Programme Area: Distributed Energy

Project: Macro DE

Title: An Assessment of the GB Benefits Associated with Potential DE Technology Development

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Abstract:

Please note, this document was produced in Sept 2012 and the contents of the report may now be out of date.
This report summarisies the output from work package 5, whose objective is to identify how technology development can support the potential for DE across GB. In particular, it aims to examine the following:

- Establish the role which novel technologies may take and the importance of novel technologies for DE nationally.
- Identify the key novel technologies for future technology development and commercialisation which may have a large impact on the macro DE potential.
- Understand the high level impacts of the novel technologies on existing and new supply chains, in particular in relation to availability of biomass and waste.

Context:

This project quantified the opportunity for Macro level Distributed Energy (DE) across the UK and accelerate the development of appropriate technology by 2020 for the purposes of significant implementation by 2030. The project studied energy demand such as residential accommodation, local services, hospitals, business parks and equipment, and is developing a software methodology to analyse local combinations of sites and technologies. This enabled the design of optimised distributed energy delivery solutions for these areas. The project identified a number of larger scale technology development and demonstration projects for the ETI to consider developing. The findings from this project is now being distilled into our Smart Systems and Heat programme. The ETI acknowledges that the project was undertaken and reports produced by Caterpillar, EDF, and the University of Manchester.

ETI Macro Distributed Energy Project

Work Package 5, Task 5.3

An assessment of the GB benefits associated with potential DE technology development. FINAL REPORT

September 2012

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Executive Summary

Introduction

The UK Government's Climate Change Act (2008) sets a legally binding target of 80% reduction in CO_2 emissions from 1990 levels by 2050. Meeting this target will require action across all energy consuming and carbon emitting sectors to reduce energy demand and provide energy more efficiently and from lower carbon sources.

This Macro Distributed Energy (DE) Study for the ETI aims to examine the role that DE could have in Great Britain (GB)[1] in providing low carbon and low cost heat to buildings. The work examines schemes of up to 50 MWe CHP capacity, representing large scale networks which would cover a significant part of towns and cities. The key aims of this work are to:

- understand the technologies, tools, and skills available for DE deployment in GB and where gaps exist;
- identify areas which may be suitable for DE schemes;
- assess the performance of schemes using a range of technologies in these areas in terms of cost, and CO_2 savings;
- calculate the GB benefits case with mass deployment of DE.

Methodology

This report is part of work package 5 (WP5) and provides results and analysis from work package 5.3 which aims to identify how technology development can support the potential for DE across GB. In particular, it aims to examine the following:

- Establish the role which novel technologies may take and the importance of novel technologies for DE nationally.
- Identify the key novel technologies for future technology development and commercialisation which may have a large impact on the macro DE potential.
- Understand the high level impacts of the novel technologies on existing and new supply chains, in particular in relation to availability of biomass and waste.
- Identify whether expected improvements in performance or reductions in costs of existing technologies could materially alter the conclusions from the WP5.1 results

The technologies considered in this report include:

- The 'conventional' technologies considered in the WP 5.1 assessment and WP 3.2 technology library.
- Fuel cells
- Solar thermal
- Large scale heat pumps using elevated temperatures
- Gas turbines
- Dual fuel engines
- Combined cycle gas turbines
- Biomass CHP (gasification and steam turbine)
- Biomass boilers

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[1] The project has been limited to Great Britain as data from which heat demands could be predicted was not available for Northern Ireland (see WP2 report)

- Anaerobic digestion
- Energy from waste (incineration)

The assessment in this report is split into stages, which are used to examine and promote different technology types. The initial stages proposed for the assessment were:

- **Stage 1: All technology options.** Macro DE schemes are optimised for each of the 20 CZs with a full technology library, allowing the optimisation tool to select any technology. This allows the developing technologies to compete against the more established technologies examined previously in WP 5.1.
- **Stage 2: A future with limited availability of natural gas.** This stage again optimises macro DE schemes for each of the CZs, but removes natural gas prime-movers from the technology library to reflect a scenario where natural gas becomes more scarce or expensive and alternative options are required. Natural gas back up boilers are retained on the basis that their contribution will be relatively small (allowing the use of gas) and they provide a low cost back up and peak source.
- **Stage 3: Investigation of individual technologies.** The previous stages allow the open selection of technologies across all CZs. This final stage assesses individual technologies on a reduced set of CZs to examine the costs and environmental performance, and the barriers which need to be overcome for the technology to be competitive.

