SRS Technical Consultancy

Lot 3 – Business Cases

Project Report

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Prepared by: .... Checked by: ....

Robert MacGregor
Principal Engineer

Graeme Gidney
Regional Director

Approved by: ....

Graeme Gidney
Regional Director

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1 Tanfield, Edinburgh, EH3 5DA
Telephone: 0131 301 8600 Website: http://www.aecom.com

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EXECUTIVE SUMMARY

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1. Executive Summary

This report details the work carried out under Lot 3 of the SRS Technical Consultancy programme for the University of Edinburgh. The focus of Lot 3 was business cases for carbon reduction measures. The driver for this work is the University of Edinburgh's carbon reduction target, a 29% reduction in emissions by 2020, as set out in their Climate Action Plan. At present emissions are rising, in response to increasing student numbers and improvements in building utilisation and the increased energy intensity across the University estate. Whilst these appear to be negative factors, the picture does not accurately reflect the significant progress made in reducing emissions over recent years. This includes the four CHP - district heating schemes including a trigeneration scheme at George Square which also provides district cooling. Most energy efficiency options have been considered and many of the more suitable ones having already been implemented in whole or part. However, there are still opportunities available to reduce emissions further from both an energy reduction perspective and through the introduction of further renewable energy systems. The options are investigated in this report.

An initial literature review report from the first stage of the project provides information around energy efficiency measures that have been successfully implemented in other sectors. Lot 2 provides detailed information as to what other universities across the globe are doing to reduce their carbon emissions. The scope of the initial report and Lot 3 has developed over the course of the commission, with input from the University. Key focus areas identified through dialogue include:

- Developing / improving business case information and presentation - this evolved to providing a carbon assessment spreadsheet for the business case template developed in conjunction with the University Finance Department
- Technology assessment - a list of technologies was developed and input gathered from stakeholders on what could be suitable for the University, with high level assessments carried out to identify benefits where possible
- An investigation into potential technology funding options - input was gathered from the Finance Department and external funders including the Green Investment Bank and Scottish Equity Partners to build an understanding of how projects could be funded
- The provision of example business cases - business cases were provided using the carbon assessment spreadsheet, with supporting information in this report

The business case template under development by the Finance Department contains the information required for assessment of a project from a purely financial perspective. The information is presented in a format consistent with the University's assessment process. However, it was decided that carbon should also feature in the University's project assessment governance. This was felt to be an important requirement for the University, as Carbon assessment is a feature of its duty of care as a Public Body. Providing a carbon assessment as part of the business case template will be a powerful step in driving the importance of carbon through the decision making process and will also give a basis for the University to make informed choices around projects that are aimed at reducing emissions and those identified through other drivers. For the non-carbon projects, introducing carbon into the decision process will encourage project teams to consider it as part of their assessment and it is felt that this may lead to improved project outcomes. SRS will have a role to play in both reviewing the carbon spreadsheet for projects and as part of the decision making group, providing them with better information to support further carbon savings.

The funding review concluded that in general universities tend to fund internally or use low cost finance available through Government / EU linked sources, such as the European Investment Bank (EIB). The rate of return required by the University is generally fairly low, but this does include significant spend on non-profitable projects so this can increase the rate required for other projects. At present there is no specific funding for carbon reduction projects, but consideration is being given to setting up a revolving green fund to support projects with the primary aim of providing environmental benefits. External funders are in general interested in supporting suitable projects in the higher education sector, but there are limited cases to date. The rates of return required for external funding are generally higher and increase with risk. The minimum project size is generally fairly high which means it is difficult to fund projects such as those focussed on the implementation of energy efficiency measures for instance. Funding for the development stages of projects is most likely to come from government backed bodies, such as the Scottish Futures Trust (SFT), the Scottish Funding Council (SFC) or/and Resource Efficient Scotland (RES). There are also renewable energy support programmes in place currently, such as the Feed In Tariff (FIT) and Renewable Heat Incentive (RHI). These provide subsidy payments over 20 years for useful renewable energy generated. They aim to offset the increased capital costs over the life of the project which has meant that only the most financially attractive projects have benefitted. These support mechanisms are currently under review by the UK government with the objective of scaling back subsidy payments. Therefore any subsidy benefits need to be carefully considered when assessing a project's viability.

The main renewable energy technologies reviewed in this report are wind, solar PV, heat pumps and fuel cells. Each of the options has been looked at and high level calculations carried out to assess potential carbon reduction and the cost per tonne of carbon saved. The picture is further complicated by the ongoing process of de-carbonisation of the electricity grid, a result of the increasing proportion of renewable technologies in the grid generation mix. In general decarbonisation is a good thing for the University as it will reduce the emissions associated with grid electricity. However, it also reduces the carbon benefit of low and zero carbon electricity generation technologies including wind, PV and fuel cells. To include this in the assessment 25 years of emissions have been assessed using decarbonisation forecasts as well as the current emissions associated with the options. The projections available tend to be overly optimistic on the rate of progress of decarbonisation so there is some caution needed when considering these figures. AECOM have raised this issue with the Department of Energy and Climate Change (DECC) and are in dialogue but without a clear resolution at present. The costs of different technologies are also changing at different rates. Information from DECC suggests that onshore wind may already be comparable in cost terms to grid electricity, while PV at large scale should be soon. In the longer term it is likely that PV at smaller scale may also reach parity with the grid, at which point even without incentive schemes it will be beneficial financially to have as much generation as possible through PV rather than buying from the grid. Offsetting of emissions has also been reviewed as it is used by other large organisations to achieve carbon neutrality.

The measures have been considered at campus scale and also at a larger strategic scale for wind and PV. At campus scale the measures typically provide carbon savings of a few percent of the University total emissions, meaning that to achieve a reduction of the scale required to bring emissions back to the target level (29% reduction by 2020) will be difficult and will require a concerted effort to implement all possible measures. PV on the roof tops of the University can make a useful reduction, if implemented at a large scale. Heat pumps were the poorest in terms of £ / tonne of carbon saved on the basis of the current gird emissions factor, but over a 25 year assessment became the best and will become a more attractive choice in the future. However, it is difficult to predict when this will happen due to the uncertainty surrounding the rate of grid decarbonisation.

In terms of achieving a significant emissions reduction, the strategic options review found that off site wind energy is the strongest option, offering the best economic efficiency. A medium size wind farm on a favourable site would give the equivalent carbon reduction to balance the University emissions. A PV farm or farms would also be possible, but would be on a scale several times of the largest installation to date in the UK. Work would be required to progress these options, including on carbon accounting and procurement of the assets. The University would still report its actual emissions based on fuel use on the campus and the offsite asset would be claimed as an offset. Some of the potential benefit of the asset is lost as the financial merit is increased if the renewable generation is used directly by the University rather than exported to the grid.

Offsetting through other means, such as forestry or projects in other locations, requires following established protocols, such as ISO14064. This requires organisations to reduce their carbon emissions as far as practically possible prior to the use of offsetting to allow the remaining emissions to be offset, so carbon neutrality can be claimed. There are accredited offset schemes and these should be used if offsetting is to be considered. Offsetting should be understood in the context of paying for the carbon emissions twice to encourage every effort to be made to reduce emissions first, with initial payment for the fuel and the second payment for the offset.

For energy efficiency measures promising options have been identified but they would require survey information to provide quantitative data, and for the purposes of this report are largely ignored. There is a strong case for providing dedicated staff resource to develop and implement energy efficiency projects as much of the University's efforts to date have focussed on those schemes that are most easily implemented. Those options left tend to require a significant investment of time and resource to identify and raise awareness with the relevant users. There is activity in engagement and awareness raising at present that can be built on to progress these possible measures.

It is recommended that the University continue to make strong efforts in energy reduction, ideally supporting this with a dedicated green fund and sufficient resource to allow projects to be developed and implemented in reasonable timescales. Campus scale renewable energy should also be implemented where possible. This will provide a reasonable improvement in carbon emissions. The large scale, strategic measures should also be considered carefully as they may be the only practical option to ensure that the emissions target is met.

INTRODUCTION

2. Introduction

This report details the work carried out under Lot 3 of the SRS Technical Consultancy work stream, on business cases. The main aims of the work were to identify carbon reduction measures suitable for the University of Edinburgh and prepare business cases for energy reduction using small and large scale renewable energy technologies.

To accomplish this, research was undertaken in conjunction with Lot 2 to understand what technologies and approaches other universities have implemented to reduce their carbon emissions. This research was extended in Lot 3 to review published data on the uptake of carbon reduction measures, to develop an understanding of what measures are proving popular and thus likely to be effective. This work is covered in the initial research report.

During the inception meeting for the project a further aim was added, to establish the form and content of future business cases to increase the chances of project implementation and to ensure these were considered on an equal basis. This lead to discussions with a range of project funders, including the University Finance Department and external funding bodies. As the University Finance Department was in the process of developing a new business case template, it was agreed to use this should provide the basis for future project assessment. This project therefore was directed toward the development and addition of a carbon appraisal section to the business case template, as this is currently not factored into the University's template.

A range of possible measures was developed from the initial research. These were discussed with the University during the project stakeholder workshop and in a subsequent meeting with the University Estates team. This lead to the development of a list of possible projects. Favourable options were then appraised against carbon emissions and overall project economics. The most favourable options were then used to populate the carbon template for the new University business case to provide further information on these options and demonstrate use of the template.

Context

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3. Context

The main driver for this work is to identify ways to reduce the University's carbon footprint and assist in the implementation of the most promising measures. The University has a target of reducing absolute carbon emissions by 29% by 2020 over a 2007 baseline, as set out in the 2010 Climate Action Plan, see Figure 1. There is also a requirement for universities to contribute to the carbon reduction in the Scottish Climate Change Act which includes the University of Edinburgh.

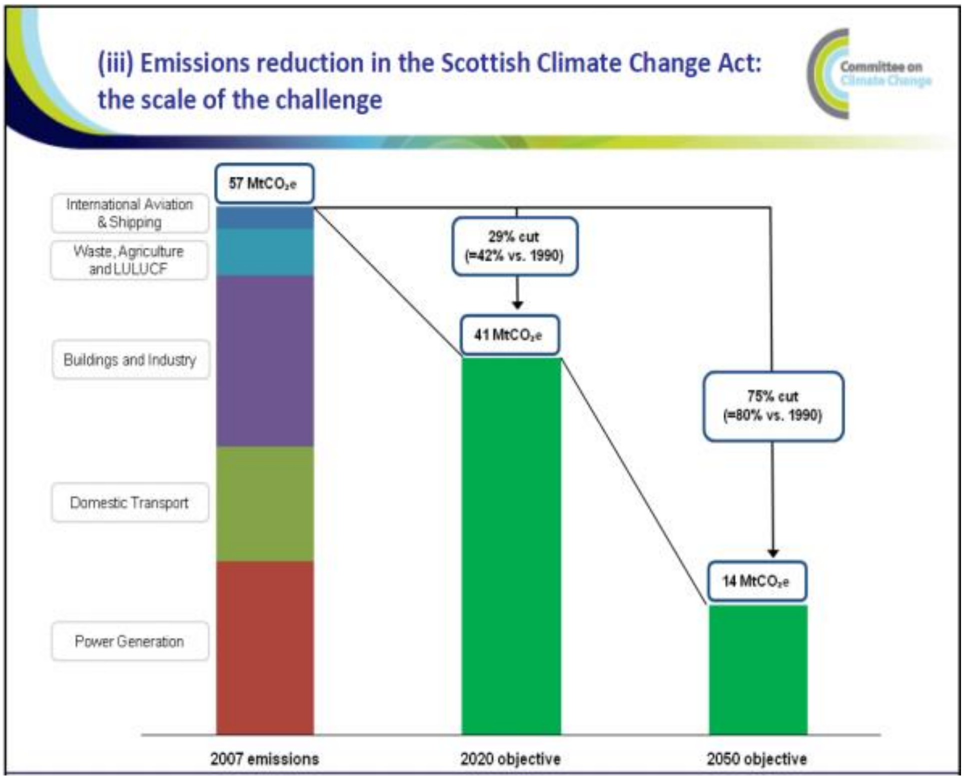

Figure 1 Scottish Climate Change Act Carbon Emissions Reduction Requirement (source: Committee on Climate Change)

At present, the University is failing to achieve its committed target carbon reduction, as shown in Figure 2. There are good reasons for this and in part it reflects the success of the University in attracting greater numbers of students and in developing buildings and increasing utilisation. Concurrently some aspects of the energy intensity of the estate are increasing, as a result of an increase in science and engineering research facilities which are typically more heavily serviced and contain energy intensive equipment. An increase in the uptake of IT has resulted in a requirement for IT infrastructure in all areas which has increased power demand, despite increases in device efficiency. It is worth noting that many of the energy intensive research facilities the University operates are designed to tackle other socially important problem such as ageing, animal and human health, or renewable energy technology deployment. The FlowWave tank, requiring a 2MW electrical capacity, is a good example of this tension.

The University has made significant efforts to reduce its carbon emissions. This is illustrated in figure 3 by the fact that when these are normalised against income there is a reducing trend. Other examples include the CHP district heating schemes which the University has invested heavily in. Despite this progress it is obvious that a business as usual approach is no longer sufficient if the University is to meet its target. Significant change is required and the work undertaken as part of the Technical Consultancy Lots will assist in identifying how this might be achieved.

It is important for the University's reputation to achieve the target it set out. As an organisation, it is committed to achieve its target through the Climate Action Plan and has a duty to do so as a highly respected public body in Scotland. There is a strong possibility that failing to achieve the target would be detrimental to the University, for instance by reducing likelihood of success in securing future funding and research grants. There are direct costs associated with carbon emissions, as a result of carbon reduction commitment payments, although these appear to provide insufficient incentive to skew economic appraisals in favour of low and zero carbon technologies.

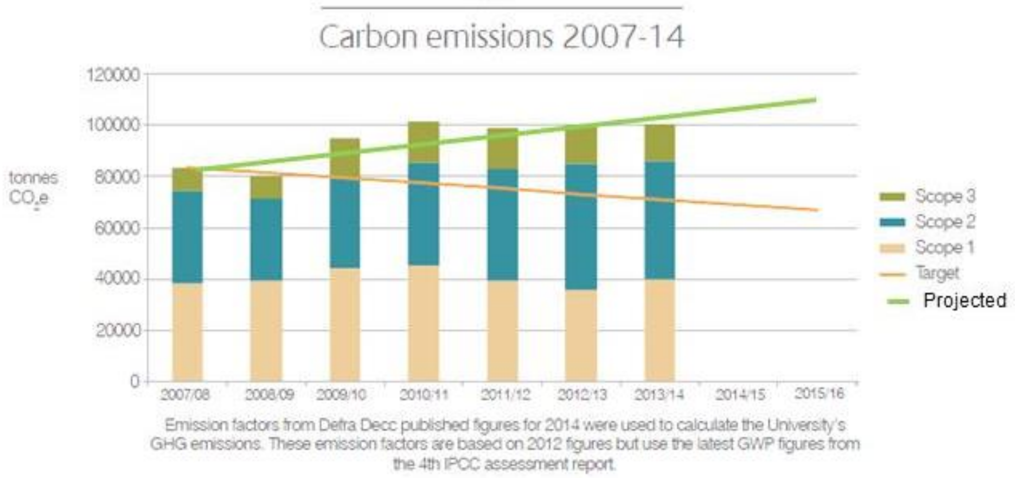

Figure 2 University of Edinburgh Target and Actual emissions

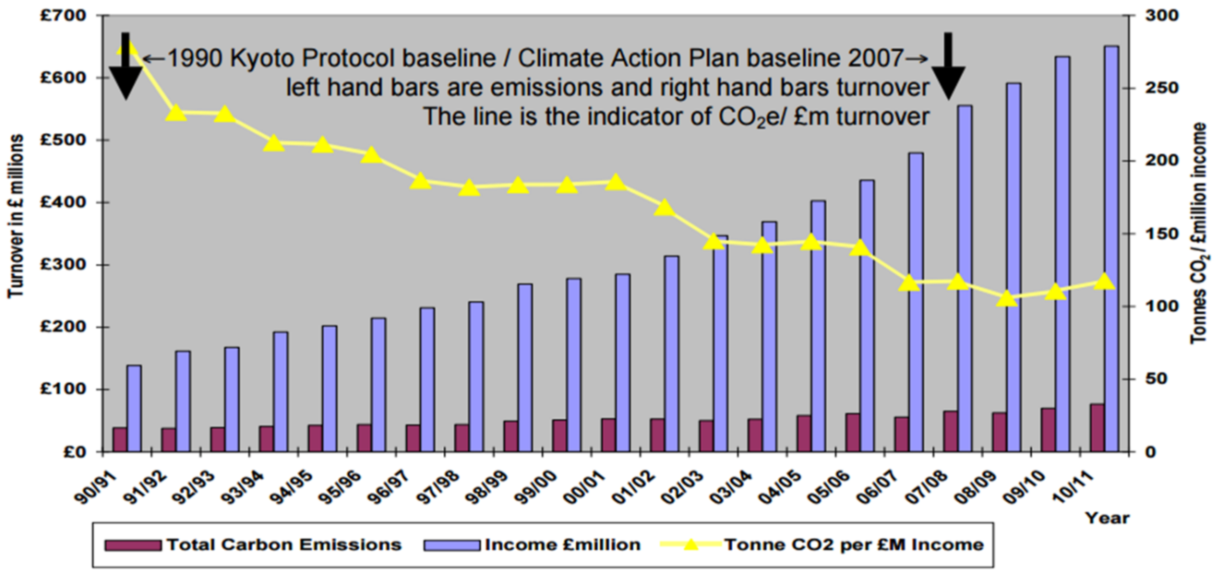

Figure 3 Carbon emissions against income, from 2012 Climate Action Plan update

Wider Context – Decarbonisation of the electricity grid

To understand how the University can reduce its carbon emissions it is important to consider this in a wider context which can also impact on progress against the target. Decarbonisation of the electricity grid will have a major influence on University emissions by 2020 and beyond, but the projections for this when compared with the progress achieved, do not correlate well and lead to significant uncertainty as to how quickly the carbon intensity of grid electricity will decrease over time. Decarbonisation is a result of a change in generation technologies away from fossil fuels, including coal and gas, to low or zero carbon technologies including nuclear and wind. The mix of technology on the grid is largely determined by market forces, with an element of steering by Government. With the recent change of Government at UK level, the policies and support mechanisms are in a state of flux, making it less clear what generation will be added to the grid when and as a result the rate of progress towards decarbonisation. Grid decarbonisation is also likely to become increasingly expensive and much of this cost will be passed on to consumers through increased electrical unit cost. It is also important to consider the likely increases in energy unit cost over the same projected periods. A whole sale shift of building heating from fossil fuels to electricity will also have a significant impact on UK generating capacity and it is uncertain how this will be addressed. These changes also impact on project finances and the future viability of alternative technologies.

