. Therefore transferring from a gas boiler is both economically, and environmentally beneficial. The largest environmental benefit of the system is that the indirect carbon emissions involved in the heating system are not extracted directly from the building as the electricity to power the system is either is generated via solar panels on the roof which emit no carbon emissions or is generated elsewhere, this results in an improved local air quality.

3.3.3 Transport

Another way of reducing the carbon emissions generated by this home and its owners is to change their petrol vehicle to either a plug in hybrid or a fully electric vehicle, Table 7 shows the effects of transferring to an EV.

Table 7: Showing the environmental and economic benefits of the different vehicle types.

	Initial Price	**Average Miles per Year**	**gC02 per Mile**	**Preformance (0-100kph)**	**Cost per Mile (p)**	**Value after 3 Years**	**Expense Over 3 Years**	**Total Co2 Released (Kg Co2)**	**Kg CO2 more than full EV per Year**
Tesla Model S 100 KWh Full EV 375 Range	£ 80,800.00	10000	93.3	4.3	5.1	£ 54,000.00	£ 28,323.61	933	
BMW 5 Series 3L Petrol	£ 53,530.00	10000	283	4.8	14	£ 21,000.00	£ 36,730.00	2830	632.3
BMW 5 Series Plug in Hybrid	£ 50,000.00	10000	120	6.2	13	£ 22,000.00	£ 31,900.00	1200	89

The Table shows that both the full EV and the plug in hybrid produce far fewer emissions than 3L petrol vehicle per year. Also the full EV and the plug in hybrid are charged up by the grid, therefore as the grid reduces the quantity of carbon emitted per kWh of electricity generated the indirect emissions produced by EV's reduces. Another large benefit of the full EVs and plug in hybrids is that the local emissions are kept low as the full EV emits no tail pipe CO_2 and the plug in hybrid emits very little in residential areas as they would normally run on electric power only at low speeds therefore the local air quality would be better. Economically the full EV is the most beneficial, because the running costs are so low and the depreciation on the vehicle is relatively low. The Plug in hybrid is also less expensive after three years than the full petrol vehicle. This makes a difference to which is the most suitable for this home owner. Also the performance of the full EV is significantly better than the petrol or hybrid vehicle making the vehicle more attractive. The environmental and economic differences between the hybrid and full EV are not significant enough to make a choice of which one is most suitable, this would depend on the owner's preference and whether the owner often makes long journeys for which he would be best with the hybrid vehicle.

In conclusion, making these three changes would be very environmentally beneficial, it would reduce both the direct and indirect carbon emissions of the house and also significantly reduce the local emissions and thus increase the local air quality. The economic benefits of changing the vehicle to a full electric or hybrid vehicle and changing the gas boiler to an ASHP are significant and present a substantial benefit to the owner. Since the government tariffs have been removed from solar panels the economic benefit of solar panels has almost been removed and therefore from an economic perspective the solar panels are not worth the investment. (Energy sage, 2019 Green Match(b), 2019 Energy saving trust, (b) 2019)

4. Conclusion

4.1 Technology Review

In conclusion, the carbon saving technologies that have been described each have their advantages and disadvantages and each have their different optimum usage. The analysis shows that there are technologies available to combat the growing threats of climate change and shows how they can be used for the benefit of the environment.

The research into wind turbines showed how they can be used to generate electricity with relatively low life cycle carbon emissions. Wind turbines are both economical and environmentally beneficial and therefore it is likely that this technology will continued to be used in the future. However, wind turbines are generally only suitable for grid electricity or for large industrial installations. They are not suited to individual domestic home owners or to urban areas, therefore this technology was not used in the case studies that were researched.

The research completed on PV solar panels showed that they can be used effectively in both urban and rural areas to generate low carbon electricity. PV solar panel technology has developed significantly over the last decade which has resulted in a lower price per kW of capacity and higher efficiencies. The development has been driven by the increasing demand of PV panels in the developing world. Solar arrays were included in all the case studies because they are both environmentally and economically beneficial. However, the UK government has now removed the tariffs on solar energy as of March 2019, and the hypothetical London house showed that the economic benefits have been significantly reduced due to tariff removal, resulting in a long payback time which is not desirable. This could cause only larger scale arrays to be economically beneficial in the near future. Nevertheless, as the price of electricity continues to rise and the price of solar panels continues to fall this picture could change in the future and it may again be economically viable to have solar panels on small domestic rooves.