Conclusions

The analysis of developing technologies in this report demonstrates that there is a strong role for macro DE to provide heat in urban areas into the future. In the 2010s and 2020s, the results demonstrate natural gas engine CHP schemes will remain the most economic solution out of all the technologies for large scale deployment.

The original aims of this study were to examine how less mature and novel technologies could support the future development of macro DE. The analysis in this report covers many areas with wide ranging conclusions, but specifically in relation to the project aims, succinct conclusions can be drawn:

Aim 1: Establish the role which novel technologies may take and the importance of novel technologies for DE nationally.

The analysis demonstrates that in the shorter term (2010s), there is a small role for some novel technologies but based on cost and performance combined with fuel and resource constraints, gas-fired CHP is likely to be the preferred technology enabling widespread deployment of up to 43% of the heat market. In the 2030s, the reducing CO_2 intensity of the electricity grid means that the CO_2 savings from gas CHP will become marginal, and the role of novel technologies becomes more important.

The most economic technology identified, suited to wide scale deployment, other than gas-engine CHP is large scale heat pumps provided an elevated temperature heat source (c30℃) is available. These provide a more cost and carbon efficient solution to individual building Air Source Heat Pumps (ASHPs), demonstrating that in a future with limited natural gas use, the combination of macro DE with large heat pumps offers the optimal solution for urban areas, being cost effective for most zones. The performance of the heat pumps depends on the availability of elevated temperature sources which could include industrial processes, mines water, or power generation condenser circuits. The modelling demonstrates that through using elevated temperature heat pumps (which make use of waste or excess heat), alongside gas CHP with an emission constraint of 50% reduction from the gas boiler counterfactual, virtually all CZs remain economic. It is recommended that further work examines the potential of these sources and their locations in relation to the zones.

Large heat pumps, both at an elevated temperature and at temperatures closer to ambient (from WP 5.1 analysis) provide a transition option from gas engine CHP schemes, towards a long term option. They also could potentially operate in tandem with gas CHP systems to allow optimisation of generation technology with the heat pumps operating when there is surplus low carbon electricity on the grid, and the gas engines when there are low levels of renewable grid generation in combination with peak demand periods. It is recommended that further work is conducted to examine how these 'smart heat grid' macro DE schemes could operate.

Out of the remaining technologies, Combined Cycle Gas Turbine (CCGT) CHP and Energy from Waste (EfW) offer the most economic solutions with the greatest potential. CCGT systems can be used in heat led modes with smaller systems, or with heat off-take from larger schemes, which may also be suited to Carbon Capture and Storage (CCS). Given the long term UK Government predictions for CCGT on the electricity grid, and the potential for using CCS, it is recommended that heat off-take options are examined in more detail. Where smaller CCGT units are used in a heat led macro DE scheme, the lack of modularity and load following means that there is only a marginal benefit over gas engine schemes even though the electrical efficiency is slightly higher..

Aim 2: Identify the key novel technologies for future technology development and commercialisation which may have a large impact on the macro DE potential.

The analysis in this report shows that the most suitable 'novel' technologies are in fact systems which have a large degree of maturity, and which are already used in some macro DE schemes.

Heat pumps in particular offer a flexible option, especially when a higher than ambient temperature source is available allowing improved Coefficient of Performance (CoP). There are no direct fuel or feedstock constraints, although, clearly, access to electricity will be important and widespread deployment will increase the need for low carbon grid generation. On the other hand, the increase in load provided by the heat pumps could provide a useful sink in times of excess renewable generation, which would be enhanced if storage in the form of heat is included. Heat pumps with large-scale storage would also enable heating demands to be managed over the day to avoid high peak demands on the grid. It is therefore recommended that further work examines the technology development of heat pumps, alongside the technical design and operation protocols of District Heating Networks (DHNs) to allow operation at lower flow temperatures with the aim of improving overall CoPs of large units,. It will also be important to identify and assess the viability of waste / excess heat sources for use with heat pumps.