Decarbonisation of the grid has a direct impact on the emissions associated with grid electricity purchased by the University but it also interacts with the carbon benefits offered by electricity generating and using technologies. For low and zero carbon electricity generating technologies, as the grid decarbonises their carbon benefits reduce. For low carbon technologies that are supplied by grid electricity, such as heat pumps, this means that as the grid decarbonises their benefits increase and beyond a certain level, the carbon emission savings will be better than those anticipated for CHP. Albeit, due to an anticipated increased cost per unit of electricity to the consumer, resulting from decarbonisation, there could still be an economic argument for fossil fuelled heating sources.

Figure 4 and Figure 5 shows the CO_2 emissions from different heat sources, against time and grid emissions factor. For CHP the heat emissions factor takes account of the gas input to the CHP engine and the avoided grid emissions from the electricity generated by the CHP. Figure 4 uses the IAG grid emissions projection, which is likely to be optimistic, so the timings should be treated with caution, and Figure 5 removes the time element, by showing the technologies against grid emissions factor. The overall pattern shows that as the grid decarbonises the relative benefits of different technologies change. At present, CHP delivers a good carbon reduction, as the grid emissions factor is around 0.5kgCO_2 / kWh. Once the gird reaches around 0.35kgCO_2 / kWh heat pumps should give better emissions reductions and with further reduction i,e <0.3 gas boilers start to be a better alternative to CHP, depending on efficiencies. Similarly, beyond around 0.2kgCO_2 / kWh, direct electric heating is a lower carbon choice than gas boilers. Biomass gives emissions (around 0.015kgCO_2 / kWh) only matched by CHP at higher grid emissions factors and heat pumps at very low grid emissions factors.

The picture for CHP is not quite as simple however, as the actual generation on the grid displaced by the CHP should be considered and not just the annual average emissions factor shown in the charts. The marginal plant on the gird at present is most likely to be combined cycle gas turbines, which have an emissions factor of around 0.35 – 0.4 kgCO_2 / kWh, which would mean that CHP is still a good choice compared to gas boilers. As the proportion of wind and solar increases on the grid, the marginal plant will consist of more renewable energy so the emissions factor for this will also change. In future the grid may provide carbon signals that could be used to determine when to operate CHP plant as part of a bivalent solution utilising a range of low and zero carbon technologies. Carbon reporting is based on annual average emissions factors at present so this also needs to be remembered if considering running plant based on grid carbon factor.

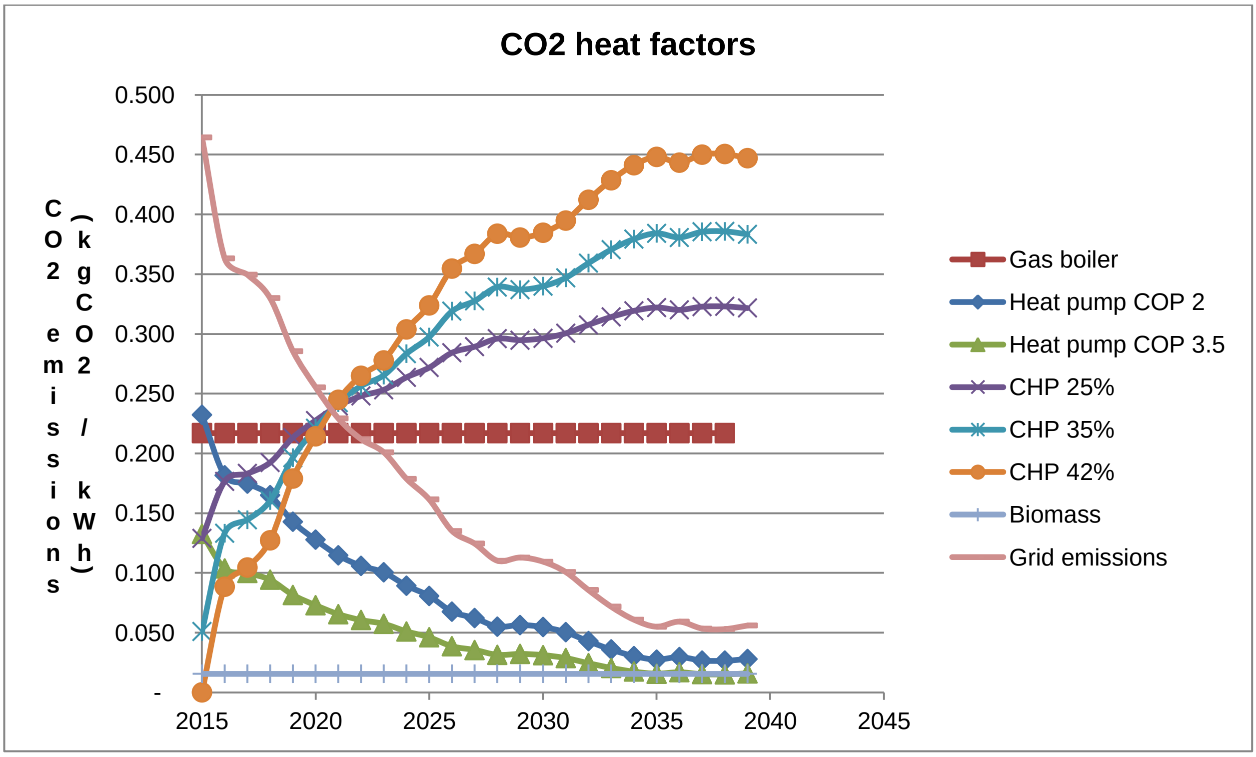

Figure 4 Heat carbon emissions factors by time based on IAG grid emissions projection. In the key, CHP efficiency refers to electrical efficiency, all CHPs are assumed to have an overall efficiency of 78% including electricity and heat. Data used in the graph, including the IAG projection for grid emissions, is presented in a table in Appendix C.

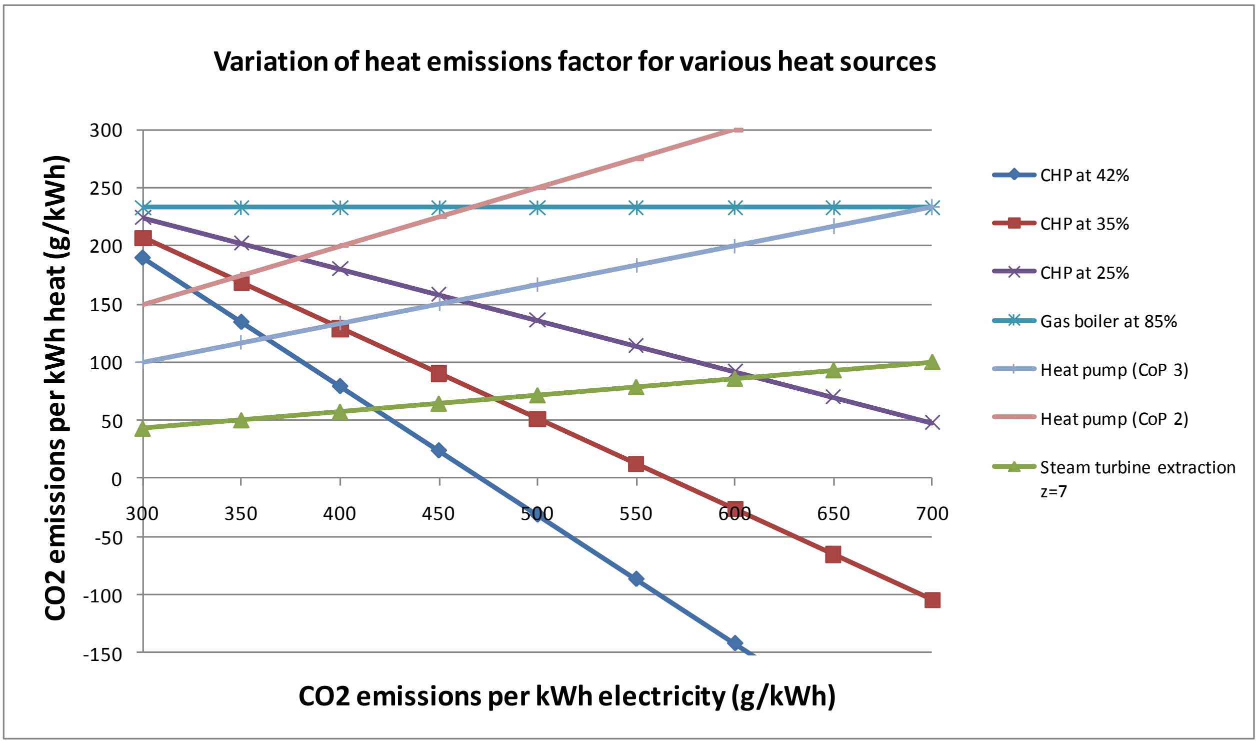

Figure 5 Heat carbon emissions by grid emissions factor – at present emissions are approximately 500 g/kWh

Wider Context - Levelised costs for Energy Generation

Various sources publish data on the levelised cost for electricity generation, including DECC. This gives costs per MWh of electricity for the different technologies, including capital and operational costs, discount rate and accounts for the life of the asset. The information published by DECC includes projected future costs as well as current costs. The most recent data was published in December 2013[1], and is plotted against the IAG energy costs projections[2]. Both the levelised costs and the energy price projections have three scenarios, Low, Central and High, based on different sets of assumptions. It is important to note that the assumptions used by DECC and the IAG are not the same, so while we are comparing the data there is some uncertainty and error implicit in the comparison. The overall trends can be considered valid but details regarding costs / timings of transitions should not be used as a basis for decisions.

The three plots (Figure 6, Figure 7and Figure 8) are based on the different DECC scenarios, with the three IAG scenarios included in each plot. The plots indicate that the costs of onshore wind and large scale PV are expected to be lower than that of grid electricity by 2030, with the transition for larger wind imminent or perhaps already having occurred and for large PV likely to occur around 2020. Small scale solar only achieves this in the DECC Low scenario, although in all cases the capex trajectory is significantly down over time. Biomass CHP is not expected to achieve grid parity from the data.

While this information is interesting, it is applicable to electricity generators and for the University it is important to remember that the location of the asset and whether it is supplying the University private wire networks (PWN) or being sold to the grid has a major impact on the value of the electricity generated in financial terms.

[1] https://www.gov.uk/government/publications/electricity-generation-costs-december-2013

[2] https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

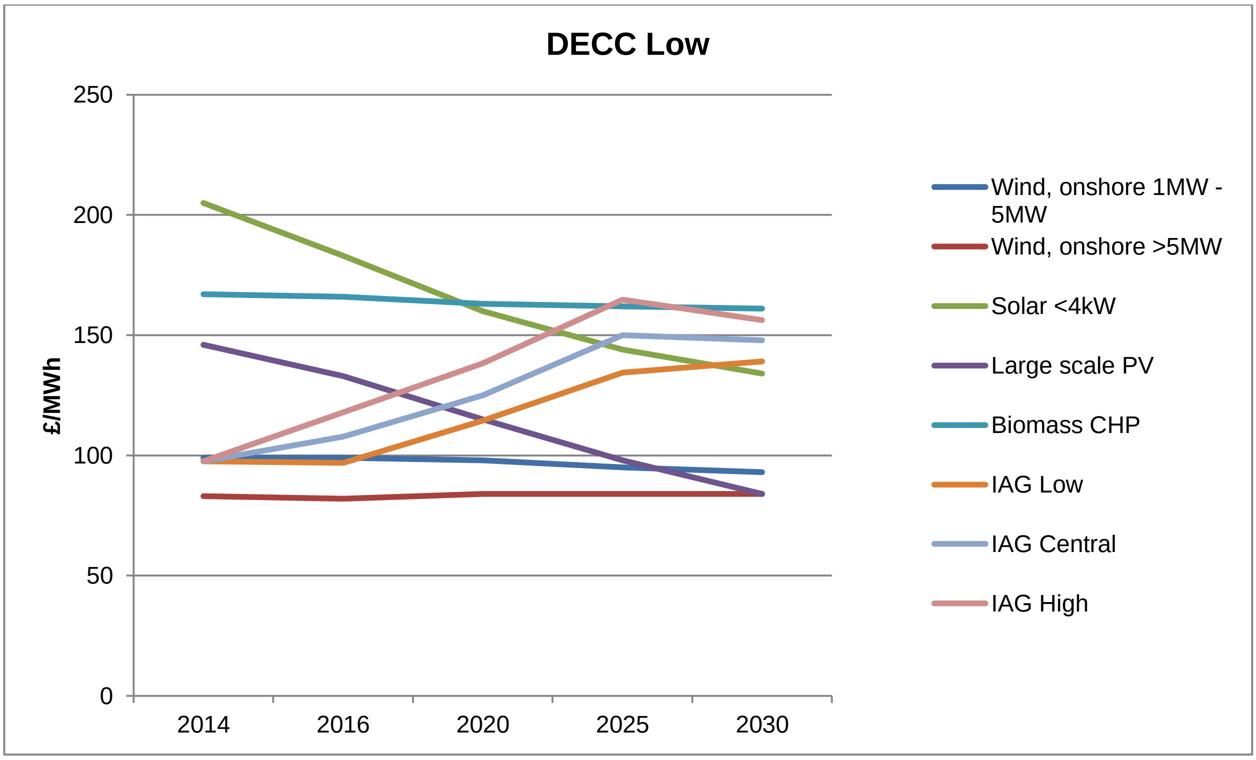

Figure 6 Levelised cost of energy – DECC Low scenario, including IAG electricity cost projections

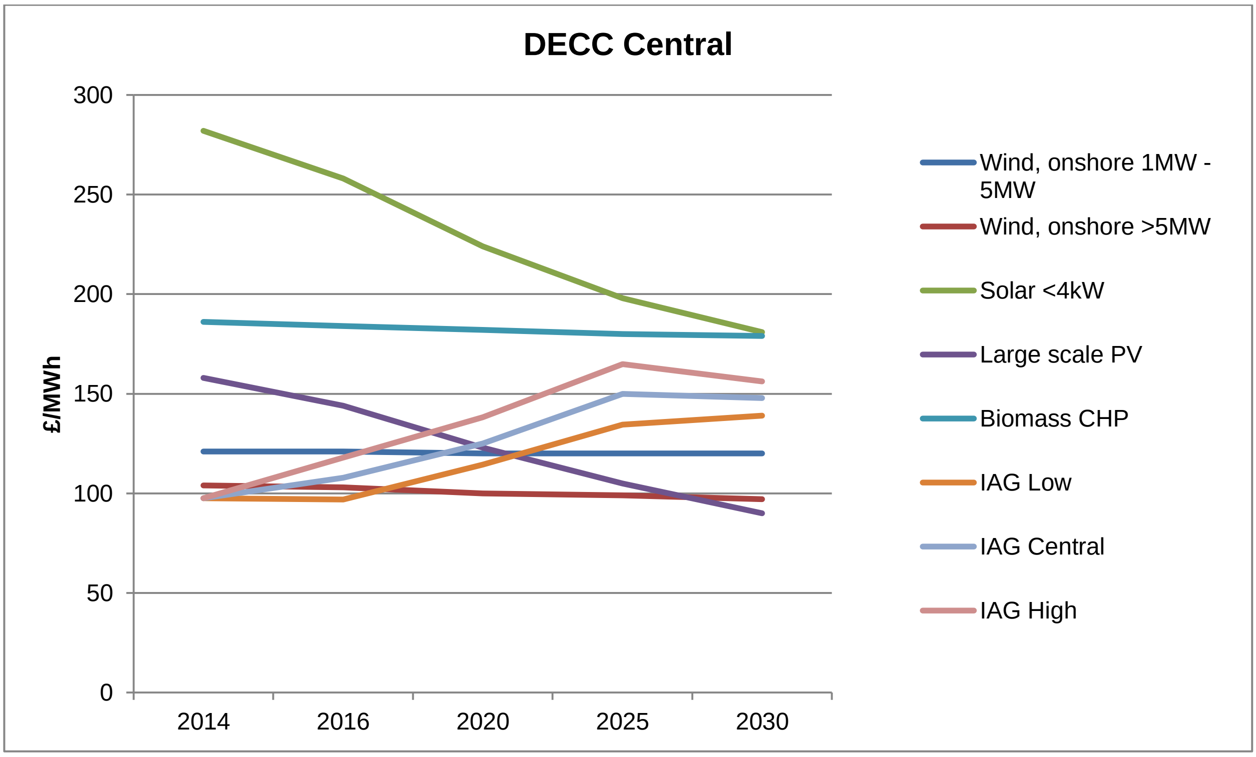

Figure 7 Levelised cost of energy – DECC Central scenario, including IAG electricity cost projections

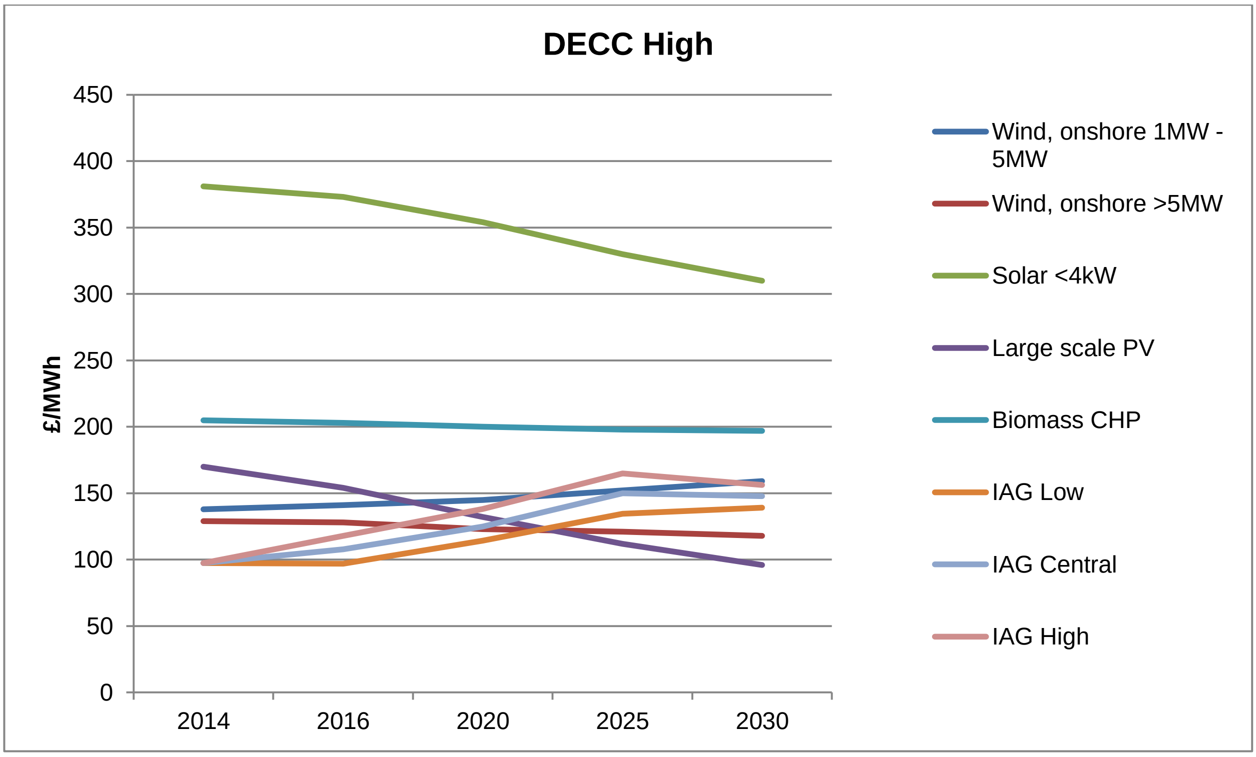

Figure 8 Levelised cost of energy – DECC High scenario, including IAG electricity cost projections

Business Case
Template Development

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4. Business Case Context Development

At the inception meeting it was agreed that a priority of the work was to investigate how to improve the way business cases were presented within the University to increase the chances of success. In order to achieve this, AECOM reviewed the development cycle to assess where issues were likely to occur and gathered input from a variety of sources on what a business case template should contain and how this should be presented to improve outcomes and the levels of return required to secure funding. This research extended to both the University and external organisations.