This project has also investigated the use of batteries for energy storage infrastructure as energy storage is an essential part of a predominantly renewable electricity grid. For electricity storage in both the grid and buildings, batteries are the most suitable. Many different battery technologies were researched, the most widely used technology for EVs and also domestic home storage is lithium-ion batteries. They have their advantages; however, they also have many issues with the carbon emissions in manufacturing and also the disposal of the used batteries – or their recycling. Battery technologies are constantly being developed and improved so it is difficult to tell which specific technology will be the most suitable for energy storage in the future.

The research completed on solar heating shows how the technology has been developed to maximise the efficiency of the system in the last decade. The fundamental issue with solar heating in the UK is that it is only able to generate up to 40% of the domestic households heating needs during the year. Therefore another heating system is necessary which adds expense and inconvenience. The system is approximately three times as efficient in converting solar rays into useful thermal energy as PV panels are at converting solar rays into electricity. However, heat pumps have a coefficient of performance of approximately three and therefore if a heat pump is powered by a PV solar array it would be able to generate as much useful thermal energy as a solar heating system with the same size solar panels. Therefore it would appear that solar heating technology is a passing technology.

Micro Combined heat and power is another technology that has been researched - micro CHP has the benefit of adding efficiency to how buildings are supplied with electricity and heat, therefore the total CO_2 produced by the building is reduced. However, CHP often still use fossil fuels as an energy source and therefore are not renewable, they also have the disadvantage of generating more local carbon and other pollutant emissions (e.g. nitrogen oxides) from the buildings than traditional methods, which reduces local air quality. So CHP is a good technology for improving the current overall efficiency but cannot offer the solution to zero carbon future.

Heat pump technology was also researched - heat pumps can reduce the quantity of energy consumed in heating buildings. They also only emit indirect carbon emissions so the local air quality is improved compared to traditional heating methods. The heat source can also come from many different places so is a suitable heating method for almost all the buildings in the UK. Heat pumps were used in the case studies as they have environmental and economic benefits. The economic benefits of heat pumps however mostly come from the government tariffs, and if the government tariffs were removed then the technology would not be economically viable for domestic homes. This shows how the government incentives are being used to encourage the use of carbon saving technologies before they become economically viable in themselves. The overall conclusion is that heat pumps will continue to be used extensively whilst the government tariffs remains and as the price of the heat pumps continue to fall they could become economically viable without the government tariffs however it’s difficult to tell.

The smart grid is another technology that was reviewed, concluding that the smart grid will be used in the future to stabilise the grid by giving the customer live feedback on the electricity grids peaks and troughs of output. This will enable smart appliances, heat pumps and bi-directional electric vehicle charges to adapt to minimise the cost to the customer and stabilise the grid.

Insulation and ventilation systems were also discussed. Building regulations in the UK state a minimum insulation level for extensions and new builds, this requirement is enough to reduce the energy consumed in the building by a large amount. The positive effects of increasing the insulation level above that which is required in building regulations will not reduce the energy consumed by a significant amount. Ventilation systems are sometimes necessary to ensure that the air quality inside the building remains good quality. It is likely that natural ventilation systems will become more commonly used in the future and buildings will be designed to reduce the use of mechanical air conditioning and heating systems which will further reduce the carbon emissions.

4.2 Case Study Review

The Farm case study shows the financial and economic benefits of using carbon reducing technologies driven by government policy and associated tariffs. This case study shows that the government incentives are enabling businesses to economically benefit from the carbon saving technologies. This is important as not many businesses would use a carbon saving technology if it disadvantaged them financially. The technologies the farm case study has used could be used in many buildings where there is space to have a ground source heat pumps so they are transferable to other businesses.

The carbon natural house in Canada shows how the technologies can work together to remove the dependency of a dwelling to ensure a greener future. The technologies used in Canada are transferable to the UK climate and therefore it is likely that some of the technologies that were used will become more popular in the UK. However, the energy storage system that the carbon natural house has will become unnecessary when the carbon emissions from the electricity generation industry are removed. Also the use of electric vehicle batteries for energy storage may become more favourable than a static home battery.