Energy from Waste has also been identified as a technology which could have an impact on the macro DE potential. A detailed study of waste resource was outside the scope of this study, but the high level data analysed suggests that a useful fraction of the overall macro DE potential can be met using energy from waste systems with household waste alone. A key consideration of EfW is the calculation of CO_2 emissions, in the context of alternative waste management and disposal options and further work needs to consider this. The EfW systems examined in this work are based around incineration, and alternative treatment forms could offer additional benefits and should also be considered in future work.

Aim 3: Understand the high level impacts of the novel technologies on existing and new supply chains, in particular in relation to feedstock and waste outputs.

Anaerobic digestion (AD) systems could provide a more cost optimal solution where the opportunities exist. However the feedstock is extremely limited in relation to the heat demand, and the location of feedstock and digestate disposal needs considering in addition to proximity to heat loads. In reality, these constraints, combined with land take requirements, may mean that more localised DE deployment of AD is likely to be more practical, potentially not connected to DHNs. Future work should examine how access to feedstock can be maximised, and whether there are opportunities for growing dedicated feedstock, but the overall feedstock constraint will remain significant.

Biomass is not predicted to be a significant component of macro DE schemes in GB. Whilst boilers can be used to develop economic and low carbon schemes in the near term, there are significant concerns over the potential fuel available for macro DE and the sustainability of the supply chain in the longer term. The Committee on Climate Change has highlighted that stationary heat and power applications are one of the less useful applications for the limited biomass resource available[2]. Their preferred applications are industrial heat and aviation and shipping. Our modelling demonstrates that current biomass CHP systems are much less cost effective than biomass boilers and small scale systems have a very limited benefit. However much larger biomass CHP systems with heat off-take would be more efficient and can be equipped with CCS to increase the benefits.

Aim 4: Identify whether expected improvements in performance or reductions in costs of existing technologies could materially alter the conclusions from the WP5.1 results

The analysis in this report suggests that technologies which offer the best potential for macro DE other than gas CHP are large heat pumps, EfW, and CCGT heat off-take. All of these technologies are relatively mature and used in both the UK and other countries. Therefore the barriers appear not to be technological development and cost (although reductions in cost will improve economic viability), but many of the other barriers discussed in WP1 and WP 5.4 which prevent their use or uptake. Therefore further technical improvements are unlikely to improve their uptake further and efforts should be concentrated on overcoming the other barriers. Examples include identification and securing of waste feedstocks and waste heat, addressing public perception issues around the location of technologies (EfW), ensuring that the technologies are suitable located (for example, that all new CCGT systems with CCS are built near urban areas with potential for DHNs) and potentially introducing regulation which enables strategic decisions to be taken around the co-location of technologies with DHNs.

For technologies where the level of maturity is lower, the potential for use in macro DE appears to be relatively limited. In the case of biomass technologies, in particular CHP systems, there is widespread acceptance that the current smaller systems are immature and not performing as desired. However, even with extensive development, the feedstock availability constraints will remain, fundamentally limiting the uptake of macro DE.

Fuel cells are another example of a technology which is relatively immature and where there is further scope for technical development. However, the increase in economic lifetime of small scale gas-fired CHP offered by fuel cell technology over gas-engines is limited, and significant cost reductions and technological improvements are required in a very short time to enable fuel cells to contribute to macro DE before the grid is decarbonised and the benefits of gas-fired CHP are lost. If alternative fuels such as hydrogen are to be used, then there are wider issues around the development of new energy vector fuel supply chains and infrastructure, and the efficiencies of generating hydrogen and corresponding increase in electricity demand.

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[2] Chapter 4, Bioenergy Review, Committee on Climate Change, December 2011

Introduction

Background

The UK Government's Climate Change Act (2008) sets a legally binding target of 80% reduction in CO_2 emissions from 1990 levels by 2050. Meeting this target will require action across all energy consuming and carbon emitting sectors to reduce energy demand and provide energy more efficiently and from lower carbon sources.