This aspect of the work changed in focus during the project as it was discovered that the finance department of the University were in the later stages of development of a new business case tool to be used in the appraisal of all future capital projects. This tool includes sections on strategic fit, narrative, finance and tax, but did not account for carbon impacts. It was therefore agreed with the University that our work should additionally focus on the development of a carbon assessment module for incorporation into the business case template already being developed by the University.

Analysis of Development Cycle

An overview of the development cycle is identified in Table 1. It is important to understand this when considering how to present a business case, that funding streams can be different at different stages of a project. What is important, however, is that funding is required throughout the entire development cycle to ensure success.

For many carbon reduction projects the main hurdle is gaining the development funding, or "devex". This is required to develop the business case that allows the project to be considered for capital funding, or "capex". At the devex stage there is a growing risk that the investment required to develop the project will not be recovered if it is found that the detailed analysis reveals that the scheme is not worthy of further pursuit. This is one reason why most traditional sources of project funding (e.g. banks, institutional investors) are not interested in funding this stage and why so few low and zero carbon projects make it to the funding application stage.

Once at the capex stage, a project that looks favourable has a range of options for funding, so provided it offers a suitable return and meets other criteria around risk, strategic fit etc., then it should proceed unhindered. Often the biggest barrier to universities being able to carry out this work, is lack of resource, due to the time and resource required to develop the business case. Often the people who have the skills and knowledge to do so are fully committed to their core activities.

Phase	Question to Answer	Deliverable	Type of Funding
1. Development			**Risk Money**
1.1 Scope of Idea	Is there a business case?	Desktop Scope	Low Risk, minimal cash spend. Development Funds – Equity: "devex"
1.2 Outline Scheme	What does project look like?	Feasibility Report, [Heads of Terms signed by partner(s).] Sources of cash identified	Risk increasing, cash spend rising. Development Funds – Equity, "devex"
1.3 Scheme Development	Proof of concept, no more changes to design? Planning? Connections? (elec./heat/gas)	Design freeze – locking in technology.	High Risk, High Cash Spend. Development Funds – Equity: "devex"
1.4 Contract Finalisation	Who is responsible for what?	Financial Close	Capital and Development overlap. Risks lower
2. Build	**-**	**Plant**	**Capital or Project Financing: "capex"**
3. Commissioning	**-**	**Electricity & Heat production.**	**"capex"**
4. Operations	**-**	**Profitable plant**	**Can refinance to balance debt /equity and ownership.**

Table 1 Typical development cycle stages

As part of the discussions with funders we asked if they would support devex or if they could recommend sources of funding for this. The outcome from these discussions are discussed in detail below:

Funding Projects

To better understand how projects achieve funding, discussions where held with:

- Terry Fox, Director – Finance Specialist Services, University of Edinburgh
- Green Investment Bank
- Scottish Equity Partners

The Lot 2 research included questions on how projects were funded also.

The discussion with Terry Fox highlighted that the University funds many projects internally and is considering ways to increase the funding available for carbon reduction projects, as the importance of achieving the carbon target is recognised. The University currently also uses external funding for some projects, due to the volume of the capital works programme at the current time. It is recognised that not all universities will have internal funding available so for the sector as a whole acquiring external funding is important in driving forward a carbon reduction agenda.

Typically there are two main types of funders for projects, and they have different requirements. These are equity and debt funders. Table 2 gives an overview of some of the differences between them. The Higher Education sector benefits from access to Government funding sources, including EU funding. This in general offers the lowest interest rates and so is likely to be the preferred source of funding in the vast majority of cases, unless there are specific requirements or time pressures that can be better met by a commercial funder.

	Equity	Debt
Example investors	Venture Capitalists; Equity Investors	Banks; Government
Timescales	Typically short term; up to 5 years after which sell to e.g. pension fund	Up to life of project
Ownership / Control	Yes	No
Interest Rates	Typically higher as will take more risk; e.g. min 10 – 15%	Can be lower; from around 3 – 4% for Government backed lenders

Table 2 Funder categories

The Lot 2 research found the following types of funding were used by the different universities, with numbers of each indicated in brackets:

- Revolving green funds – (3)
- Long term debts – (2)
- Bond funding – (1)
- Salix funding – (3)
- Capital program – (1)
- Government funding demo – (1)

Revolving Green Funds use the income from projects (or the savings achieved) to then fund further projects. They require and initial sum of capital to be established, thereafter they continue to fund future projects. The level of future project investment they can support is completely dependant on the success of the previously implemented projects. The main advantages of this type of fund, is that it ring fences the investment to prevent it being used for other purposes. Discussions are commencing on the possibility of establishing such a fund.

External Funding
Discussions were held with the Green Investment Bank and Scottish Equity Partners to gather further information on the investment decision making criteria used by external funders. This should allow assessment of the ability of a project to gain funding if required and aid the filtering out of projects where financial return is an overriding factor.

Green Investment Bank (GIB)
The Green Investment Bank was set up by the Government to deliver investment in green projects at a time when the banks were not lending. They have two main restrictions they must operate by, firstly the rates they offer must be similar to other commercial lenders (to comply with State Aid regulations) and secondly the projects they support must deliver green benefits. So long as these criteria are met, they are able to invest in projects. To date the GIB has mostly supported embedded generation / energy centres for large sites, for example hospitals and distilleries. These have typically been based around technologies such as CHP or biomass. The returns are reasonable and the technologies and their application are well understood. Another area of investment has been LED street lighting, supporting local authorities to replace existing lights. This is also straight forward and offers good returns so it is a good scheme from a GIB perspective. The GIB is able to offer local authorities a longer payback of debt than alternate finance sources so although the interest rate may be higher (around 8%) it can be paid back over time from the savings making this highly beneficial.

The GIB do not generally provide devex funding but for the higher education sector they suggested the Scottish Futures Trust (SFT) as a good source of seed funding to allow development of business cases. In the GIB's experience there can often be a lack of resource at local authorities level to develop business cases. This confirms that this is a wider issue. They have considered setting up Energy Services Companies (ESCOs) to help develop projects and noted that the Scottish Funding Council (SFC) is currently setting up an ESCO for Scottish Colleges to aid the development of projects.

In the higher education sector, the GIB has not made any investments to date. In their experience universities tend to fund projects internally, and have limited interest in external funding. They are in contact with the SFC to discuss where they can work together. The SFC can provide support for developing business cases but have a limited budget available this year. Another possible source of funding is the Innovation Fund run by the SFT, however this year the funding pot is limited to between £70m and £100m.

The first project the GIB will fund in the HE sector is likely to have had some work done already on the business case. They are currently looking at a project with Heriot Watt University but this is slow to develop and it may still be a while before they have had experience in funding a HE project. The GIB recognise that there are better rates of funding available to the HE sector, for example Scottish Partnership for Regeneration in Urban Centres (SPRUCE) and the European Investment Bank (EIB). The GIB is mostly likely to be of benefit where the project requires a longer return period to repay the debt, as they can be more flexible in the terms of the loan. The down side is that this would have to be against commercial rates.

GIB Process
At present the GIB has three main products:

1. Green Loan – long paybacks possible, aimed at long life assets, e.g. 25 years (DH + CHP for example); Rates 3.75 – 4%; risk is limited to achievement of savings beyond costs.
2. Asset model – shorter term projects (8 – 10 years), e.g. PV, retrofits; higher rates 6 – 8%; finance only.
3. Service provision sale – sale of receivables, payment to banks for debt; residual risk with contractor; minimum payments must be met even if there are issues.

Of these the Green Loan could be of interest to the HE sector – typically universities can get lower rates but these have short terms and require security. The Green Loan can be packaged so repayment starts only when savings are being made. The main barrier is the minimum investment size, which is around £1m, with typical loan values between £2m – £2.5m. It would be possible to aggregate projects across universities to achieve the required funding scale required. The GIB can spend time on worthwhile projects to make them work, but they need to have clear commitment from the client, a demonstrable green benefit, a commercial return and the potential for a wider role out for smaller projects. Development funding can be included in the loan as part of the whole, but the GIB is not mandated to provide development funding only. GIB funding could be blended with SALIX funding if there was a short fall as a further option. This was tried with local authorities but there was little interest in loans on this basis.

The life of the loan is limited by the life of the asset and payments are based on the expected savings. The rates are fixed and the project also needs to deliver Green benefit. The criteria for this are flexible (see GIB Handbook on their website for more details)' For smaller or more risky projects the GIB can pull in Equity funders, e.g. Aviva. The smallest project size they would support is around £0.5m but higher interest rates of 13 – 14% are typical. Example projects of this type include, e.g. biomass for distilleries. This is not likely to be of interest to universities as they have access to more cost effective borrowing terms.

Other Funding Sources suggested by the GIB

- Low Carbon Infrastructure Transition Programme (LCITP)[3] (Glasgow based)
- SFT / Resource Efficient Scotland - £100m – £120m over next 3 years to develop projects, including project support and development funding
- EIB has better rates for universities

Scottish Equity Partners (SEP)

SEP's core business is to supply venture capital for technology and technology enabling companies at early stages of their development. They have backed University of Edinburgh spin-off companies in the past. They are 20 years old, with 40 employees. They receive their funding from pension funds across the UK and Europe.

They now have a fund for clean energy (solar / wind / hydro / DH / heat pumps / hydro), which was established one year ago. This has grown from the purchase of a portfolio of companies from SSE five years ago, including Green Hydro, Vital Energy and Smarter Grid Solutions. Through this a gap in funding for small projects was identified and so they can fund projects if the client is not able to.

The fund is called the Euro Capital Fund. It funds amounts of £1-10m,with target returns of 10 – 11%. Technologies covered include small wind, hydro, heat pumps and renewable energy technologies. As not all the projects are successful the rates need to be higher for some to cover this. Decision making is internal, with thorough due diligence, including input from external consultants on engineering aspects as required. The decision making process can take between three to six months. Similar to the GIB, SEP are interested in energy efficiency projects and noted that at times it was difficult to find ways to align project size, shorter timescales and project life (e.g. compared to an infrastructure investment) and for this reason the returns need to be better. They do not invest at feasibility or development stage, i.e. no devex.

Process

The first step is to agree heads of terms. They expect strong commitment from the client and expect to be working in partnership to develop the project. The rates applicable will depend on the risk profile. A typical approach would then be to set up a special purpose vehicle (SPV) owned by SEP which is sold to a pension fund at a suitable stage. They will also consider shared ownership and will buy assets, for example they will buy an existing district heating system and take on ownership and operation, releasing capital to the client to start new project(s) or expand current schemes.

Incentive Schemes for Renewable Energy

At present there are various schemes in operation to support uptake of renewable energy generation technologies. These include the Renewable Obligation (large scale electricity – now closed to new entrants for PV, closing to other technologies in 2017), the Feed In Tariff (FIT) for small scale electricity generation and the Renewable Heat Incentive (RHI) which give payments based on the type of technology deployed and the extent of useful output. The payments for FIT and RHI are for 20 years and are index linked. The replacement for the Renewable Obligation is the Contract For Difference, this is based on an auction approach with generators stating their selling price with the lowest prices being supported up to the required capacity. The operation stage result is roughly similar but it means there more uncertainty until the project qualifies. These mechanisms have supported significant growth in the renewable energy sector and have made the financial case strong for a wide range of projects and technology solutions.

At present the U.K. Government is reducing the support available through the FIT and RHI and the longer term future for these schemes is far from certain, an important consideration when assessing project finances. The rates are also reducing and in some instances dramatically, for example, the published consultation rates for PV.

[3] http://www.gov.scot/Topics/Business-Industry/Energy/Action/lowcarbon/LCITP

Summary of Funding Options
Discussions around potential funding options identified the following main points:

- Universities typically use internal funding and can get finance at favourable rates through sources such as EIB
- In Scotland the Scottish Futures Trust and Scottish Funding Council can support projects, typically through specific funds or programmes and Resource Efficient Scotland also have funding which could be available to support carbon reduction activities in the HE sector
- Other external funders are available who will support capital expenditure for carbon reduction, this is typically dependant on minimum project size, which are substantial (£1m is typical) and the rates will be higher than for sources like EIB
- External funders will mostly support projects with a good return and low risk – if there are a portfolio of projects some of which can be funded internally then the lowest risk and projects with the best return should be identified for accessing external funding to increase the success rate
- External funders that invest in carbon reduction may have useful experience to bring in developing projects and they are also committed to project success
- Development funding is limited to Government backed entities such as SFT, SFC and RES, although it may be possible to include some development costs in the overall loan, from GIB
- Renewable energy incentive schemes have been beneficial and supported the financial case for numerous projects but there is some uncertainty over the long term future of the schemes which needs to be considered when appraising projects

University of Edinburgh Decision Process
The method used for the assessment of projects was discussed with Terry Fox and can be summarised as follows:

The capital projects group (senior staff - the group is one year old) acts as filter for the Estates Committee and carries out an initial assessment for viability based on:

- Strategic fit
- Geographical fit / context
- Financial assessment (payback / IRR / capital resource)
- Business continuity / student experience (wide range of issues, e.g. number of lorries to deliver biomass in centre of campus)
- Resource to deliver

If a project passes all initial screening questions the next stage involves reviewing how the project will be funded. The major capital projects are often driven by research funding, which will cover much of the requirements with additional funds pulled in from other sources by the University.

At present there is no requirement to include information on carbon associated with the project. Including carbon in the assessment is important not only to help reduce emissions within the University but also as part of the University's public bodies duties.

The new business case tool will include:

- Narrative – description of project and requirement
- Financial assessment – using new financial assessment spreadsheet developed by the University's finance department – this is populated by the project team and then rigorously tested by the finance team
- Tax benefits assessment – part of the financial spreadsheet
- Strategic fit – how the project meets the University strategy

There is an opportunity to add carbon assessment and this has been developed through this project. It is not expected that all projects will immediately be able to provide robust data for the carbon assessment but having it in the business case template will encourage project teams and decision makers to consider the carbon implications of their proposals. In future, the requirement could be extended to include waste, water and transportation impacts to contribute to a more holistic assessment.

The financial assessment includes analysis based on discounted cash flow (DCF), net present value (NPV), internal rate of return (IRR) and / or simple payback period depending on the type of project. The financial model for calculating this is built into the tool and project teams will be supported by the business planning accountants to set it up. Finance then use the model to robustly test the assumptions, for example, considering changes to student numbers, research income and other parameters that could impact on the project.

The financial model considers four scenarios:

- Baseline
- Most likely
- Best case
- Worst case

The best and worst cases are based on reasonably likely events rather than unpredictable, force majeure type events.

Decisions are based on achieving a return of 6 – 8% across the portfolio of projects. There is a significant defensive spend with no return, examples include compliance issues and asbestos removal etc. The Edinburgh College of Art is a good example the University's defensive spending at the current time. On average; around one third of the total spend is in defensive spending and this pushes up the rate of return required for other projects, to around 10%. Further examples of similar projects which will not generate a return could include a new library, which is essential for the University experience but does not generate revenue, or the works at the Pleasance, where a £10m upgrade is planned to improve the student experience. Any process to encourage the uptake of low carbon infrastructure needs to be flexible to cope with all other competing demands.

The discount rate used is based on the cost of borrowing, the rate of return and the surplus required by the University (currently 5%) to fund future projects. As the University is a charity it does not make a profit so any surplus is re-invested in the estate – this gives a rate of between 6-8% currently.

Adding Carbon to the Decision Process

At present there is an ideal opportunity to incorporate a carbon impact assessment into the capital projects decision making process. This is best achieved through an additional section to the new business case template tool. AECOM have prepared a carbon assessment tool to accompany the economic appraisal as part of this project.

The requirements for the carbon assessment tool are:

- Simple to complete so it can be used by a wide variety of project teams
- Flexible so it can cope with a wide range of projects, from carbon reduction to new buildings
- Robust to allow assumptions to be tested
- Clear results to allow comparison across projects

To achieve these aims, a Microsoft Excel based tool has been developed. The calculation process requires the input of annual fuel requirements for the operational project and also for the baseline case, where applicable. The tool uses current carbon conversion factors from the University carbon reporting tool to provide baseline carbon emissions for the project for comparison purposes.

Grid decarbonisation will impact on the carbon savings achieved by any project electrical use over its life. For this reason carbon emissions are assessed over a 25 year period. The Interdepartmental Analysts' Group (IAG) data set[4] was used, This is supported by other public bodies and is referenced in the HM Treasury Green Book Supplementary Guidance. This provides a projection of future grid carbon intensity factors. An average value of the carbon emissions over the twenty five years is used to indicate future carbon emissions. This will give an indication of how the carbon benefit of each option might vary into the future, taking into account grid decarbonisation. There are limitations of this approach as the available projections are optimistic and the timing of the decarbonisation over the 25 years is also important. Carbon reporting at present is based on annual grid average figures and this approach offers a similar level of detail.

To allow a comparison between projects both costs are normalised by both carbon figures, to give a £ / tonne CO_2 figure. This metric is fairly commonly used in appraisal of carbon reduction options, including by a number of the universities contacted under the Lot 2 work. Both the emissions at the current grid factor and emissions based on the 25 year projected average are considered to give an idea of the long term implications.

A basic whole life cost model has been built into the tool to allow example projects to be assessed and also to improve the applicability and usefulness of the tool to the wider HE sector. The cost model includes inputs for project cost, uses the fuel consumption data from the carbon analysis and allows inputs for additional cost items associated with activities such as maintenance. It also facilitates potential revenue streams from other sources such as incentives or subsidies for renewable energy. The tool uses the IAG projections for future fuel cost price increases. The discount rate is set at 3.5%,

[4] https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

based on the recommendation in the HM Treasury Green Book[5]. It is relatively straightforward to use and to update which would allow the process to be adopted by other universities but the intention for University of Edinburgh would be for the finance department financial model to be used and the relevant cost data taken from it for comparison with the baseline scenario. Other university finance departments are likely to use similar financial models for the assessment of their own projects and the preference should be to use these were they exist to avoid any duplication of effort. The University of Edinburgh could also consider making their new business case template, including the carbon assessment, available to other Universities.

Future Development of the Business Case Template

During discussions it was identified that in future the business case template could be developed to include further environmental indicators, such as waste and water impacts. There are numerous challenges involved in achieving this. Notes from our discussions with Fleur Ruckley of SRS where the issues were identified are included in Appendix C of this report.