4.3 Hypothetical London Home Review

The three changes made to the London home would be very environmentally beneficial, they would reduce both the direct and indirect carbon emissions of the house significantly reducing the local emissions and thus increase the local air quality. The economic benefits of changing the vehicle to a full electric or hybrid vehicle and changing the gas boiler to an ASHP are significant and present however the benefits in the future could change due to a change in the government tariffs on heat pumps. Since the government tariffs on solar energy have been removed the economic benefit have almost been removed too and therefore from an economic perspective the solar panels are not worth the investment. The technologies used in this hypothetical home could almost be used on every house in the UK. This would substantially reduce the carbon emissions of both the residential and electricity generation industry. However, there are disadvantages to these technologies, for example the initial expense, this is why some home owners do not adopt these technologies.

At present there are relatively few homes in the UK which have adopted the technologies used in the hypothetical home in London, however as more homes do it will significantly increase the load on the grid infrastructure. Therefore more testing and research needs to be completed to ensure the existing grid has both the generation and transmission capacity to facilitate this large increase in demand.

4.4 Low Carbon Grid Electricity Generation

Clearly, the decarbonisation of electricity production and the control of demand are key factors in achieving emission targets, nationally and at the level of an individual dwelling or building. Only wind power has been discussed in this context, as this is outside the scope of the review. It is pertinent though to comment here on the role of nuclear power because this is a contentious issue. Nuclear power plants have a low life cycle carbon emissions per kWh of electricity generated, which is a large advantage that some countries have exploited (e.g. France). However, they generate reactive waste products which has to be disposed of and the consequences of nuclear accidents can be substantial, though improbable. This review has not considered nuclear power in any depth because the materials used are not renewable and also it is purely a grid technology and clearly not suitable for home owners or small businesses.

4.5 The foreseeable future

Analysis of the different technologies currently available suggests that the largest changes that will take place in both the electricity generation sector and residential sector can fit under three headings: Decarbonisation, Decentralisation and Digitalisation.

Decarbonisation is the reduction of CO2 in both electricity generation and heating buildings, and this will be achieved by the increased use of carbon saving technologies such as solar panels, wind turbines and reducing the use of coal fired power stations. For heating buildings it is predicted that there will be more buildings heated by heat pumps. This project has shown that heating buildings in this way has a large carbon saving and, with government incentives it is now economically viable. Uptake would be particularly advantageous in urban areas as they only emit indirect carbon emissions and therefore also maintain good local air quality. The increasing use of heat pumps coupled with EVs will significantly increase the demand on the grid and therefore these additional carbon saving electricity generation technologies will become essential in order to generate sufficient electricity.

Decentralisation describes how the use of domestic PV solar arrays, local wind farms, solar farms and other small-scale electricity generation technologies becomes more frequently, and reduces the demand on large power stations. Electricity is then generated closer to where the power is needed. As the renewable share increases, there is an increasing demand for suitable energy storage technologies. Currently most of the energy storage capacity in the UK grid is from hydro pump storage, however in the future a significant share for the energy storage capacity could come from electric vehicles using bi-directional charges – plus other uses of domestic and commercial storage and bi-directional transmission technology. The would be a large saving to the national grid as energy storage infrastructure is expensive; also the manufacture of batteries or alternative energy storage systems would release a considerable quantity of CO_2, therefore, if existing batteries were used, i.e. the ones in EVs then there would be a significant carbon saving.

Digitalisation is the introduction of the smart grid, where there is two-way communication between the customer and the supplier. This can be to communicate with bi-directional chargers and other smart appliances so the grid can be stabilised. Such systems could be integrated into heat pump systems to maximise the use of grid electricity in times of low demand and reduce the use of electricity at peak demand. With the growing use of technologies that have a high electricity demand (such as EVs and Heat pumps) there is a key need for flexible electricity pricing so the chargers and heat pumps can adapt to stabilise the grid. To repeat a previous and obvious point, decarbonisation of the grid is an essential requirement.