Distributed energy (DE) schemes offer one method of providing lower carbon energy to buildings. The CO_2 emissions associated with heating are around a third of the total UK greenhouse gas (GHG) emissions with the majority of this used for heating domestic and non-domestic buildings. Therefore the provision of lower carbon heat will be important in achieving the 80% reduction target. It is also possible that buildings will need to exceed the 80% target due to difficulties in reducing emissions in other sectors such as aviation and shipping, and therefore taking a strategic approach is vital.

Emissions can be reduced in the buildings sector by reducing the demand through efficiency improvements, and building highly efficient new buildings. However the majority of the building stock which is likely to exist in 2050 has already been built with much of this difficult to make more efficient or classed as "hard to treat". Reducing emissions therefore requires the widespread provision of low carbon heat, potentially through DE schemes.

DE schemes consist of a heat producing technology such as a combined heat and power (CHP) system providing heat to a district heating network (DHN). This consists of a series of insulated pipes distributing heat from the central source to individual buildings. The advantages of DE are that technologies providing high overall efficiencies (such as CHP) can be used, or other sources of heat such as waste heat from industry can be collected and distributed. However the cost of installing heat networks and energy centres can be high, and the viability of a DE scheme can depend on the economic performance of the DE scheme compared with alternative options employed at an individual building or dwelling scale.

This Macro Distributed Energy Study for the ETI aims to examine the role that DE could have in Great Britain (GB)[3] in providing low carbon and low cost heat to buildings. The work examines schemes of up to 50 MWe CHP capacity representing large scale networks which would cover a significant part of towns and cities. The key aims of this work are to:

- understand the technologies, tools, and skills available for DE deployment in GB, and where gaps exist;
- identify areas which may be suitable for DE schemes;
- assess the performance of schemes using a range of technologies in these areas in terms of cost, and CO_2 savings;
- calculate the GB benefits case with mass deployment of DE.

The work in the Macro DE project is split into distinct 5 work packages which aim to characterise DE in GB, and develop a suite of data and materials to allow the assessment of the potential and benefits from DE across GB. In summary, the separate work packages are:

- WP 1: DE Design Practice Characterisation. The first work package provides an overview of current practices and regimes for DE deployment. It identifies key suppliers and stakeholders in the industry, business and deployment models, and a range of barriers to uptake.

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[3] The project has been limited to Great Britain as data from which heat demands could be predicted was not available for Northern Ireland (see WP2 report)

- WP 2: Site and Zone Energy Demand Characterisation. This work package examines the energy demand characteristics of GB on a spatial basis, identifying the suitability of different areas for DE deployment. A number of zones are identified which may be suitable for DE (these typically represent towns and cities) which are then analysed and represented by grouping into 20 distinct Classes based on a range of criteria. For each class, a Characteristic Zones (CZ) is selected for subsequent analysis. A set of energy demand profiles are developed which will allow modelling of energy supply technologies in work package 4.
- WP 3: Energy Supply Characterisation. This work package develops energy supply options for the CZs based around DHN infrastructure and generation technologies. DHNs were designed for three CZs which contain representative areas for most of the other CZs covering a range of building types and layouts. The outputs from this were used to develop a set of algorithms describing the cost of networks based on energy demand information and spatial information. The second main component of work package 3 is the development of a database of energy supply technologies covering currently available and mature technologies (work package 3.2) and future or developing technologies (work package 3.3).
- WP 4: Tool Development Methodology and Performance Evaluation by Zones. The focus of work package 4 is to develop an optimisation tool for the evaluation of DE schemes for each CZ. The tool optimises solutions for each CZ based on the performance of supply technologies, lifecycle costs, CZ demand characteristics, and a number of other inputs. The output from the tool is the most appropriate system based on either minimising lifecycle cost or including constraint on CO_2 emissions.
- WP 5: GB Benefits Case Opportunity Identification & Summary of the Individual Development Options. Work package 5 is the final work stage, and includes the assessment of potential for DE at a GB level, assessment of the opportunity for new or novel technologies, and a summary report of the overall study.

Further details for each of the previous work packages can be found in the relevant technical reports produced for each stage.

Work package 5.3: An assessment of the GB benefits associated with potential DE technology development.