[5] https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent

Carbon Reduction Options

05

5. Carbon Reduction Options

The options to be considered in this project were split into four main areas:

- Large scale strategic renewable energy
- Offsetting – achieving carbon neutrality
- Small scale renewable energy
- Energy reduction or carbon efficiency measures

To commence the review a list of possible technologies was compiled. This included input from the Lot 2 research work. The technology choices from the Lot 2 work and AECOM's wider knowledge and previous experience were then reviewed with the University to assess their applicability. A meeting was then held with David Barratt and Dougie Williams of the Estates Department to discuss which measures had already been implemented and those measures that were most suitable and worthy of further consideration. The full list of technologies and notes from discussions are included in appendix A. The offsetting section was added after the initial round of feedback on the report.

Further opportunities were identified in relation to new projects. There are repeated lessons learned issues that come through new estate buildings that have significant impacts on carbon emissions. Many of these could be avoided through improved design or the identification of common operational issues through the early involvement of the soft landings process. Some typical issues / opportunities are:

- Over design, e.g. chillers on buildings when these are likely required only for a very short period because CIBSE Guidance suggests they should be installed – the University could insist that the chillers should not be installed, by stating their own more relaxed comfort thresholds for design teams to adhere to – ECCI is an example
- Data centres / server rooms included at a building level instead of using more efficient central facilities.
- Include low flow taps – to improve water use efficiency.
- Fridge-freezer farms – consider heat recovery opportunities from these to pre-heat domestic hot water or heat buildings rather than rejecting it to atmosphere.
- Sun pipes, better use of daylight to reduce artificial lighting requirements.
- Plan zoning and controls to allow shutting off when areas not in use.

Further input was provided during the Stakeholder consultation event held on the 19th August and in meetings held with Dave Gorman and David Somervell of the University's SRS Department. From this a final list of technologies was drawn up for consideration under this study, these included:

- PV – Building integrated
- Large scale PV solar farm
- Wind (on shore) – generic location based on CO_2 impact
- Geothermal – screen campus based on BGS work
- Heat Pumps
- Bioenergy
- Fuel Cells
- Demand control ventilation
- Controlled environment set points - change to range / reduce
- User change (through SRS)
- Cold storage
- Demand management / smart grid

Technologies were screened on the basis of barriers to implementation, carbon impact, financial implications, project risk and other issues. The results from this assessment and a general overview of each technology follow in the next section of this report. Please note that calculations are based on high level estimations with the intent of providing an initial indication of the options and their likely viability. These will require a more detailed bespoke analysis once the details of specific projects are known before solutions are taken forward.

The analysis uses fuel cost and carbon factors from the IAG projections. These are included in full in the carbon assessment tool for reference. Key parameters are included below:

Data used for analysis		
Carbon emission factors (DEFRA) - Current		
Grid electricity	0.50035	kgCO2/kWh
Natural gas	0.18445	kgCO2/kWh
Fuel prices (IAG – 2015 Commercial / public sector – Central scenario)		
Grid electricity	3.1	p/kWh
Natural gas	10.5	p/kWh

Analysis Methodology

The analysis carried out for the options in this section was undertaken to arrive at indicative figures for the carbon savings and costs for the different options. For the large scale strategic options analysis was based on achieving percentage reductions in the carbon footprint of the University. For other options the carbon reduction possible is tied to the project possibilities.

The modelling approaches vary with the technologies and an overview of the approach used is given in the information provided for each technology. This modelling was used to populate the carbon assessment spreadsheet, which was also used for the whole life costing exercise. The inputs required for this were the capital cost, fuel consumption of all fuels used in the option and baseline (if there is no baseline / current scenario, e.g. offsite renewables, then the baseline assumes zero energy use), and inputs for the whole life costing including:

- Annual maintenance costs
- Replacement costs at 5 and 10 year intervals
- Incentives, such as RHI, FIT etc
- Any grid export for electricity generation options

Emissions are calculated firstly on the basis of the current emissions factors published by DEFRA and used for CRC reporting and also on a whole life basis using the grid emissions factor projections from IAG. Emissions are based on operational energy consumption and generation only, i.e. embedded carbon is not considered, nor is carbon associated with the construction of projects.

The whole life costing approach used is:

- Costs and any income are summed for each year
- Discount factor applied (3.5% as recommended by Treasury Green Book)
- This repeated for the 25 year period used
- Sum of the annual discounted totals gives the whole life cost
- This is compared to the baseline cost to show the project whole life cost saving
- Annual savings are calculated based on year two, as this avoids the capital costs which are applied in year one
- Fuel cost projections for the whole life costing are taken from the IAG projections, as referred to in the Treasury Green Book.

The whole life costing element is intended to be carried out using the university business case financial tool and so the included cost analysis is a basic tool to give a first pass analysis where it is not possible to complete the university financial tool.

The life cycle emissions are calculated on the fuel consumption for each fuel and any electricity generation. The relevant emissions factors are applied to each fuel for both the baseline and the project cases. For electricity the grid emissions factors used are taken from the IAG projections. The emissions factors for the grid are applied over the 25 year period, and then the average of the emissions over the 25 year period is used as the annual whole life cycle emissions. The IAG public sector consumption – marginal emissions factor projection has been used.

It should be noted that the use of these emissions factors and the projected future emissions will show a decreasing benefit for renewable generation technologies. However, the projections are based on the installation of these renewables and their contribution to the electricity grid so if the reducing emissions benefit discourages implementation then the projections will not be achieved and the emissions reduction would be higher over the period. It could be argued that the emissions factor to use for this could be that for marginal gas – fired plant that will be the most likely technology to be displaced until the projected renewables are all installed. This issue is unlikely to be resolved soon, so the suggestion is not to place too much value on the longer term emissions projections when judging the merit of schemes.

The cost per tonne of carbon saved is based on the capital cost against the current emissions scenario and for the whole life case, the capital cost against the whole life cycle emissions annual average.

Large Scale Strategic Renewable Energy Options

This section considers the options for large scale renewable energy, in particular off site wind and solar PV. Both technologies are considered on the basis of offsetting the equivalent of 25%, 50% or 100% of the current emissions of 100,233 tCO_2. At this scale, the options are small to medium sized wind farms, and PV farms as large or larger than any presently built in the U.K. There are some common issues to both technologies, including the grid connections required from a technical / cost perspective, possible costs for land acquisition, and the question for the university as to whether purchasing offsite renewable energy assets or land to develop these, should be part of its remit.

PV – Offsite Solar Farm

There is interest in the potential for a large solar farm beyond what could be accommodated at Easter Bush. This would be a large facility that would generate renewable electricity which would be sold to the grid. This would allow a carbon offset to be claimed under scope 3 emissions.

Three options have been considered, based on achieving carbon offsets of 25%, 50% and 100%. The land required is based on two hectares per MWp capacity, as this is the approximate requirement stated by the largest solar farms constructed in the U.K., with the largest to date 69.5MW at DTTC Lyneham[6]. The areas of land required are fairly large, even for the smallest option.

Scheme sizes				
Carbon reduction		25%	50%	100%
CO_2 saving	tCO_2	25,050	50,100	100,200
Generation required	MWh	54,200	108,400	216,800
Annual generation	MWh / MWp	820	820	820
Capacity required	MW	66	132	264
Land required	ha	132	264	528

The generation required figure is derived from the CO_2 savings target and the current emissions factor for grid generation. The annual generation figure is the expected output for PV of 1 MWp capacity located in the Edinburgh area, with southerly aspect and pitched at around 35^{o}, i.e. able to be installed in the best orientation. As the solar farm is offsite, the location would not necessarily be close to Edinburgh. The output would change with location, in general improving as the location moves south and to areas with higher hours of sunshine. If this option were to be implemented, selecting a favourable site will help maximise the benefit, although this will depend on availability of suitable land and whether the university prefers the location to be reasonably close in distance terms, e.g. to allow site visits. There are arguments around whether productive agricultural land should be used for solar farms. Possibilities to help mitigate this include grazing animals in the fields with the solar arrays and increasing biodiversity by planting appropriate species.

The capacities for these schemes are well above the typical limit for whether a connection is made to the local, DNO grid, or to the national grid. The threshold for this varies from region to region, but is typically 15 – 50MW. Above this, it is more expensive to connect to the grid as different transformers are required to step-up voltage to 33kV or 132kV, depending on the requirements imposed. Transmission infrastructure to reach the nearest suitable grid connection point is also required and the costs for this vary with distance. These costs will be significant (£millions). A possible way to reduce these costs would be to procure a number of smaller schemes, below the thresholds in the locations chosen. This might increase build costs for the PV aspect but this is likely to be less than the savings on the grid connection.

For the financial information table the following assumptions have been made:

- There are no incentives available, as the schemes are above the limits for the Feed In Tariff (maximum of 5MW)

[6] http://www.solarpowerportal.co.uk/news/the_government_just_completed_the_uks_largest_solar_farm_56342

- Income is assumed to be for export only, it may be possible to bid into and receive CFD to get higher payments for generation but this has not be included as it is not certain
- Maintenance / operation costs of £5,000 / MW / year have been assumed
- Grid connection costs are not included as while an allowance could be made for typical transformers, the costs are site dependent
- Costs for land acquisition and any consents, e.g. planning have not been considered, and these will be variable with the site

Costs / Income				
Carbon reduction		25%	50%	100%
Cost £ / kWp		£1,000	£1,000	£1,000
Total Cost	£000's	66,000	132,000	264,000
Electricity sale / CFD Rate	£/MWh	59.88	59.88	59.88
	£000's	3,000	6,500	13,000
Operation / maintenance	£000's	300	700	1,300
Total annual savings	£000's	**2,900**	**5,800**	**11,700**

Results				
Carbon reduction		25%	50%	100%
CO_2 savings	tCO_2 / yr	25,100	50,100	100,200
Annual cost savings	£000's	2,900	5,800	11,700
25 year WLC savings	£000's	1,100	2,300	4,600
25 year average CO_2 savings	tCO_2 / yr	9,400	18,800	37,600
Simple payback period	years	22.7	22.7	22.7
Cost per tonne CO_2 current	£ / tCO_2	2,600	2,600	2,600
Cost per tonne CO_2 25 year average	£ / tCO_2	7,000	7,000	7,000

The results show that a longer term financial benefit is possible and the size of the scheme required to deliver the carbon emissions offset. The relative benefits do not change with the scale of the scheme as the cost assumptions are based on high level estimates and a more detailed study would be required to develop a fuller understanding of the different scales on the costs.

Wind

The previous AECOM report Carbon and Engineering Strategy reviewed the University Estate and found that there are no locations available within the University estate for a large wind turbine, due to anticipated planning constraints and proximity to University buildings. Wind was therefore excluded from further analysis at this point. For this report wind has been reconsidered due to its ability to contribute significant carbon emission reductions. One route to achieving this, might be for the University to acquire a wind farm and claim the carbon savings as part of the overall estate emissions under a Scope 3 saving. There are various processes and restrictions to consider in how the emissions benefit is claimed, the main one being the carbon emissions benefit can only be claimed if the scheme is considered to be "additional" and would not otherwise exist – this would mean that FIT / ROCs cannot be claimed. The aim of incentive schemes such as these is to increase the amount of renewable energy, so any asset receiving this funding will be considered as part of the benefit deriving from these schemes. If the incentives are not claimed, the asset can be considered additional as it has not had government support to develop it. Contract for Difference (CFDs) may be claimable as these are technology neutral, however, there is no guidance on this at the time of writing. There are also operation, maintenance, electricity sale arrangements and other factors to be considered. Before going ahead with wind (or another offsite generation option) the full implications should be considered and understood.

The initial suggestion was to consider buying an existing wind farm, or part of one. A further suggestion was to consider buying a consented but not constructed wind farm as the costs could be lower for this.

	Operational	Consented
Advantages	➢ Savings immediately available ➢ Low risk as already in operation	➢ May be significantly cheaper to purchase ➢ Planning risk removed as has consent ➢ Due to changes to support mechanisms and market uncertainty may be easier to procure
Disadvantages	➢ Likely to be expensive as the market is very competitive ➢ May not be possible to procure for the same reason	➢ Construction risk may sit with the University ➢ Time taken to build

Both procurement options have been considered. The cost figures should be treated with caution as it was difficult to gather this information and most developers will not disclose information without knowing who the client is. Developers are also likely to base the sale price on what they consider the market will bear, with little relation to actual costs to develop the scheme.

As a wind farm can achieve large carbon benefits the capacities were calculated on the basis of achieving 25%, 50% and 100% carbon reduction, as per the offsite solar farm option. A capacity factor of 0.35 was assumed in all cases, which is typical for a wind farm site in Scotland. Note that wind farms in Scotland achieving this are sited on favourable sites with a good wind resource and it is assumed that this type of site would be favoured. There is a fairly wide range of capacity factor for wind farms, varying with location (wind resource), technology and operational factors.

Fuel / Energy							
		Consented	Consented	Consented	Operational	Operational	Operational
Carbon reduction		25%	50%	100%	25%	50%	100%
CO_2 saving	tCO_2	25,100	50,100	100,200	25,100	50,100	100,200
Generation required	MWh	54,200	108,400	216,900	54,200	108,400	216,900
Capacity factor		0.35	0.35	0.35	0.35	0.35	0.35
Capacity required	MW	17.7	35.4	70.7	17.7	35.4	70.7

The generation required figure is derived from the CO_2 savings target and the current emissions factor for grid generation.

For the financial information table the following assumptions have been made:

- The consented scheme is entered for CFD and achieves a rate of £80 / MWh
- CFD can be claimed as well as the Scope 3 emissions benefit
- The operational scheme sacrifices ROC payments to allow the Scope 3 emissions benefit to be claimed (around £40/MWh)
- Maintenance / operation costs of £20,000 / MW have been assumed

Costs / Income							
		Consented	Consented	Consented	Operational	Operational	Operational
Carbon reduction		25%	50%	100%	25%	50%	100%
Purchase cost	£/MW	1,000,000	1,000,000	1,000,000	3,000,000	3,000,000	3,000,000
	£000s	17,700	35,400	70,700	53,000	106,100	212,200
Construction cost	£/MW	1,000,000	1,000,000	1,000,000	-	-	-
	£000s	17,700	35,400	70,700	-	-	-
Total Capital Cost	**£000s**	**35,400**	**70,700**	**141,500**	**53,000**	**106,100**	**212,200**
Electricity sale / CFD Income	£/MWh	80	80	80	59.88	59.88	59.88
	£000s / yr	4,300	8,700	17,300	3,200	6,500	13,000
Operation / maintenance Costs	£000s / yr	-700	-1,400	-2,800	-700	-1,400	-2,800
Total annual savings	**£000s / yr**	**3,600**	**7,300**	**14,500**	**2,500**	**5,100**	**10,200**

Results							
		Consented	Consented	Consented	Operational	Operational	Operational
		25%	50%	100%	25%	50%	100%
CO_2 savings	tCO_2 / yr	25,100	50,100	100,200	25,100	50,100	100,200
Annual cost savings	£	3,600	7,300	14,500	2,500	5,100	10,200
25 year WLC savings	£	49,700	99,400	198,800	13,400	26,800	53,700
25 year average CO_2 savings	tCO_2 / yr	10,100	20,100	40,300	10,100	20,100	40,300
Simple payback period	years	9.7	9.7	9.7	20.9	20.9	20.9
Cost per tonne CO_2 current	£ / tCO_2	1,400	1,400	1,400	2,100	2,100	2,100
Cost per tonne CO_2 25 year average	£ / tCO_2	3,500	3,500	3,500	5,300	5,300	5,300

The results show that the consented wind farm options can give a good financial benefit alongside the carbon offset. The relative benefits do not change with the scale of the scheme as the cost assumptions are based on high level estimates and a more detailed study would be required to develop a fuller understanding of the different scales on the costs.

Summary Of Large Scale Renewable Energy Options

This section considered large scale offsite options for strategic carbon reductions, based on proportions of the current emissions. Solar PV and wind farms have been considered as the renewable energy options that would allow an offset of emissions through Scope 3 reporting. The actual consumption based gross emissions of the university would remain unchanged, unless the asset could be sited close enough to the university for a private wire connection to provide the power to the university directly, which is unlikely and so not been considered.

The table shows that a consented wind farm would offer the most cost effective option to achieve this type of strategic reduction, while there is not a great difference between the operational wind farm and a solar farm. It should be remembered that the costs for the operational wind farm in particular have significant uncertainty.

Results										
		Wind	Wind	Wind	Wind	Wind	Wind	Solar	Solar	Solar
		Consented	Consented	Consented	Operational	Operational	Operational			
		25%	50%	100%	25%	50%	100%	25%	50%	100%
Capital Cost	£000s	35,400	70,700	141,500	53,000	106,100	212,200	66,000	132,000	264,000
Operational Cost	£000s / yr	-700	-1,400	- 2,800	-700	-1,400	-2,800	-300	-700	-1,300
Operational Income	£000s / yr	4,300	8,700	17,300	3,200	6,500	13,000	3,200	6,500	13,000
Annual cost savings	£	3,600	7,300	14,500	2,500	5,100	10,200	2,900	5,800	11,700
CO_2 savings	tCO_2 / yr	25,100	50,100	100,200	25,100	50,100	100,200	25,100	50,100	100,200
25 year WLC savings	£	49,700	99,400	198,800	13,400	26,800	53,700	1,100	2,300	4,600
25 year average CO_2 savings	tCO_2 / yr	10,100	20,100	40,300	10,100	20,100	40,300	10,100	20,100	40,300
Simple payback period	years	9.7	9.7	9.7	20.9	20.9	20.9	22.7	22.7	22.7
Cost per tonne CO_2 current	£ / tCO_2	1,400	1,400	1,400	2,100	2,100	2,100	2,600	2,600	2,600
Cost per tonne CO_2 25 year average	£ / tCO_2	3,500	3,500	3,500	5,300	5,300	5,300	7,000	7,000	7,000

Offsetting – Carbon Neutral claims

There are a number of large organisations making claims around their low carbon footprint. While organisations tend not to claim 'zero carbon' operations, there are a number of organisations which achieve carbon neutral status. A zero carbon organisation would use all of its energy from renewables such as solar and wind. In contrast, a carbon neutral organisation can use conventionally generated electricity and gas (as well as renewable energy), but the emissions produced are calculated and offset.

Running a carbon neutral organisation is much more than simply offsetting emissions. The UK's Department of Energy and Climate Change (DECC) has developed guidelines to discourage "greenwashing" and a definition of carbon neutrality to provide clarity, "Carbon neutral means that – through a transparent process of calculating emissions, reducing those emissions and offsetting residual emissions – net carbon emissions equal zero."[7] DECC advises that projects should always reduce emissions before offsetting, and that a carbon neutral claim based only on offsetting should not be made. For example, carbon neutral buildings integrate passive design strategies, have high performance building envelopes, energy efficient HVAC systems, lighting and appliances, on-site renewable energy, and only after all of these measures do they arrive at carbon neutrality with the final offsetting step.