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6. Appendix

Appendix A1: Farm Case Study's Heat Pump Specifications

HEAT PUMP				
Ref	**Description**	**Specification**	**Qty**	**Comments**
AF1	Anti-freeze	Mono Ethylene Glycol Concentration 23%	176 l	X [vol %] = 23.00 T [°C] = 0.00 Density [kg/m^3] = 1040.62 Specific heat [kJ/(kg K)] = 3.716 Conductivity [W/(m K)] = 0.456 Kinematic viscocity [cSt] = 3.227 Freeze point [°C] = -10.76
GC	Ground Collector - Active Element	**40mm SDR11 Pipe** Minimum pressure rating 16 bar	**350 m**	**GC1 1 x 350 m** **GC2 1 x 2 m**
	Ground Collector - Header Pipe	**63 mm SDR11 Pipe**	20 m MAX!	Pipes must be insulated when running closer than 700mm and when running inside the property. (19 mm insulation)
~~GCM~~	~~Ground Collector Manifold~~	~~Manifold 0~~ ~~2 ways~~ ~~1130x1000x1000 mm~~ ~~InletØ: 40 mm~~ ~~OutletsØ: 63mm~~	~~1~~	To be supplied by client
	EF Fittings	40 x 32mm Black EF Reducer 63mm x 40mm Black EF Reducer 40mm Black EF to 1'' male BSP Thread	4 2 2	TBC !!
EXV1	Expansion Vessel	Expansion vessel brine circuit 35 litres DxH: 450 x 328 mm	1	
PRV1	Pressure Relief valve	Safety valve 3 bar	1	
DS1	Dirt separator	Particle filter	2	
GSHP	Ground Source heat Pump	Nibe F1345-40kW Three Phase Heating 39.3kW @ DOT 50 °C ~~Hot water 40.kW @ DOT /~~ ~~55 °C~~ Min/Nominal flow Brine 1.59/2.09 l/s Min/Nom Flow Heating 0.64/0.93 l/s 1800 x 600 x 620 mm (HxWxD) Weight: 352 kg Start Up Current 42 A Max Operating Current 30.9 A	1	**BRINE** The flow must have a temperature difference between brine out and brine in of 2-5 C deg when the system is balanced (suitable 5 minutes after compressor start). **HEATING** The flow must have a temperature difference between brine out and brine in of 5-10 C heating operation and 8-10 C water operation deg when the system is balanced.
PW1	Pipework	54mm OD + 19 mm Insulation	TBC	
PW2	Pipework	54mm OD + 19 mm Insulation	TBC	
AAV	Air Vent	Automatic Air Vent	2	
MGF	Magnetic Filter	DirtmagIQ,28 mm (no need of lever valves)	4	

Appendix A2: Farm Case Study's Ground loop Specification

Ground heat exchanger design		
Parameter	**Value**	**Comments**
Estimate of total heating energy consumption over a year for space heating and domestic hot water	183226 kWh	
HP heating capacity at 0 °C ground return temperature and design emitter temperature	39.29 kW	Heating Flow Temperature: 50°C
FLEQ run hours	4664 hrs	
Estimated average ground temperature	9.8 °C	
Estimated ground thermal conductivity	1.8 W/mK	Solid sediments, Conglomerates
Maximum power to be extracted per unit length of borehole, horizontal or slinky ground heat exchanger	15 W/m	
Heat pump SPF	3.72	
Maximum power NEEDED to be extracted from the Active Element	**28729 W**	
Maximum power ACTUALLY extracted from the Active Element	**33600 W**	
Maximum power extracted from the heat dump	28350 W	75[pax] x 180 [kg] x 2.1[W/kg]
Maximum power extracted from the Ground Collector	5250 W	
Length of ground heat exchanger calculated using the look-up tables	1916 m	

horizontal loop spacing	1 m	
Horizontal loop depth	1.2 m	
Total length of NEEDED ground heat exchanger active elements	**1916 m**	
Total length of ground heat exchanger substitued by dry cooler @ extract power rate	1890 m	Heat Dump
Total length of ground heat exchanger active elements installed in the ground	350 m	1 x 350 m of 40mm SDR11
Total length of INSTALLED ground heat exchanger active elements	**2240 m**	**1 x 350 m of 40mm SDR11 & 1 x 2m + Heat Dump**