This report is part of work package 5 and provides results and analysis from work package 5.3 which aims to identify how technology development can support the potential for DE across GB. In particular, it aims to examine the following:

- Establish the role which novel technologies may take and the importance of novel technologies for DE nationally.
- Identify the key novel technologies for future technology development and commercialisation which may have a large impact on the macro DE potential.
- Understand the high level impacts of the novel technologies on existing and new supply chains, in particular in relation to feedstocks and waste outputs.
- Identify whether expected improvements in performance or reductions in costs of existing technologies could materially alter the conclusions from the WP5.1 results

In WP5.3 we are focussing on the potential heat energy supply technologies rather than the DHN. In WP 5.1, an assessment is made of the potential for macro DE across GB, and the results demonstrate that the combination of gas fired CHP and DHNs can be economic for up to 43% of the GB building heating demand. The DHNs provide a heat delivery infrastructure which is flexible to future changes, and allows the later incorporation of new and more novel technologies which may provide an advantage over gas fired CHP systems. This work package assesses the performance and benefits which these alternative technologies may provide when connected to a DHN, and examines how they may assist macro DE schemes moving from the near future with a higher carbon electricity grid and plentiful natural gas supply, to a lower carbon electricity grid future and limited fossil fuel supplies.

The technologies considered in this section taken from the WP 3.3 technology library include:

- The ‘conventional’ technologies considered in the WP 5.1 assessment and WP 3.2 technology library.
- Fuel cells
- Solar thermal
- Large scale heat pumps using elevated temperatures
- Gas turbines
- Dual fuel engines
- Combined cycle gas turbines
- Biomass CHP (gasification and steam turbine)
- Biomass boilers
- Anaerobic digestion
- Energy from waste (incineration)

Unlike the WP 5.1 GB benefits case report, this part of the study considers the technologies on an individual scheme basis and does not attempt to extrapolate these results to a GB scale. In general, there are many factors which need considering when assessing the potential for the developing technology options, and these will require more careful consideration than for natural gas CHP, especially in the context of site suitability and feedstock availability. A simple extrapolation is therefore not generally feasible.

As with the 5.1 report, this report assumes that many of the barriers associated with DE deployment can be overcome, and DE will be treated as any other recognised utility, and decisions made purely on an economic and environmental basis. In particular the following are implicit in all the analysis:

- Large-scale town and city wide DHNs can be created with a strong customer base. As a base case, it is assumed that 80% of potential customers connect to the scheme. This implies some form of regulation which could incentivise or mandate connection, and provide certainty to potential investors and customers, similar to current gas and electricity supplies.
- There is sufficient electricity network capacity to accommodate high levels of decentralised generation. It is likely that the grid will become smarter in future allowing the connection of a greater range and scale of electricity generators.
- The current electricity market distortions which do not favour decentralised electricity generation are removed and CHP operators can receive a higher value for all the electricity they produce. This might be achieved through changes to the licensing regime to allow operators to sell some electricity directly to customers, or for the benefits to the distribution system of local de-centralised generation to be recognised in the price paid for exported power.
- That the CO_2 savings resulting from CHP operation are valued at a cost per tonne of carbon equal to the social cost of carbon published by DECC.

It is recommended that the reader of this report first reads the final WP 5.1 report to understand the assessment process, scenarios, and results presentation more fully.

Methodology for assessing the potential of developing technologies

Methodology overview

The assessments used in this report are based on results from using the macro DE optimisation tool developed in WP 4. By optimising schemes for each CZ with a modified technology library which restricts or promotes different types of technologies, it is possible to examine how they perform and compete with alternative macro DE systems. A staged approach is used for this assessment (more details below).

All assessments are made in comparison to counterfactual (individual building heating systems) options of gas boilers and heat pumps. The methodology and assumptions for these remain identical to those used in the WP 5.1 assessment.

The comparison between different systems and the counterfactual is primarily made on the basis of levelised cost and the CO_2 intensity of heat. Further detail is provided in the WP 5.1 report on these and the presentation of results.