DECC recommends that all carbon emission calculations include Scope 1 and Scope 2 emissions at a minimum. Scope 1 emissions are direct emissions from equipment that is owned or controlled at building scale such as boilers or furnaces. Scope 2 emissions are indirect emissions from purchased electricity, heat, steam, and cooling which are produced by sources which are not owned or controlled at the building scale. DECC also recommends including Scope 3 emissions (other indirect emissions) which include sources such as business travel in vehicles owned by others.

DECC also recommends that the results are verified by ISO 14064, which is a specification with guidance at the organisation level for the quantification and reporting of greenhouse gas emissions and removals, or PAS 2050, which is a specification for the assessment of life-cycle greenhouse gas emissions of goods and services. For transparency, DECC also advises that claims for carbon neutrality should always be linked to a specified period of time.

Organisations that have achieved carbon neutral status include retail brands such as the UK's Marks and Spencer, water brands such as Iceland's Icelandic Glacial, and France's Evian, and banks such as Denmark's Danske Bank, and the National Australia Bank. Other organisations like IKEA are moving towards carbon neutrality.

Marks and Spencer

Marks and Spencer (M&S), a global retailer, became carbon neutral in 2012 by reducing energy use by 28% through more efficient refrigeration, counting renewable energy sold to the grid, and offsetting. The M&S 'Plan A' strategy is to improve efficiency by 50% by 2020 with an overall position of carbon neutrality.

The main regulations applying to M&S include building regulations, the Climate Change Levy (carbon tax on non-renewable energy contracts), the Carbon Reduction Commitment Energy Efficiency Scheme, and the Energy Savings Opportunity Scheme (ESOS). Their use of refrigeration gases are regulated under the EU F-Gas regulations.

Emissions reporting for M&S is presented annually in their Plan A Report, and they are calculated following the WRI/WBCSD GHG Corporate Reporting and Accounting Standard using Defra (DECC) carbon conversion factors and Bitzer for refrigeration gases. Data is included for all areas where they have operational control.

M&S has adopted the 2015 WRI/WBCSD Scope 2 Guidance on procured renewable energy, meaning that they calculate a gross location-based figure and then net-off reductions from the procurement of high quality carbon offsets, procured renewable electricity, renewable energy generated by M&S and sold to the grid, and procured biomethane using the BMC (biomethane certification) process. Using this approach, M&S calculates a net figure of carbon neutrality.[8]

M&S plans to invest in Verified Emission Reduction (VERs), focusing on global standards such as the Clean Development Mechanism (CDM), Gold Standard (GS) or Verified Carbon Standard (VCS).

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[7] UK Department of Energy and Climate Change. Guidance on carbon neutrality.
http://www.decc.gov.uk/en/content/cms/emissions/neutrality/neutrality.aspx

[8] M&S greenhouse emissions and climate change performance 2014/15. Plan A 2020
http://corporate.marksandspencer.com/file.axd?pointerID=c3152c8a5f484bcc8b8af71a80609d21

Icelandic Glacial
Icelandic Glacial became carbon neutral by reducing emissions from the organisation's activities and offsetting the remaining emissions. They restricted staff flights and travel where possible by switching to video-conferencing, installed low-energy lighting, reduced packaging, and recycled waste.

Icelandic Glacial carried out a cradle-to-gate calculation of their carbon footprint including shipments from supplier's warehouses, business travel, waste, and employee commuting following the GHG Accounting Protocol: The GGH Protocol Corporate Standard or ISO 14064-1 or a similar protocol.

Evian
Dannone chose to seek carbon neutral status for its Evian brand rather than the entire organisation. They achieved carbon neutrality for their Evian natural mineral water product through action plans for packaging, manufacturing, and logistics as well as offsetting carbon emissions.

Sources of emissions in the Evian carbon footprint include: packaging materials, production, upstream logistics, downstream logistics, retail and home, and end-of life. The methodology they used was PAS 2050:2008, one of the recognised approaches for product carbon footprint inventory and life-cycle assessment. It is endorsed by PAS 2060 which was developed by the British Standard Institution (BSi) to provide guidelines on how to achieve carbon neutrality in a way that is transparent and effective. The calculations have been certified and verified by Carbon Trust Certification Limited.

Danske Bank
Danske Bank achieved carbon neutral status through behavioural change to reduce carbon dioxide emissions and by offsetting the remaining emission that could not be eliminated. They have reduced CO_2 emissions by reducing business trips by 35% through virtual meetings and conference calls, reducing building energy consumption, and reducing emissions from paper by digitising documents.

Emissions from the group have been registered by creating a greenhouse gas inventory and setting forth their methodology according to ISO 14064-1. The work of measuring and reducing GHG emissions is integrated into the group's environmental management system which follows the ISO 14001 standard.

Danske Bank have offset unavoidable carbon emissions from electricity, heating, and IT by purchasing carbon credits from energy products including wind turbines, biogas, and biomass in Turkey, Lithuania, and India. There are also social benefits to these projects as they help to improve the health of women and children as biogas reduces smoke in household kitchens and the projects create jobs in the local community.

National Australia Bank (NAB)
NAB is certified under the National Carbon Offset Standard for a defined inventory of carbon emissions from activities in its Australian-based business. Their Environmental Reporting and Offset Management Standard has the following steps:

- Define and measure carbon inventory or footprint
- Reduce carbon emission through energy efficiency and demand management, including behavioural change
- Avoid carbon emissions by purchasing from renewable sources to apply a zero-emissions factor to the renewable electricity purchased
- Offsetting remaining carbon emissions by purchasing quality accredited carbon offsets
- Verifying and reporting on progress towards meeting targets
- Obtaining external assurance over carbon accounts on inventory and offsets
- Regular reporting to key internal stakeholders and annually to external stakeholders

IKEA
IKEA, the Swedish home furnishing retailer, is working to increase energy-efficiency and aiming to become carbon neutral by 2020. They are also aiming to move to 100% renewable energy within the decade. IKEA is in a good position to achieve their goals as they already own wind farms and solar panels which account for approximately 27% of the company's energy use.

IKEA has a published sustainability strategy for 2020, called ‘People & Planet Positive’ which was developed after a long term programme of data collection, intensive energy audits, energy needs assessments, and a construction plan to own and operate solar and wind power systems.[9]

IKEA contributes to the development of renewable energy by investing in their own power generation equipment, including offsite wind turbines, on-site biomass boilers, and on-site solar panels. In 2014, IKEA generated renewable wind energy (410 GWh), solar PV (90 GWh), and biomass energy (1,310 GWh). IKEA also purchases renewable electricity to supply their stores and other buildings.

Example Offsetting Options for University of Edinburgh

Offset options based on forestry and peatland restoration are included by way of examples of what might be possible. As background context for these, the global market for voluntary offsets had a volume weighted average price of $3.8 / tCO_{2e} for 2014[10]. There is a wide range of costs and land requirements for the offsets claimed for forestry and peatland options. In part this is due to the variety of schemes, where current conditions, type of species, management choices and other factors all influence the results. It is also due to the difficulty in verifying the emissions associated with forestry and peatlands. The examples presented have therefore included typical, low and high values as available to give some indication of the variability. In terms of costs schemes with a good reputation will in general cost more and schemes often do not give out cost information until negotiating contracts. The options considered are based on Scottish schemes. The market for offsets is global with many schemes offering social benefits, particularly in low-income countries. The wider implications of offset schemes should be included in the decision making process to ensure a suitable fit with the aspirations of the University.

Offsetting – purchase costs					
		Peatland	Peatland	Forestry[11]	Forestry
Carbon reduction		25%	50%	25%	50%
CO_2 offset	tCO_2	25,058	50,117	25,058	50,117
Purchase cost - typical	£/tCO_2/yr	6[12]	6	10	10
Annual cost	£/yr	150,300	300,700	250,600	501,200
25 year cost	£ 000s	3,760	7,520	6,270	12,530
25 year cost	£/tCO_2	150	150	250	250
Purchase cost - low	£/tCO_2/yr	-	-	3	3
Annual cost	£/yr	-	-	75,200	150,300
25 year cost	£ 000s	-	-	1,880	3,760
25 year cost	£/tCO_2	-	-	75	75
Purchase cost - high	£/tCO_2/yr	-	-	15	15
Annual cost	£/yr	-	-	375,900	751,700
25 year cost	£ 000s	-	-	9,400	18,790
25 year cost	£/tCO_2	-	-	375	375

[9] IKEA Group Sustainability Strategy for 2020. People & Planet Positive. http://www.ikea.com/ms/en_CA/img/pdf/sustainabilitystrategy.pdf

[10] Ahead of the Curve State of the Voluntary Carbon Markets 2015: http://forest-trends.org/releases/p/ahead_of_the_curve_state_of_the_voluntary_carbon_markets_2015

[11] Forestry Commission Woodland Carbon Code: http://edinburghcentre.org/files/documents/Forestry_Commission_ECCI_WCC_event_June_2013.pdf

[12] Carbon Conservation – NTS Arran Peat restoration project: http://www.cndoscotland.com/carbon-conservation/news.php

Offsetting – land required					
		Peatland	Peatland	Forestry[13]	Forestry
Carbon reduction		25%	50%	25%	50%
CO_2 offset	tCO_2	25,058	50,117	25,058	50,117
Land requirement - typical	tCO_2 /ha	4.0[14]	4.0	4.7[15]	4.7
	ha	6,300	12,500	5,300	6,700
Land requirement - low	tCO_2 /ha	17.00[16]	17.00	7.5[17]	7.5
	ha	1,500	2,900	3,300	6,700
Land requirement - high	tCO_2 /ha	0.25[18]	0.25	1.35[19]	1.35
	ha	100,200	200,500	18,600	37,100

The options presented cover the annual cost of purchasing the offsets for a recognised scheme and the land required in hectares for the equivalent of 25% and 50% of the current total emissions of the University. Costs per year per tonne of carbon and the total cost for 25% and 50% reductions are included. To allow comparison with other measures costs for 25 years of offset are included, along with a £/tCO_2 based on the cost for the 25 year period to achieve the required annual emissions. Note that this does not include inflation for the costs, nor does it include any change to the University emissions year on year.

The results show that the costs for carbon offsets are in general favourable compared to other options. It should be remembered that offsetting will not reduce emissions at the University, so fuel costs will not decrease and the offset payments would need to continue for as long as the University wanted to state a reduced carbon footprint. Renewable energy and energy efficiency measures require upfront investment and then reduce fuel costs for the life of the project so they are quite different measures from carbon offsetting.

Summary - Offsetting

Organisations normally aim for carbon neutrality rather than zero carbon. Carbon neutral means reducing emissions where possible, investing in renewable energy, and then offsetting remaining unavoidable emissions.

Becoming carbon neutral involves gaining an understanding of the carbon footprint and establishing plans to reduce it. Organisations determine which activities should aim to become neutral. Some organisations make a product line carbon neutral, while other organisations qualify as entirely carbon neutral in the activities they directly control. Direct emissions from sources owned or controlled by the organisation such as boilers in buildings should be included. Organisation-owned vehicles and employees travelling to work should also be included.

Carbon offsets are available from projects which undertake actives such as planting trees or building wind farms, Carbon certificates from these projects are sold on the compliance or the voluntary carbon markets. These providers have already gone through the long process of establishing carbon projects and having them validated and verified. For carbon offsets to be recognised they should be purchased from recognised providers rather than attempting to start a carbon offset project – unless this is specifically part of the organisation's strategy and objectives.

Project offsets available on the compliance market include Certified Emission Reductions (CERs) and Emission Reduction Units (ERUs)[20]. Carbon credits available on the voluntary market include the Gold Standard and the Voluntary Carbon Standard which are recognised by the International Carbon Reduction and Offset Alliance (ICROA), as well as

[13] Forestry Commission Woodland Carbon Code: http://edinburghcentre.org/files/documents/Forestry_Commission_ECCI_WCC_event_June_2013.pdf

[14] Various sources including SNH and IUCN: http://www.iucn-uk-peatlandprogramme.org/sites/www.iucn-uk-peatlandprogramme.org/files/100218Briefing_Peatlands_andGreenhouseGasEmissions.pdf

[15] Based on 100 year average for woodland established with no clearfell

[16] Calculating carbon savings from wind farms on Scottish peatlands – a new approach: http://www.gov.scot/Resource/Doc/229725/0062213.pdf, p33

[17] Based on 50 year average for mixed native woodland with no clearfell

[18] Undisturbed peatlands: http://www.cndoscotland.com/carbon-conservation/news.php

[19] Based on 100 year average for sitka spruce clear felled at 40 years

20 List of government approved providers: http://offsetting.defra.gov.uk/cms/approved-offsets/

standards that promote sustainability co-benefits including Climate Community and Biodiversity, the Gold Standard, Social Carbon, and Plan Vivo.

The University of Edinburgh has a long-standing collaboration with the Plan Vivo Foundation. Recently, the MSc in Carbon Management programme[21] at Edinburgh Centre for Carbon Innovation (ECCI) at the University of Edinburgh, went virtual and zero carbon with carbon offsets purchased from the Plan Vivo Foundation (June 2015)[22].

For the University the key point to understand is that the offsetting stage is tackled at the end of the process, once all possible energy reduction and renewable energy options have been implemented. Buying offsets for carbon should be the last step to be implemented because buying offsets means that the University pays for carbon twice, initially for the fuel and subsequently for the offset.

If offsetting is a longer term aspiration, a recognised protocol such as PAS 2050 or ISO 14064 should be followed and offsets should be purchased through an accredited scheme. Due to the accreditation requirements it is not recommended that the University attempt to establish its own offset scheme, e.g. through a forestry programme.

The costs for offsetting vary significantly depending on the type of scheme and the reputation of the provider. The costs for the offset alone compare favourably with other options but do reduce energy use and costs.

Smaller Scale Renewable Energy Options – Onsite
This section looks at renewable energy options that are at a scale that can be accommodated on the university campus.

Geothermal
AECOM specialists have carried out a high level assessment of the potential use of geothermal energy across the University Estate. See appendix B for full details. The conclusions from this assessment are outlined below:

The majority of the Edinburgh University estate has limited potential for geothermal energy. However, this study has identified the possible existence of a sedimentary aquifer underlying the western half of Kings Buildings. The depth, temperature and permeability/productivity of the aquifer is unknown but it may be suitable for development. It may be suitable for development either with a GSHP borehole based system or a deeper geothermal borehole(s).

The potential mining-enhanced aquifer underlying the Easter Bush and Bush Estate also potentially warrants further investigation. This would include intrusive Site Investigations (SI) where exploratory boreholes are drilled with the objective of determining yield flows and the water chemistry, which has a major impact on the specification of the system. It may be suitable for development with a deeper geothermal borehole(s). There is also the potential for deployment of GSHP type systems more widely across the University estate.

At this stage the exploitation of geothermal energy using GSHP options is covered in the Heat Pumps review section of this report. The next steps and costs for further development of a geothermal resource would be as follows:

A detailed Desktop study should be undertaken for £1.5k - £2.5k to better define the potential geothermal resources and to determine whether closed loop or open loop systems are suitable.

Costs for investigating the potential by drilling boreholes and carrying out pumping and thermal response tests (to determine yield flows, temperatures, heat capacity) vary significantly with the depth of the boreholes and the type of system proposed, from simple shallow boreholes (less than 50m) for closed loop systems to deep or very deep boreholes (hundreds of metres to say 3km) for mine workings or sedimentary aquifer systems. Due to the costs of drilling, test wells are usually incorporated in the final system. Closed loop systems involve circulating fluid through a closed system of pipes in vertical, or horizontal, loops. Heat is exchanged between the ground and the fluid through the pipe walls. Open loop systems involve an abstraction well, which removes fluid from an aquifer and passes it through a heat exchanger, at which point heat is transferred, before returning it to the aquifer through another well located far enough from the abstraction point to avoid recirculation.

The geothermal gradient in Scotland is typically (approximately) 25°C per km depth but this will vary with location. To get groundwater at 25°C you may need to drill to 1km. Shallow ground temperatures – as utilised by Ground Source Heat Pump Systems (GSHP) are generally in the region of 10-12°C.

[21] Professor Dave Reay of the University of Edinburgh's School of GeoSciences, is Programme Director for the online MSc in Carbon Management
[22] Plan Vivo Foundation and the University of Edinburgh: http://www.planvivo.org/?s=university+of+edinburgh

A relatively shallow borehole up to 100m and thermal response testing for a GSHP system is likely to cost between £10k and £20k. This would provide information for the design of the borehole array (what length of boreholes would be required to satisfy the required heat load). The investigation borehole could then be used as part of the final system if favourable. These types of systems are generally relatively low risk if designed and installed properly.

Deeper boreholes of hundreds of metres to target abandoned mine workings or sedimentary aquifers require specialist drilling equipment, and the boreholes are likely to cost in excess of £100k. Boreholes to significantly greater depths more than 1km depth will cost considerably more.

Deeper drilling carries with it significant risks. As an example, a deep geothermal borehole at Newcastle Science Centre, to around1,800m cost circa £1M and was abandoned due to technical difficulties in the drilling process and failed to achieve the target depth or provide a reliable geothermal energy source. It should be noted that this was a special case targeting a specific source, a postulated groundwater upwelling on a major fault, but does illustrate the potential financial risks involved.

Please not the costs identified are for the investigations only and not the installed borehole / well collector systems and associated pipework, heat pumps etc.

Heat Pumps

Heat pumps utilise a mechanical refrigeration cycle to provide several units of heat for one unit of electricity input. This means that they can produce heat with lower carbon emissions than an equivalent gas boiler in the right circumstances. In addition, because they use electricity as the primary fuel, carbon emissions will decrease over time as grid decarbonisation increases.

The drawbacks with heat pumps relate to the how they operate. The efficiency (known as the co-efficient of performance, COP) increases as the temperature difference between the ambient heat source (ground, water or air) and the required output or sink temperature decreases. This means they operate most efficiently at lower temperature heating applications, for instance underfloor heating. In general they do not perform well in old buildings with traditional heating systems requiring flow temperatures of 80^{o}C or higher. Additionally, to get the best performance ground source or water sources are preferred as they provide higher source temperatures in winter. The infrastructure required for ground source or water source is expensive and can require considerable land area, as it can involve boreholes, abstraction wells and river abstraction points for instance. Heat pumps are eligible for RHI subsidy so can be cost effective if the high initial capital costs can be met. For larger systems it is possible to procure heat pumps offering reasonable COP's (>3.0) with higher flow temperatures up to 80^{o}C which is not possible in small scale building integrated systems.
For the University, the most suitable opportunities are therefore in new buildings where the heating system operates at low temperature or at larger scale, for example, as an additional or replacement heat source in the University's district heating schemes.

The options considered in light of the information above are based on ground source heat pump solutions using vertical boreholes at the Edinburgh College of Art (ECA) and their integration into the Easter Bush district heating and cooling scheme. These are intended to provide examples to demonstrate the possibility of large scale deployment of this technology in the University estate.

ECA Ground Source Heat Pump

There is a possibility to install GSHP at ECA. The GSHP would be sized to provide heat to the all four buildings (Main, Hunter, Architecture and Evolution House). This would allow a sufficiently large heat pump to ensure a suitable flow temperature for optimised integration into the existing heating systems. If this option is to be considered further it would be worth reviewing the possibility of updating the heating systems in the buildings to run on lower temperatures where possible during refurbishment works as this would improve heat pump COP significantly.

From existing data AECOM hold from previous work on the estate, the annual heat demand for the four buildings has been estimated at around 4,550,000kWh. We have assumed that the GSHP would be lead heat source and would have adequate thermal storage to operate the equivalent of 5 months' continual operation.

It would be possible to site a borehole array in the central quad area. An array of approximately 40 boreholes with a typical separation of 10m could be accommodated in the quad area. On the basis of typical ground conductivities and the use of 300m deep boreholes, a heating capacity of around 350kW could be supported. This would provide close to 30% of the site heat demand with gas boilers picking up the remainder of the load. Further details of the assumptions used are provided in the following tables.

Fuel / Energy		
Annual heat demand	4,549,000	kWh
Heat pump capacity assumed	350	kW
Heat pump hours	3,650	Hrs
Assumed $COP_{(heat\ pump)}$	3.0	
Heat pump contribution to heating load	1,277,000	kWh
Elec required	426,000	kWh
Gas boiler heat load	3,272,000	kWh
Boiler efficiency	85	%
Gas required	3,850,000	kWh
Baseline (Gas)	5,352,000	kWh

Costs		
Boreholes	£ / borehole	1,000
Based on 40 boreholes	£	40,000
Heat pump installed price	£/kW	1,500
Installed cost	£	565,000
Thermal Store	£/l	1
Thermal Store cost	£	67,200
Development		25,000
Sub-total	£	657,200
Contingency / Fees		25%
Total cost	£	821,500

Results		
CO_2 savings	tCO_2 / yr	64
Annual cost savings	£	34,000
25 year WLC savings	£	-338,000
25 year average CO_2 savings	tCO_2 / yr	180
Simple payback period	years	24
Cost per tonne CO_2 current	£ / tCO_2	12,800
Cost per tonne CO_2 25 year average	£ / tCO_2	4,600

Easter Bush Ground Source Heat Pump
Easter Bush will soon have a four pipe district energy system allowing heating and cooling. This is an ideal arrangement for a GSHP as they can provide heating and cooling simultaneously and if either load is not available, the heat or cool rejected from the heat pump can "charge" the ground to improve long term system performance. There is land available so it should be possible to install a borehole array of a suitable size for a heat pump system of an appropriate capacity.

From existing data AECOM hold from previous work on the estate, the annual heat demand for the Easter Bush site, including planned buildings, has been taken as 10,760,000kWh. Cooling load data was not available so this has not been included in the assessment at present. Including this would improve the overall performance of the scheme, both in carbon and financial terms.

For the purposes of this assessment it is assumed that the GSHP could provide 85% of the heat load.

Fuel / Energy		
Annual heat demand	10,758,300	kWh
Proportion of load from GSHP	85	%
Total heat pump load	9,144,600	kWh
HP COP	3.5	
Elec required	2,612,700	kWh
Gas boiler heat load	1,613,800	kWh
Boiler efficiency	85	%
Gas required	1,898,500	kWh
Baseline (Gas)	12,656,900	kWh

Costs		
Boreholes	£ / borehole	1000
Based on 330 boreholes	£	280,000
HP Cost	£/kW	1500
HP Cost	£	3,150,000
Thermal Store	£/l	1
Thermal Store cost	£	210,000
Development		50,000
Sub-total	£	3,690,000
Contingency / Fees		25%
Total cost	£	4,612,500

Results		
CO_2 savings	tCO_2 / yr	680
Annual cost savings	£	323,500
25 year WLC savings	£	102,000
25 year average CO_2 savings	tCO_2 / yr	1,390
Simple payback period	years	14.3
Cost per tonne CO_2 current	£ / tCO_2	6,800
Cost per tonne CO_2 25 year average	£ / tCO_2	3,330

PV - Onsite

Two main onsite options have been considered for PV, these include utilising available roof space in building integrated solutions across the University campus and the provision of a large scale solar farm. To date the University has very little PV capacity so there is an opportunity to expand this significantly. In the U.K. there has been a great increase in PV since FIT was introduced. The costs have reduced significantly FIT returns have been reduced since their introduction but this has not halted the uptake of PV as a technology. As a technology, it is a low risk option, with no moving parts and its ease of installation. Deployment is possible where suitable unshaded roof (or ground) space is available.

Roof Space Option – Building Integrated PV

A high level assessment of available roof space was carried out based on information AECOM held on floor area and number of storeys for each building. To account for differing orientations, possible shading, possible planning restrictions and availability of roof space, it has been assumed that 25% of the total roof area is usable. This crude assessment leads to a total useable area of approximately 40,000m^2. To account for the space required for maintenance access and space required for framing and other necessary infrastructure, it is assumed 75% of this useable roof space is the equivalent PV panel area.

Based on a typical performance of 7.5m^2 area per kW_p this gives a total capacity of 3,980kW_p. For Edinburgh the expected output is in the region of 820 kWh / kW_p / year. It has been assumed that 15% of the electricity generated is exported as there is not sufficient demand in the building to use the generated power. It is possible the figure could be lower than but there is a variety in the types of buildings and use so some export is likely.

To aid in implementation it may be worth considering instating a policy that whenever works are being carried out on a roof, or scaffolding is in place, PV should be installed assuming there are no reasons not to for the specific building. The costs will be reduced for this approach as the scaffolding or access arrangements are in place. The options presented have been based on PV suppliers installing the systems.

Fuel / Energy		
Annual electricity generation	3,262,000	kWh
Proportion exported to grid	15	%
	489,000	kWh

Costs / Income		
FIT rate (Jan 2016 Consultation rate)	p / kWh	1.03
FIT Income	£	33,600
Export rate (FIT guaranteed minimum)	p / kWh	4.85
Export Income	£	23,700
Grid electricity cost	p / kWh	10.5
Grid electricity savings	£	291,200
Total savings	£	348,500
PV installed cost	£/kW_p	1,300
Total cost	£	5,172,000

Results		
CO_2 savings	tCO_2 / yr	1,630
Annual cost savings	£	337,000
25 year WLC savings	£	1,560,000
25 year average CO_2 savings	tCO_2 / yr	750
Simple payback period	years	15.3
Cost per tonne CO_2 current	£ / tCO_2	3,170
Cost per tonne CO_2 25 year average	£ / tCO_2	6,920

ECA Roof Example

As an example, ECA has been selected as it is understood works on the roof will be carried out as part of the refurbishment. Utilising the south facing aspects of the Main building roof only would give an area of around 280m^2. As the proposed location for the PV is not visible from outside the building planning permissions may be simpler to achieve but this would need to be confirmed. The available roof area is estimated at approximately 280m^2, giving a possible PV capacity of 37kW_p. It is expected that this load can be utilised on the site at all times, with no need to export.

Fuel / Energy		
Annual electricity generation	30,600	kWh
Proportion exported to grid	0	%
	0	kWh

Costs / Income		
FIT rate (Jan 2016 Consultation rate)	p / kWh	1.03
FIT Income	£	315
Export rate (FIT guaranteed minimum)	p / kWh	4.85
Export Income	£	0
Grid electricity cost	p / kWh	10.08
Grid electricity savings	£	3,090
Total savings	£	3,400
PV installed cost	£/kW$_p$	1,315
Total cost	£	49,100

Results		
CO_2 savings	tCO_2 / yr	15
Annual cost savings	£	3,800
25 year WLC savings	£	22,400
25 year average CO_2 savings	tCO_2 / yr	7
Simple payback period	years	12.9
Cost per tonne CO_2 current	£ / tCO_2	3,200
Cost per tonne CO_2 25 year average	£ / tCO_2	7,000

Solar Farm – Easter Bush

AECOM have modelled a 4MW array at the University of Edinburgh Easter Bush campus to establish the potential annual generation that could be expected from a well-designed scheme. The results of this exercise show that such an array can be expected to generate approximately 3,600MWh/yr. The carbon dioxide reduction would be approximately 2,000 tCO_2/year.

A general rule is that a 1 MW array will require circa 30,000m^2 of relatively un-shaded and level ground. The arrays consist of rows of panels that cover approximately 25% of the land area with corridors between the panels that can be kept as grassland. A major benefit of locating a solar farm at Easter Bush is there are large electrical loads available so it should be possible to use all generation onsite, thereby improving the financial return. A similar option was reported in more detail in the previous AECOM report Carbon and Engineering Strategy but taking agricultural land out of production was considered sufficient reason to exclude this option from further consideration.

Fuel / Energy		
Annual electricity generation	3,280,000	kWh
Proportion exported to grid	0	%
	0	kWh

Costs / Income		
FIT rate (Jan 2016 Consultation rate)	p / kWh	1.03
FIT Income	£	33,800
Export rate (FIT guaranteed minimum)	p / kWh	4.85
Export Income	£	0
Grid electricity cost	p / kWh	10.08
Grid electricity savings	£	330,600
Total savings	£	364,400
PV installed cost	£/kW$_p$	1,200
Total cost	£	4,800,000

Results		
CO_2 savings	tCO_2 / yr	1,640
Annual cost savings	£	403,100
25 year WLC savings	£	2,915,000
25 year average CO_2 savings	tCO_2 / yr	750
Simple payback period	years	11.9
Cost per tonne CO_2 current	£ / tCO_2	2,920
Cost per tonne CO_2 25 year average	£ / tCO_2	6,390

Fuel cells

Fuel cells offer an alternative approach to gas engine CHP for providing both heating and power. They can operate on natural gas and in general should offer higher efficiencies in terms of electrical production, which is beneficial as electrical loads are generally on the increase with heating loads decreasing in line with increasingly more stringent building regulation approvals. This is particularly evident in research science buildings where the electrical load can be several times that of the heating load.

Fuel cells rely on a chemical process and require the fuel input to be of high purity and at the correct pressure. This often requires additional ancillary plant. For some units the heat output is at two temperatures, with a higher grade heat available at up to around 120^{o}C and lower grade up to 50^{o}C, with some flexibility in temperatures and flow rates for these cooling circuits. The higher grade heat output would allow a two stage absorption chiller which would give a higher efficiency, assumed to be 100% in this case. The low grade heat could be used for pre-heat for domestic hot water and it has been assumed that 75% of this heat can be captured and used, which may require further infrastructure.

The Estates Department identified King's Buildings as being a good potential option for fuel cells, with the existing CHP – District heating scheme having a baseload of 2.73MW and a CHP engine of 2.7MW capacity. A fuel cell of up to 1MW could operate continually and the existing CHP could be used for load top up. The heat output from the fuel cell could be used to run an absorption chiller to address ever increasing cooling loads on the site as part of a new district cooling system. There is a concentration of cooling in the south – east corner of the site and it is suggested that the system would focus on these loads. The previous AECOM report Carbon and Engineering Strategy Phase 2 provides details of a possible absorption chiller district cooling option for King's Buildings (based on the provision of an additional gas engine CHP rather than a fuel cell).

An initial review of the costs of this based on the previous study and costs from SPON's[23] for 800kW of fuel cell capacity (2no Purecell 400kW units) suggesting budget costs of around £5.7m for the fuel cell, absorption chiller and distribution pipe work. Carbon savings will depend on run hours and what technologies the fuel cell displaces. To give an indication the following assumptions have been applied:

[23] Spon's Mechanical and Electrical Services Price Book 2015,

- Fuel Cell displaces gas CHP 7 hours per day throughout the year
- Electrical efficiency is 37.9%
- Heat efficiency is 42.2% (split between high and low T)
- Runs continually
- Absorption chiller size 375kW heat output; COP 1.0
- Annual run hours 2,920 – thermal store used to allow continual operation for 4 months
- Mechanical chiller displaced EER of 3.5
- Carbon savings around 850 tCO_2 p.a.

These assumptions are reasonably conservative and it is likely the absorption chiller efficiency could be improved and the cooling loads could be for longer than the 4 months assumed given the spaces served are labs and not offices. Logan Energy provided input on approximate costs. It should also be noted that there are further savings possible through use of the fuel cell for standby power generation, removing / reducing the requirement for diesel generators giving cost savings. The whole life costing exercise has been based on fuel costs only, with no servicing or maintenance costs as these were not available. The suppliers do not make these costs available without provision of a full feasibility study. The results are therefore to be treated with caution.

Fuel / Energy		
Electricity generated	4,380,000	kWh
Heat generated for district heating / DHW (less used by absorption chiller)	2,572,000	kWh
Gas input	9,251,000	kWh
Absorption chiller cooling output	1,097,000	kWh
Electricity savings from mechanical chiller	314,000	kWh

Costs		
Fuel Cell	£	4,500,000
Absorption chiller / district cooling network	£	676,000
Ancillary plant / district heating pipe work (from previous study)	£	550,000
Total cost	£	5,726,000

Results		
CO_2 savings	tCO_2 / yr	850
Annual cost savings	£	269,000
25 year WLC savings	£	615,000
25 year average CO_2 savings	tCO_2 / yr	-420
Simple payback period	years	21.3
Cost per tonne CO_2 current	£ / tCO_2	6,730
Cost per tonne CO_2 25 year average	£ / tCO_2	n/a

Note that there is no carbon saving based on the average emissions over 25 years as the projected grid carbon factor from the IAG data used decreases quickly to a value that natural gas CHP (including fuel cell) no longer offers a carbon benefit. As mentioned previously this projection is ambitious and it expected that CHP will offer carbon savings over the life of the asset.

Biofuels

The most common use of biofuels in the U.K. is biomass use in boilers for providing heat, particularly since the introduction of the RHI. The majority of the increased uptake has been for small boilers of up to 200kW capacity, as the economics for these were particularly favourable, particularly in off gas grid areas. For the University, the main campus areas in the City of Edinburgh Council area are unlikely to be able to use biomass for the foreseeable future due to air quality restrictions. Biomass produces higher NO_x and particulate emissions than gas boilers and both of these are a concern in Edinburgh, mainly due to traffic. In the past liquid biofuel was considered for King's Buildings, as an alternative low carbon fuel source, but as interest in biofuels increased the sustainability and carbon benefits were soon questioned. In the previous AECOM report for University of Edinburgh, Carbon and Engineering Strategy, the use of biofuels was reviewed in detail and the conclusions were that liquid biofuels may not result in a CO_2 saving dependent on the sourcing and there are limited quantities available that would provide a saving, which should therefore be used for applications with no viable alternative. The use of woody biomass for use in boilers for heating buildings and as a fuel for CHP plants was found to be an acceptable approach in the short to medium term when the resource available is underdeveloped. The two main reports considered for this were:

- The Bioenergy Review – Committee on Climate Change – December 2011
- The UK Bioenergy Strategy – DECC/DoT/Defra – April 2012

The conclusions of the work are still considered to be valid.

For the University this means that the main possibility for biofuel is the Easter Bush campus. This was reviewed in the previous report, with options for biomass boilers and biomass CHP considered. The biomass option offered lower carbon savings than a gas CHP option, due partly to the higher electrical loads than heat loads. Biomass CHP had very high capital costs and did not result in any return on investment over the life cycle cost period.

The biomass CHP option was developed further for an Scottish Funding Council innovation fund application, including potential for carbon capture and storage, allowing negative carbon emissions. The funding application was not successful. Due to the high costs and poor financial performance and the risks associated with what is a relatively unproven technology in the UK the project was not considered further at that point.

As the Easter Bush district heating scheme has been developed based on gas CHP at this time it is not suggested that biomass should be considered further. However, at the time when the plant requires replacement biomass should be included in the options. St Andrews University will soon have a large biomass CHP in operation and there will be other examples that can provide a better understanding of the technology by the time of the decision, and the concerns on reliability should hopefully be addressed through these schemes. Biomass for heat only could also be an option at that point, as CHP may no longer offer a carbon benefit.

Energy reduction measures

Appendix A contains the full list of energy reduction measures and comments on the ease of deployment in the University based on discussions with the Estates team. Amongst the favourable energy efficiency measures the following have been included for further discussion:

- Demand control ventilation
- Controlled environment set points - change to range / reduce
- Behaviour change (through SRS)
- Cold storage
- Demand Management / Smart Grid

For all the measures listed above, and other energy efficiency measures, it is difficult to identify the extent of possible energy / carbon savings or the likely costs associated with the works as these factors are site dependent. To give an indication we have used findings from our research on the deployment of similar measures in other universities where surveys have been carried out.

Demand Control Ventilation

This measure has been implemented at the University's main library at George Square. The aim of the measure is to use air quality sensors in mechanically ventilated spaces to monitor for pollutants and adjust air supply / extract volumes in direct relation to building occupancy levels. This requires sensors (often CO_2 based), controls between sensors and air handling units, variable speed drives on the fans and also the possibility to control the flow to each space if the air handling unit serves more than one area. The measure is most suitable where the occupation or pollutant production is variable and not easily predicted. The sensors tend to require recalibration regularly so there are some maintenance and operational implications. University of Cambridge have used this approach successfully in a Lab building, sampling air quality for CO_2, VOCs and other pollutants every 15 minutes. This makes the ventilation responsive to actual load. Users have reported an improvement in air quality and energy use has fallen significantly.

It is also possible to link the ventilation to occupancy sensors which can be effective where the occupation varies between unoccupied and a relatively constant occupation level, meaning there is less benefit from changing the fan speed and simplifying the controls. Occupancy sensors are generally reliable and do not need regular calibration. They can also be used to control lighting as well.

The extent of the savings possible depends on how well the current operation of the air handling unit is matched to the use of the space. If time schedules closely match the occupation and fan speeds have been commissioned to match the occupation levels then potential savings are limited. However, it is a major challenge in terms of resource commitment to keep time clock controls current there will often be a potential for savings.

To investigate this measure further would require the following:

- Identify buildings with mechanical ventilation where there is variable occupancy or variable pollutant levels and there is not a fixed ventilation requirement
- Carry out surveys to gather details of occupation hours, plant schedule, fan ratings, system design suitability for demand control
- Identify sensor and controls required to enable demand control; including which (if any) pollutants need to be measured
- Calculations on energy savings and costs to determine viability
- Engage with users to discuss their requirements

Costs for this are variable and to a certain extent depend on the type of sensor required. The Estates Department are looking into this and trying to establish a reliable supplier of sensors and control equipment. The payback period for this measure is expected to be favourable where the measure is considered worthwhile.

Controlled Environment Set-Points

Some locations require ventilation, heating, cooling and humidification plant to be running / available continually so the end result is high energy use. This measure investigates the set-points used in controlled environments to establish whether there is a possibility to change from a fixed number to a range or to reduce current set-points. One example where this approach has been successfully deployed is at University of Cambridge where this was introduced in their library archives. The process involved extensive consultation with user groups and visits to the Museum of Scotland, to demonstrate that this did not cause any issues in conservation terms and could be proved to work successfully. Animal rooms may also warrant a similar approach. Different species have different requirements so by reviewing on a room by room basis it may be possible to identify the extent and potential for savings.