Examining different technology types

Overview of assessment process

The assessment in this report is split into stages, which are used to examine and promote different technology types. The initial stages proposed for the assessment were:

- **Stage 1: All technology options.** Macro DE schemes are optimised for each of the 20 CZs with a full technology library, allowing the optimisation tool to select any technology. This allows the developing technologies to compete against the more established technologies examined previously in WP 5.1.
- **Stage 2: A future with limited availability of natural gas.** This stage again optimises macro DE schemes for each of the CZs, but removes natural gas prime-movers from the technology library to reflect a scenario where natural gas becomes more scarce or expensive and alternative options are required. Natural gas back up boilers are retained on the basis that their contribution will be relatively small (allowing the use of gas) and they provide a low cost back up and peak source.
- **Stage 3: Investigation of individual technologies.** The previous stages allow the open selection of technologies across all CZs. This final stage will asses individual technologies on a reduced set of CZs to examine the costs and environmental performance, and the barriers which need to be overcome for the technology to be competitive. Further detail is provided below.

However due to the uncertainties expected with modelling the developing technologies, it was accepted at the planning stage of this work that the assessment process would need to be flexible and modified as required during the process. Changes from this procedure are therefore detailed throughout this report.

Stage 3 – individual technology optimisation

Each of the remaining unselected technologies after stages 1 and 2 are modelled on one or more of the CZs. The CZs are selected on the basis of choosing a number of CZs from the middle of the marginal abatement curve (taken from the central scenario for WP 5.1). These zones represent the majority of the CO_2 reduction potential, and the similarity in heat price means that the overall GB potential is more sensitive to changes for these CZs than the high and low cost CZs at each end of the MAC curve.

The CZs selected for modelling are given in Table 1. The selection of CZs forms a hierarchy, and if the first CZ is deemed ‘suitable’ for a technology, then it will be used. If the first is deemed unsuitable, then the next CZ will be examined and so on. This means that the majority of results will be on the same CZ allowing comparison.

The suitability of a CZ for modelling a technology is based purely on peak load and simple criteria that the peak CZ load must be 4 times larger than the technology capacity is used. In reality, many of the WP 3.3 library technologies will have a number of other criteria when selecting a suitable zone. These could include access to feedstock / resources, transportation, planning, air quality and land take to name a few. However the CZs have not been constructed on a basis of these practical parameters. Therefore it is not possible to suggest that if a technology is suitable for one zone (i.e. the CZ) in a class, it is always also suitable for all of the other zones in the class. If this view is taken, then the CZ no longer becomes a characteristic zone, but simply a sample zone with no direct representation of the other zones in the class apart from energy loads. The analysis therefore considers the combination of a CZ and technology as example scheme on a sample site and does not attempt to aggregate the results to a GB level.

The MAC curve in Figure 1 shows the performance of each zone for the central case of 5.1 against a gas boiler counterfactual. All the DE solutions comprise gas fired CHP engines in this scenario. The central region of the curve comprises characteristic zones 4, 17, 13, 7, 2, 6, 19, and 12, and provides around 2/3 of the overall CO_2 reduction potential. Despite the high potential, the cost of heat varies by only 0.8 p/kWh, and thus these zones represent the marginal zones where small changes in viability can have a large impact on national potential.