To investigate this measure further would require the following:

- Identify locations with closely controlled environments
- Review plant settings against guidance / recommendations for use of space and consider potential for changes to the settings
- Discuss requirements with users; if required build a case to support the measure using examples from other locations that have had success with this measure
- Calculations on energy savings and costs to determine viability

There are no direct costs involved as there is no new plant or equipment required. However, this measure requires resource to carry out the required action and may require a significant time investment to gain support from the user groups. There will also be time required for updating BMS settings once new set points are agreed.

Behaviour Change

There is normally a reasonable amount of savings that can be achieved through addressing user behaviour, in particular shutting off equipment, lights etc. when not required. The way to address this is through engagement with the users and this needs to be a long term programme as often improvements are short lived before old habits are re-established. It was noted in discussions with the Estates Department that IT equipment already has power down controls enabled. Even with these settings there are savings to be made if users switch off computers and monitors when not in use. In labs there can often be equipment left on, sometimes this is required for experiments but not always. One University we are in contact with outside of this study is preparing switch off priority lists for each room, based on surveys, to identify items that can be switched off and the expected benefits / equipment ratings, to help facilitate this on a room by room basis. SRS already engage with users generally and there is a specific lab group that could tackle this issue in labs. The main requirement for implementation is staff resource to prepare materials, speak to users and identify items that could be switched off. There is also likely to be an opportunity in the student residences.

To investigate this measure further would require the following:

- Plan campaign to engage biggest possible audience
- Consider materials and communications channels

- Consider if surveys could improve outcomes
- Maintain campaign over the long term with changes in approach to keep interest

There is little cost involved, possibly some for supporting materials. This measure requires resource to carry out the required action and may require a significant time investment depending on the extent of the actions planned.

Cold Storage
The University has a large amount of cold storage, which will have a significant energy cost. This will include standard fridges and freezers in residential and office type buildings, to a wide range of equipment in laboratories and catering facilities also require significant cold storage. In general there is likely to be a significant opportunity to rationalise cold storage. This could include:

- Removing individual fridges from offices and providing one per corridor / floor
- Requiring regular audits of long term cold storage in labs
- Providing centralised cold storage for labs where practical
- Review storage temperatures – is -80^{o}C always required or could this be raised?

Where it is possible to remove multiple fridges / freezers and replace with shared facilities these can be larger and more efficient. The main barrier to this measure is acceptance by users who are unlikely to appreciate the additional time to collect items from shared facilities and the burden of reviewing and managing their storage. This requires leadership and resource to manage the process of identifying where the benefits can be found.

Demand Control / Smart Grid
There is increasing interest in demand control and smart grids, which offer the possibility to switch loads on and off to match available supply. This can be at campus scale for a university or it can be at grid scale, if sufficient loads can be operated by the grid to provide a useful balancing mechanism. For the first of these, the benefits at campus scale are particularly relevant if there is an onsite low carbon (or low cost) generation source. Demand control through a Smart Grid can allow the loads to be managed such that the low carbon generation asset can operate at full output as much as possible, thereby reducing the amount of grid electricity imported. This helps to smooth out the typical daily peaks in load. For intermittent renewable technologies which depend on weather conditions, time of day and other factors, loads can be shifted to match the predicted generation, within the limits of the type of load. Typical loads that can be used for this are refrigeration and heat loads. The Smart Grid approach would provide the intelligence to manage the loads, predict generation and balance the system to maximise the use of the low carbon supply in meeting the loads. Heat loads on district heating networks can also be managed, through the use of thermal storage for instance.
To investigate this option further, suitable loads would need to be identified. For the University of Edinburgh loads on the private wire networks should be the initial target to maximise the use of the CHP generation, although this is utilised effectively already, so might not be able to offer much additional benefit without an increase in capacity, which may be limited by the demand for heat.
It is also possible to off a demand control package to grid operators who will give payments for being able to switch off loads at times of peak demand. The University already participates in Short Term Operating Reserve (STOR), which offers payments for allowing generation assets to be switched on by the grid in times of peak demand and can also provide payments for demand response. There are further opportunities available for income through footroom (provision of load in times of high wind generation) and TRIAD (load response for the highest peaks in a year on the grid). These provide income but the carbon savings that result are not able to be reported through the current procedures.

Energy Reduction Summary
In terms of achieving carbon savings the most effective step that the University can take is likely to be providing dedicated resource to identify and drive through implementation of projects, as the barrier to many of the suggestions above and many of the others in Appendix A is resource related. Ideally this would be supported by a dedicated budget perhaps directly funded from savings made with project costs met from a revolving green fund.

Options Appraisal – Small Scale renewable energy

The results from the various options considered above are summarised in the following table, to ease comparison between options. Note the energy reduction options are not listed as we are unable to quantify the extent of measures without further survey information.

Option	CO_2 savings current (tCO_2)	CO_2 savings 25 year average (tCO_2)	Indicative costs (£)	Simple Payback Period (years)	£ / tCO_2 current	£ / tCO_2 25 year average
Heat Pumps						
ECA	64	180	821,500	24.0	12,800	4,600
Easter Bush	680	1,390	4,612,500	14.3	6,800	3,330
PV						
ECA	15	7	49,100	12.9	3,200	7,000
Estate wide roof installations	1,630	750	5,172,000	15.3	3,170	6,920
Solar Farm at Easter Bush	1,640	75	4,800,00	11.9	2,920	6,390
Fuel cell						
King's Buildings, including absorption chiller	850	-420	5,726,000	21.3	6,730	-

Note current is based on the current emissions factors and 25 year is based on the IAG factors for the next 25 years.

The energy reduction measures would be expected to be most cost effective as they have limited capital expenditure, only requiring resource allocation. The extent of the carbon savings is anticipated to be limited, with perhaps 10% of the overall emissions targeted as realistic and achievable. This might be possible if an extensive campaign was carried out and there was a reasonable budget set aside for the implementation of energy reduction measures. Energy audits have been reported to identify 20 – 40% savings on a building by building basis, but the costs and practicalities of implementation mean this would be very difficult to achieve across the entire University estate. Prioritising the buildings with the highest energy consumption for a programme of detailed audits followed by implementation of energy reduction measures is likely to achieve a good carbon saving.

The results show that the most cost effective measure in the short term is likely to be wind, which can also provide the best carbon savings. PV would be next in terms of cost effectiveness and carbon savings, if implemented at scale. Building by building integrated PV will lead to marginal carbon savings. It should be noted that the carbon savings will diminish over time due to grid decarbonisation.

The fuel cell option could be beneficial in the shorter term, but the costs for this are high in relation to carbon benefits. Carbon benefits for fossil fuelled technologies using natural gas will be subject to obsolescence in the medium to long term. There may still be an economic argument for such technologies over the longer term due to anticipated electrical unit cost increase required to fund wholesale decarbonisation of the grid or capacity constraints utility suppliers are forced to implement because of increasing demand generated by the transfer of heat load from fossil fuel sources to electricity.

Heat pumps have the highest cost per carbon saved at the current time but perform well against long term average emissions reductions. They offer increasing carbon benefits which are further enhanced as the grid decarbonises and will be an important part of the technology mix in the future. The projections used for grid decarbonisation are unlikely to be met so the carbon benefits will be over a longer period of time than this study suggests.

Conclusion

06

6. Conclusion

This report covers the work carried out to prepare business cases for energy reduction and renewable energy measures to reduce the carbon emissions for the University of Edinburgh. The University is falling behind on its carbon target of a 29% reduction by 2020, due to expansion and increased utilisation of the estate and rising student numbers. Major interventions are required or the carbon emissions target will not be met.

The work undertaken as part of this project included the development of a carbon assessment spreadsheet which will form part of the new business case template prepared by the University's finance department. This will allow future projects to be assessed on their carbon implications, as well as the current criteria of strategic fit, financial performance and tax. The spreadsheet is designed to be flexible so it can be applied to a wide range of projects and simple to use so project teams are able to complete it. It may require staff with carbon expertise to review the spreadsheets as part of the assessment of business cases, and in turn it could give SRS greater influence over the outcome of projects under review by including carbon as part of the decision making process. It also paves the way for additional assessments in future which might be extended to waste, water and other wider sustainability impacts.

Possible funding sources were investigated, through discussions with internal and external funders. This highlighted that the majority of projects are funded internally but external funding is used in some cases. Universities have access to finance at favourable rates through the EIB, SPRUCE programme and other Government sources. This will in general be preferable to other lenders / investors, although there are willing partners for projects that can demonstrate good returns. There are incentive schemes for renewable energy, although these are currently being scaled back. The capital costs for wind and PV have reduced sufficiently that this is no longer a barrier to implementation. For other technologies the implications of future changes to the subsidies landscape for new schemes should be carefully considered as projects develop.

A wide range of possible measures were considered for their carbon saving potential. Input was received from University stakeholders, including the Estates Department, on which measures have already been implemented and those of greatest interest. In terms of energy efficiency measures some of the most promising have been identified. However, without further detailed studies, including surveys, it is not possible to quantify the likely benefits as the range of variables is too great. Most of the measures identified require staff resource rather than capital expenditure to implement so the returns would be expected to be very worthwhile.

Of the renewable energy options considered, wind has the greatest potential to offset the University emissions in a single measure. However, there are questions that the University will have to consider as to whether it would be willing to take on an offsite wind asset, due to the lack of suitable sites within the estate. PV also has significant promise, if carried out at sufficient scale.

Heat pumps and natural gas fuel cell CHP have also been reviewed, with heat pumps giving increasing carbon benefits over the longer term. Presently their overall effectiveness from a cost and carbon perspective tends to be lower than fuel cells or CHP. Fuel cell and CHP technologies are becoming less effective potentially leading to no carbon benefit once the grid decarbonises sufficiently. If a non-fossil based fuel were available this picture might change.

Offsetting of emissions was considered, by reviewing how other large organisations have used this to claim carbon neutrality. The general pattern to emerge from this is that it is important to first reduce emissions as far as possible through energy reduction and onsite renewable energy, and only then consider the options for offsetting the remaining emissions. Any offsetting should be viewed from the perspective of paying for the carbon twice and its value considered accordingly. There are recognised accreditations for working towards carbon neutrality and for carbon offset providers, and were this to be considered as an option in the future, using recognised standards and suppliers is recommended. The costs for offsetting are favourable in terms of the cost per year per tonne of carbon, but this would be an ongoing cost for as long as the offsets were to be claimed.

It is recommended that the University consider how to resource the energy efficiency measures so these can be implemented, focussed initially on a programme of carbon reduction around the highest energy consuming buildings. It should then consider the renewable energy options in light of progress towards the carbon target and decide which measures it is willing to implement.

There are important considerations around the choice of technologies due to grid decarbonisation and the uncertainty in the rate at which this will progress. In the short term reducing electricity imported from the gird gives good carbon savings but as the grid decarbonises, emissions from other fuels become more prominent. This may suggest that the immediate focus should be on energy reduction relating to electricity use and implementation of onsite PV, while the large scale strategic options are considered, with a change in focus to reducing gas related emissions once the grid decarbonises enough to warrant a change in approach. The financial support available for different options through incentives, grants and other channels will not necessarily coincide with the aim of reducing the carbon footprint quickly and effectively so the various options need to be balanced in relation to the opportunities that income from an incentive scheme could bring, which could then fund further projects through a green fund.

Appendices

07

7. Appendix A

The following table gives a full list of the technologies initially considered and notes of the discussion with the Estates team.

Type	Category	Technology		Discussion notes	Responsible party
Energy reduction	Building envelope	Building fabric improvement	Insulate external building envelope where possible (roofs, walls, doors, floors) Roofs could be fitted with thermal insulation to reduce heat loss and improve control of comfort conditions for occupants. Insulate cavity walls.	Ongoing - typically during refurbishments / redevelopments; University standards require better than Government standards (T46 form)	project PM
		Improve windows	Where windows are single glazed, consider fitting secondary glazing to reduce heat losses in the winter and, to some extent, heat gains in the summer Repair seals and ventilators, install weather stripping, seal gaps between window frames and walls	As above; windows usually changed due to maintenance requirement not for energy only - long payback	project PM
		Draught proofing	Reduce uncontrolled air infiltration. Add draught lobbies to entrances, weather stripping on doors, automatic door closers on external doors, signs on doors reminding to close them, fast acting automatic door for high traffic areas, transparent plastic curtain doors for warehouse areas, make delivery entrances smaller. Seal exterior joints (between walls and roof and wall panels), seal openings at service penetrations (piping and electrical conduits) Fit external covers to outside air connections of window and all fans, air conditioners to prevent air infiltration when not in use	As above	
	Compressed air	Isolation valves and interlocks	Consider installing isolation valves and interlocks for certain supply branches to reduce system volumes, and minimise losses. Consider a programme of leak identification and repair	Limited compressed air so not major issue	

Type	Category	Technology		Discussion notes	Responsible party
	Controls	BEMs and controls	Where systems are not running according to expected operating patterns, recommission the controls and BEMS to bring systems back under control	This has been looked at and carried out in the past; main issue is resource as ongoing commitment required; 4no premises teams control this but not all staff may have awareness / knowledge of what set points should be to know if they are not an accurate reflection of building use	premises teams
		BEMS	BEMS energy audit to systematically review and update settings, set points and schedules with a specific focus on achieving energy savings whilst maintaining required accommodation standards		
		Controls	Replace controls where functionality is poor Reduce excessive operation (e.g. entire system for a few rooms) and unwanted operation of equipment (e.g. heating or air conditioning left on at night) Time control, temperature control, plant capacity control for part-load operation and excessive cycling Ensure there is a dead band between heating and cooling		
	Cooling	Chillers	Replace chillers and associated controls that have become inefficient through age (over 15 years old)	Cooling of science buildings is an issue Looking at set points / RH controls	
		Night set-back and purge cooling	Use mechanical or natural ventilation to pre-cool the building structure to reduce energy consumption for cooling during the day	Issues with accuators / security. Accuators on windows tend to fail as different manufacturers for window and accuator	
		Split units	Replace older split conditioning units, particularly those operating on R22	An issue with splits appearing that estates are not aware of	
		Split units	Review settings on split units, including time settings and temperature settings		
		Server room	Allow server room temperatures to be increased in line with modern guidelines and equipment manufacturer specifications	Doing this and organising to hot / cold aisles	
		Server room	Consolidate IT servers, and provide server room cooling using an existing condenser water circuit, rather than VC split units	Part way through doing this	

Type	Category	Technology		Discussion notes	Responsible party
	Domestic hot water (DHW)	HWS flow reducers, Sanitary areas	For toilet blocks, fit low-flow taps to reduce DHW demand, and presence detection to shut off water when the space is unoccupied.	As CHP requires load (in summer) DHW not major issue these considered as expensive & prone to failure (auto taps)	
		HWS electric point of use	Consider switching to point of use electric heating for outlets remote from the central point. Replace centralised systems with point of use where low DHW demand.		
	Equipment	Fridges & freezers	Review fridges & freezer contents, and consolidate storage where possible	Not tackled this yet Might be possible to replace -80 freezers with -70 or even -40 freezers	SRS Lab Group
		Fridges & freezers	Efficient freezer management (freezer farm)		
		Fridges & freezers	Where possible, install motor-loss controllers on compressor motors - for fridges & freezers, split units, chillers and compressed air systems		
		Lab equipment	Ensure all lab equipment is turned off when not in use, and that multiple devices are not used when one would suffice	SRS have lab group to look at this	SRS
	Heat recovery	Heat recovery, AHUs	Install heat recovery run-around coils to AHUs to reduce demand for heating and cooling in the system	On all new AHUs, hard (expensive) to retrofit	
		Heat recovery, server rooms	Heat recovery from server rooms	Location makes this difficult	
	Heating	Boiler	Consider replacing older, inefficient boiler plant	Doing this, also CHP	
		Heating plant insulation	Install additional thermal insulation to plant and pipework in plant rooms and other relevant areas		
		Low pressure hot water (LPHW)	Where old inefficient heating systems are present, install new LPHW distribution including the replacement of all required components to control and distribute unvented, low temperature hot water throughout buildings. Add VSDs as appropriate	VSDs added	
		Perimeter heating and controls	Where condition is poor, recondition perimeter natural convectors and redesign and replace associated controls including modern TRVs		
		Hot water thermal insulation	Insulate cylinders and pipework	Already in place	

Type	Category	Technology		Discussion notes	Responsible party
	Heating and cooling	Split units	Commission local controls with time schedules, wider dead bands, night setback. Install interlocks with other split systems, central HVAC, and openable windows	Ongoing but splits appear without estates knowledge, very difficult to control	
	Humidification	Electric steam humidifiers	Review AHU humidification requirements in conjunction with requirements for spaces served. Implement alterations to control systems to minimise or even eliminate use of electric steam humidifiers.	All large units changed to adiabatic, with good savings	
		Electric steam humidifiers	If humidification requirement remains (after reviewing humidification requirements and controls), consider switching to gas-fired steam generator due to lower cost of fuel and GHG emissions.	See above	
	Lighting	Upgrade lighting systems	Upgrade lighting systems where possible, e.g.T12/T8 to T5 fluorescent tubes, and GLS / halogen to CFL / LED equivalents		
		PIRs, timers, energy awareness	Install PIRs, timers, etc. and improve energy awareness for switch off when lights are not required		
		Improve natural lighting	Use sun pipes to five additional daylight penetration, and light shelves to enhance penetration of daylight into office areas	Limited use of these	
		Reduce solar gain	Add solar shading (awnings, shutters, solar blinds)	More for new build	
		Car park	Replace car park lighting with newer LED equivalents. Include timer or daylight-sensing controls	All LED	
	Maintenance	Energy efficiency	Air conditioning inspections, planning maintenance, maintenance contracts, monitoring maintenance		
	PCs	Switch off	Some PCs may need to be left on for research purposes, however there could be significant opportunity to reduce demand by encouraging users to switch off at the end of the working day. In	Information Services has rolled out auto shut down etc to PCs SRS – may run campaigns on this	SRS

Type	Category	Technology		Discussion notes	Responsible party
			addition or alternatively, it may be possible to implement some centralised software or script which monitors when a workstation has been left on but is idle for long periods, and then puts the machine into a low power or sleep state until user intervention to switch back on.		
		Low power	Ultra low-power computers (E.g. Chrome PCs)		
		Policy	Establish a purchasing policy to introduce lower-energy using computers, make use of energy saving features, introduce a switch-off policy at night and weekends		
	Variable speed drives (VSD)	Motors, pumps, and fans	Add VSDs to motors, pumps, and fans	Already in place	
	Ventilation	Ventilation	Review the required air change rates in occupied spaces and labs.	Ventilation is a huge opportunity - demand response already added to library, can be added to many other spaces Some areas difficult to tackle, e,g, animal rooms but may be flexibility in guidance possibilities for fume cupboards - e.g. southampton, cambridge SRS lab group - tackle fume cupboards, user behaviour change	
		Natural ventilation	Consider using external air at night for cooling		
		Ventilation control - enthalpy	Consider enthalpy control to reduce energy consumption. Enthalpy sensors detect cooling capacity of external air and modulate dampers to draw in more air than the basic fresh air requirement.		
		Lab fume cupboards	Ensure all lab fume cupboards are switched off or to minimum flow when not required. Use automatic or timed ramp down control.		SRS
		AHUs	Where performance is poor, overhaul AHUs including air intakes, filter and fan housings, heater and chiller batteries, the associated controls, fans, motors, mountings, etc. Include addition of VSDs		
	Zoning	Building zoning for use and access	Review and update building zoning for systems including heating, cooling, lighting, and controls to reflect the activities of building occupants	University policy is 24/7 campus so zoning not helpful and often difficult to get the benefits, but with better information, e.g. occupancy sensing / CO_2 sensing might be more useful	
		HVAC zoning controls	Install controls to enable improved zoning of HVAC systems		
		Lab usage ratios	Lab usage ratios (the era of one lab per researcher	SRS lab group	SRS

Type	Category	Technology		Discussion notes	Responsible party
			has gone). May be difficult to change		
	Behaviour Change	Windows	Encourage staff not to open windows when heating or air-conditioning systems are operating to reducing losses	SRS behaviour change	SRS
		Splits	Encourage staff not to alter settings on splits, and only to use when necessary.		
		Controls	Encourage staff to switch off HVAC / ventilation plant equipment locally where practical when spaces are not in use		
	Servers / Data Centres	Consolidate servers	Consider consolidating server provision to a purpose built data centre building with highly efficient cooling system	Doing this as mentioned above	
	Rationalisation	Space use	Consider opportunities for rationalisation of the estate that could reduce energy use through a reduction in space requirements or shift to more efficient buildings where for high demand activities	This is tackled by Estate Development	
Travel & Transportation		Reduction in commuting energy use	Develop estate wide travel plans. Incentives for public transport, walking, cycling. Incentives for car sharing and low CO2 cars	This is tackled by default by number of parking spaces being reduced	
		Business travel	Policies around car hire, and travel around and between campuses. Bike hire schemes, shuttle buses, etc.		
		Coordinate international travel - limit participation to conferences (1 or 2 instead of several)		SRS	SRS
		Measure-ment	Set up a process for monitoring transport emissions - Scope 3		
		Consolidate orders by campus to reduce deliveries			
		Electric fleet vehicles		Have some electric vans - works well as charged by CHP in quieter periods few pool cars but use city car club	
		Biofuel fleet vehicles			
		Hydrogen fuel cell fleet vehicles			

Type	Category	Technology		Discussion notes	Responsible party
		CGN fleet vehicles	CGN, Compressed natural gas, is methane stored at high pressure		
Energy Storage		Batteries		Electricity storage could be a benefit but current costs high / technologies not proven	
Note options in italics are still in research and development stages and not suitable for immediate implementation		Electric vehicle to grid (V2G) technology			
		Pumped hydro	Unlikely at University scale		
		Hydrogen			
		Flywheels			
		Super-conducting magnetic energy storage (SMES)		Not at present	
		Super-capacitors			
		Embedded storage (building level)			
		Cryogenic energy storage			
		Underground thermal energy storage			
		Thermal storage (buffer vessels)		Already used on CHPs	
		Seasonal thermal energy storage (STES)	Store solar energy in summer for space heating during winter		
Low / Zero Carbon Energy Generation		Biofuels, biogas generation	Generation by Anaerobic Digestion	Reviewed in previous AECOM study and waste streams not sufficient / food waste collections in Edinburgh now	
(all scales)		Syngas	Synthesis gas produced by gasification of materials such as coal or waste. Syngas is used as a fuel source		
		Gas fired CHP	Natural gas and / or biogas. Could be mini/micro scale (building level) or large (site level, possibly with district heating)	Already in place	
		Biomass CHP		Funding application unsuccessful	
		Biomass boilers		Not permissible within Edinburgh	
		Heat pumps	Heat pumps may be air-source, water-source, and/or ground-source heat pumps	GSHP at SCRIM which had issues to begin but now working better Possibility for the ECA?	
		Solar CSP (concentrated solar power)			

Type	Category	Technology		Discussion notes	Responsible party
		Solar thermal panels		a few	
		Solar photovoltaics (PV electricity) - building and site scale		Limited at present and not working brilliantly	
		Solar photovoltaics (PV electricity) - commercial site scale	On University land outside of Edinburgh, or investment in commercial operation	no interest if using agricultural land	
		Tidal power - energy generation			
		Hydro electricity			
		Wind turbines - commercial scale	On University land outside of Edinburgh, or investment in commercial operation		
		Wind turbines - building / site scale			
Efficiency of energy supply		District heating network		Already in place	
		Low temperature (i.e. 4th gen) district heating network		Moving towards this as buildings are refurbished	
		Cooling network		Already in place at George Square and built in at Easter Bush; possibility for King's Buildings	
		Low voltage / DC electricity network			
Energy monitoring and control	Distribution automation	Distributed intelligence			
		Systems to capture data in real time			
		Visible power meters showing energy usage in buildings		6 or 7 of these in place	
		Enhanced remote control		can do via BMS	
		Active network monitoring		Participate in STOR - trial with 1 at present	
		Dynamic asset rating			
		Outage management / supply restoration			
		Preventative maintenance / asset monitoring			

Type	Category	Technology	Discussion notes	Responsible party
		Low voltage network monitoring and control		
	Distributed generation	Voltage and volt-ampere-reactive optimisation (VVO)	Control this on the private wire by volt tapping at transformers	
		Enhanced monitoring & control schemes		
		Enhanced automatic voltage control (EAVC)		
	Metering, Monitoring & Targeting	Data collectors / concentrators		
		Aggregators (distributed energy sources)		
		Demand side management	Worth reviewing - Glasgow Caledonian do via Open Energy involved in TRIAD; Possible to control load shedding through the BMS; if limit is 50kW University could participate independently Telemetry costs high so need existing BMS link to make it worth while	
		Regular analysis for over-consumption	Not done - resource for this an issue	
		Awareness campaigns		
Smart products	Appliances and packaged systems		Not yet	
		Smart meters		
		Smart asset management		
		Smart domestic appliances		
		Remote smart controls		
		Energy monitoring packages		
Other innovation				
		Centralised logistics hub for materials produced and waste out		

Type	Category	Technology		Discussion notes	Responsible party
		Sustainable, local food growing - trees bushes, etc.	May include carbon sequestration in living biomass (trees) as well as biodiversity and ecosystem services		
		Link between local farms and catering			
		Accelerated carbonation (building bricks) - research			
		Repair and refurbishment hub			
		Symbiotic processes			
		Encourage biodiversity on campus			
		Info displays on technological solutions in suitable buildings		Tried in Asham Court but not working well - little benefit	
		Location markers e.g. at George Square showing local effect of say 3 degree rise in temperature			
		Negotiate with suppliers to reduce packaging			
		Safe sustainable labs			
	Building fabric	Phase change materials	Thermal mass is part of passive solar heating design. Phase-change materials increase thermal mass without adding weight or bulk		

Appendix B

1. Introduction

This report provides a preliminary review of land within the Edinburgh University estate for potentially developing geothermal energy.

2. Background to Geothermal Resources

Geothermal energy is the vast amount of heat energy that exists within our planet. The Scottish Government considers geothermal to have a role in meeting our climate change targets and previously commissioned AECOM to carry out a study into the potential for deep geothermal energy in Scotland[24]. The report classified geothermal resources in Scotland in terms of three main geological settings: abandoned mine workings (low temperature), hot sedimentary aquifers (low and possibly relatively high temperature), and hot dry/wet rocks or 'petrothermal' sources (relatively high temperature). The areas of geothermal potential identified in AECOM's report are included in the Scottish Government's Scotland Heat Map.

Abandoned mine workings potentially increase the mass permeability within the mined strata, allowing enhanced groundwater flow, which in turn allows extraction of low-grade heat from greater volumes of water. The British Geological Survey (within the AECOM deep geothermal report) found that it would be reasonable to expect a yield of about 10 litres per second in mining-enhanced aquifers. The report found a compilation of mine water temperatures for boreholes in the Midland Valley to have a median temperature of 17°C, however, this may not accurately reflect the higher temperatures that may occur in some of the deepest mine workings in Scotland.

Hot sedimentary aquifers are bodies of permeable rock that can conduct significant quantities of groundwater that are hot enough and have sufficient productivity to constitute a potential geothermal resource. The Scottish Government report found these geothermal resource are likely to exist, in general, down to depths of around 4km, and most will yield water in the temperature range 20 to 80°C (or potentially higher). It should be noted that sedimentary aquifers are incorrectly referred to as "Hot Wet Rocks" in the Scotland Heat Map.

For petrothermal resources, heat is extracted from 'dry' crystalline rocks by fracturing them at significant depth (circa 4 to 5km), injecting cool water into the hot fractured rock, and extracting the resulting heated water. This technology is in its infancy and there are significant risks related to its development. Ground source heat pumps (GSHPs) can be used to extract heat from the relatively sub-surface. This heat is a combination of solar-derived heat and geothermal heat. GSHPs can be used across a range of geology.

Ground source heat pumps (GSHPs) can be used to extract heat from the relatively shallow sub-surface. This heat is a combination of solar-derived heat and geothermal heat. GSHPs can be used across a range of geology. GSHPs are best suited to serving the needs of an individual building.

3. Methodology

British Geological Survey (BGS) maps were analysed to determine the underlying bedrock geology. The Scotland Heat Map was consulted to identify any areas of possible geothermal resource. The results were cross-checked with the Coal Authority's mapping of former mine workings.

4. Assessment

Table 1Table 3 below indicates that the Edinburgh University estate is underlain mainly by sandstone which ranges from intermediate to moderate permeability.

The Scotland Heat Map indicates that the majority of the estate (within the City Bypass) is not underlain by former mine workings.

No petrothermal resources have been identified in the Edinburgh area.

The Little France area is within a Coal Mining Reporting and Surface Coal Resources area. The Coal Authority Interactive Map indicated that the area is adjacent to an area of probable shallow coal mine workings, defined as coal workings whose depth is 30m or less from the surface. Former mine workings may be present at greater depth in the Little France area.

The Scotland Heat Map indicates the western half of Kings Buildings is underlain by a sedimentary aquifer however the BGS GeoIndex indicates the western half is underlain by igneous Basalt and Andesite. It is possible that the sedimentary aquifer underlies the igneous bedrock.

The Heat Map indicates abandoned mine workings are potentially present at approximately 380 – 560m depth at Easter Bush and Bush Estate. The Coal Authority Interactive Map indicated probable former shallow workings, defined as coal workings whose depth is 30m or less from the surface, at the south east of the Bush estate. There is therefore potential for the aquifer here, which is rated as being moderately permeable, to have enhanced permeability.

[24] Scottish Government, 2013, "The potential for deep geothermal energy in Scotland"

5. Ground Source Heat Pumps

There is the potential for deploying ground source heat pumps, installed in boreholes or in relatively shallow trenches (ground collectors). Boreholes and ground collectors can generally be installed to fit in with other infrastructure, under a car park for example. Depending on the scale of the GSHP system, either estimates can be made on the likely output or testing can be undertaken to determine the output.

6. Conclusions and Further Work

The majority of the Edinburgh University estate has limited potential for geothermal energy.

However, this study has identified the possible existence of a sedimentary aquifer underlying the western half of Kings Buildings. The depth, temperature and permeability/productivity of the aquifer is unknown but it may be suitable for development. It may be suitable for development either with GSHP borehole based system or a deeper geothermal borehole(s).

The potential mining-enhanced aquifer underlying the Easter Bush and Bush Estate also potentially warrants further investigation. This would include intrusive Site Investigations (SI) where exploratory boreholes are drilled with the objective of determining yield flows and the water chemistry, which has a major impact on the specification of the system. It may be suitable for development with a deeper geothermal borehole(s).

There is also the potential for deployment of GSHP type systems more widely across the University estate.

	BGS GeoIndex		Hydrogeological Map of Scotland		Coal Authority Interactive Map				Scotland Heat Map					GSHP
Area	**Bedrock Geology**	**Superficial Geology**	**Productivity**	**Permeability**	**Coal Mining Reporting Area?**	**Mine Entries?**	**Past Shallow Coal Workings?**	**Probable Past Shallow Coal Workings?**	**Hot Wet Rocks?**	**Hot Dry Rocks?**	**Abandoned Mine Workings**	**Development High Risk Area?**	**Surface Coal Resources Area**	**GSHP Potential**
Central Area	Sandstone incised with Microgabbro sills and dykes.	Till, Devensian – Diamicton	Lower and Middle Old Red Sandstone highly productive aquifer. Flow dominantly in fissures and other discontinuities. Borehole yields are moderate and 5 l/s is exceptional.	Moderate	No	No	No	No	No	No	No	No	No	Yes
Lauriston Campus	Ballagan Formation - Sandstone	Till, Devensian – Diamicton		Moderate	No	No	No	No	No	No	No	No	No	Yes
Warrender Park	Kinnesswood Formation - Sandstone	Till, Devensian – Diamicton		Moderate	No	No	No	No	No	No	No	No	No	Yes
Kings Buildings	Kinnesswood Formation Sandstone underlying eastern half. Blackford Hill member Olivine-Basalt and Andesite underlying western half.	Till, Devensian – Diamicton		Highly (Intermediate soil class)	No	No	No	No	Underlying western half of site.	No	No	No	No	Yes
Peffermill Playing Fields	Kinnesswood Formation - Sandstone	North of railway: Lacustrine deposits – Clay, Silt and Sand South of railway: Glaciofluvial ice contact deposits – Sand and Gravel	Carboniferous highly productive aquifer. Flow dominantly in fissures and other discontinuities. Boreholes yields generally moderate and Not greater than 10l/s.	Highly (Intermediate soil class)	No	No	No	No	No	No	No	No	No	Yes
Gilmerton Road	Kinnesswood Formation - Sandstone			Highly (Intermediate soil class)	No	No	No	No	No	No	No	No	No	Yes
Little France	Hopetoun Member – Sedimentary rock cycles, Strathcylde group type.	North of track: Glaciofluvial ice contact deposits – Sand and Gravel South of track: Till, Devensian – Diamicton		Highly (Intermediate soil class)	Yes	No	No	No	No	No	No	No	Yes	Yes
Western General Hospital	Craigleith Sandstone and Gullane formation - Sedimentary rock cycles, Strathcylde group type.	Till, Devensian – Diamicton		Moderate	Yes	No	No	No	No	No	No	No	No	Yes
Easter Bush	Hopetoun Member – Sedimentary rock cycles, Strathcylde group type	Till, Devensian – Diamicton		Moderate	Yes	No	No	No	No	No	380m – 560m	No	Yes	Yes

	BGS GeoIndex		Hydrogeological Map of Scotland		Coal Authority Interactive Map				Scotland Heat Map					GSHP
Area	**Bedrock Geology**	**Superficial Geology**	**Productivity**	**Permeability**	**Coal Mining Reporting Area?**	**Mine Entries?**	**Past Shallow Coal Workings?**	**Probable Past Shallow Coal Workings?**	**Hot Wet Rocks?**	**Hot Dry Rocks?**	**Abandoned Mine Workings**	**Development High Risk Area?**	**Surface Coal Resources Area**	**GSHP Potential**
Bush Estate	Hopetoun Member – Sedimentary rock cycles, Strathcylde group type	Western half: Glaciofluvial sheet deposits – Sand and Gravel Eastern half: Till, Devensian – Diamicton		Moderate	Yes	No	No	At south-eastern extent of estate	No	No	380m – 560m	No	Yes	Yes
Langhill Farm	Limestone including Coal Formation	Till, Devensian – Diamicton		Moderate	Yes	Mine entry to north of Bilston Burn	No	Area to north of Bilston Burn	No	No	740m – 920m	Yes	Yes	Yes
Firbush	Schist	Till and Morainic deposits (undifferentiated) – Diamicton, Sand and Gravel	Impermeable rocks generally without groundwater except at shallow depth.	Weakly	No	No	No	No	No	No	No	No	No	Limited

Table 3 Geothermal summary

Appendix C

Data used in figure 4. Heat eff and elec eff refer to heat and electrical efficiency of the plant. Numbers are the emissions factors in $kgCO_2$ / kWh for each technology based on the IAG projections for grid average emissions for public sector given in the last row of the table.

	heat eff	elec eff	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Gas boiler	0.85		0.217	0.217	0.217	0.217	0.217	0.217	0.217	0.217	0.217	0.217	0.217	0.217	0.217
Heat pump COP 2	2		0.23225	0.181612	0.17477	0.164975	0.14282	0.12771	0.114626	0.105985	0.100473	0.08938	0.080763	0.067593	0.062256
Heat pump COP 3.5	3.5		0.132714	0.103778	0.099869	0.094272	0.081612	0.072977	0.065501	0.060563	0.057413	0.051074	0.04615	0.038625	0.035575
CHP 25%	0.53	0.25	0.128915	0.176687	0.183141	0.192382	0.213283	0.227538	0.239881	0.248033	0.253233	0.263698	0.271828	0.284252	0.289287
CHP 35%	0.43	0.35	0.050872	0.133306	0.144444	0.160389	0.196455	0.221054	0.242352	0.256419	0.265393	0.283451	0.297479	0.318918	0.327607
CHP 42%	0.36	0.42	0	0.088599	0.104564	0.127418	0.179114	0.214371	0.244899	0.265062	0.277924	0.303808	0.323915	0.354644	0.367098
Biomass	0.85		0.015529	0.015529	0.015529	0.015529	0.015529	0.015529	0.015529	0.015529	0.015529	0.015529	0.015529	0.015529	0.015529
IAG Grid Emissions			0.464501	0.363224	0.349541	0.329951	0.285641	0.25542	0.229253	0.211971	0.200946	0.17876	0.161525	0.135186	0.124511

	heat eff	elec eff	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
Gas boiler	0.85		0.217	0.217	0.217	0.217	0.217	0.217	0.217	0.217	0.217	0.217	0.217	0.217
Heat pump COP 2	2		0.067593	0.062256	0.055107	0.056447	0.054745	0.050401	0.042864	0.035909	0.030467	0.02751	0.029619	0.026748
Heat pump COP 3.5	3.5		0.038625	0.035575	0.03149	0.032255	0.031283	0.0288	0.024494	0.020519	0.01741	0.01572	0.016925	0.015285
CHP 25%	0.53	0.25	0.284252	0.289287	0.296031	0.294767	0.296372	0.300471	0.307581	0.314143	0.319276	0.322066	0.320076	0.322785
CHP 35%	0.43	0.35	0.318918	0.327607	0.339244	0.337063	0.339833	0.346906	0.359174	0.370497	0.379355	0.38417	0.380736	0.38541
CHP 42%	0.36	0.42	0.354644	0.367098	0.383777	0.380652	0.384622	0.394759	0.412344	0.428574	0.441271	0.448171	0.44325	0.449949
Biomass	0.85		0.015529	0.015529	0.015529	0.015529	0.015529	0.015529	0.015529	0.015529	0.015529	0.015529	0.015529	0.015529
IAG Grid Emissions			0.135186	0.124511	0.110215	0.112894	0.109491	0.100802	0.085729	0.071818	0.060935	0.05502	0.059238	0.053496

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