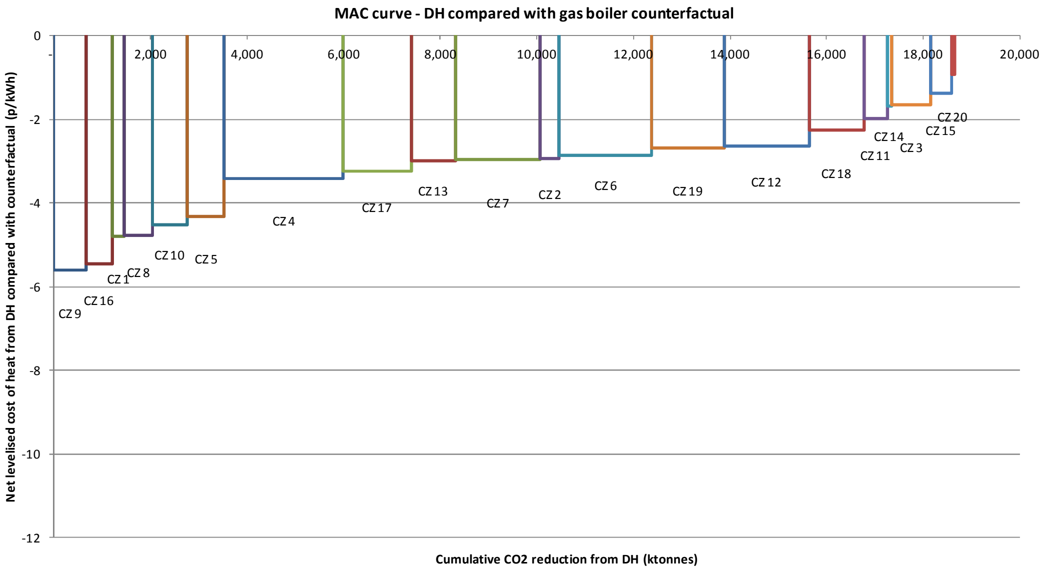

Figure 1: MAC curve from the central scenario (scenario 7) compared with a gas boiler counterfactual (taken from WP 5.1 report).

The hierarchy of the zones is determined by ranking using the CO_2 saving potential and cost of heat:

- The zones are ranked 1 to 8 in order of CO_2 savings (1 being the largest saving potential).
- The zones are ranked 1 to 8 in order of levelised heat cost difference from the median (1 being the smallest difference).
- An overall ranking score is given by adding up the two results.

- The hierarchy is based on the lowest overall ranking. Where more than one CZ has the same overall ranking, the order is based on cost differential[4].

Table 1 shows the final hierarchy of available CZs. CZ 7(characteristic zone in class 7) is the first CZ in the hierarchy and will therefore be used for the majority of the technology assessments.

Table 1: Ranking of the central CZs by CO_2 reduction potential and heat cost.

CZ number	Class CO_2 reduction (ktonnes)	CZ peak (MW)	Levelised cost of heat (p/kWh)	Difference from median (p/kWh)	Ranking: CO_2	Ranking: cost differential	Ranking: Total	Final order
4	2446	112	-3.41	0.453	1	8	9	4
17	1421	95	-3.24	0.283	6	6	12	8
13	912	16	-2.99	0.032	7	3	10	5
7	1749	152	-2.98	0.025	4	1 (joint)	5	1
2	402	86	-2.93	0.025	8	1 (joint)	9	3
6	1912	90	-2.86	0.097	2	4	6	2
19	1498	97	-2.70	0.258	5	5	10	6
12	1759	123	-2.63	0.322	3	7	10	7

Assessment scenarios

The modelling in work package 5.1 was based around twelve assessment scenarios. These scenarios are used to define the input assumptions used in the optimisation model, and allow the assessment of sensitivities which may impact the potential for DE across GB. Ten of the 12 scenarios, (including the central scenario) are based around deployment of schemes in the 2020s representing the period of mass deployment of macro DE. A final scenario examined macro DE in the 2030s to determine how the conventional technologies (primarily gas engine CHP) would perform under the 2030 economic and electricity grid CO_2 intensity conditions.

For the assessment of developing technologies, the central scenario is used unless otherwise stated. This has been selected for the following reasons:

- The 2020s will potentially represent the period of mass deployment of macro DE. During this period it will be important to ensure that the most suitable technologies are selected at the outset of schemes, which may potentially include the developing technologies if they can compete with gas engine CHP units.
- Even if the developing technologies are not deployed during this period, it will be important to understand how they perform and the extent to which they may be selected. This will help inform where further development is required, both in terms of technology development and supply chain and resource development.
- Most of the developing technologies are designed to be lower CO_2 than gas engine CHP options, and therefore it is important to understand how they may compete against the incumbent during this period, with a view that the performance will most likely improve further in the 2030s.

Further details on the assessment scenarios are provided in the WP 5.1 report. The central scenario (which forms the base case in WP 5.1) assumes deployment in the 2020s, an 8% discount rate, central capital cost assumptions, central energy prices, and the inclusion of

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[4] The order for identical rankings could be based on cost or CO_2 savings. A discrete order is required to allow consistency in selection when moving down the hierarchy.

CO_2 pricing. A market penetration of 80% is assumed meaning that 80% of the potential customers in a zone connect to the DE scheme. The scenarios are illustrated schematically in Figure 2.

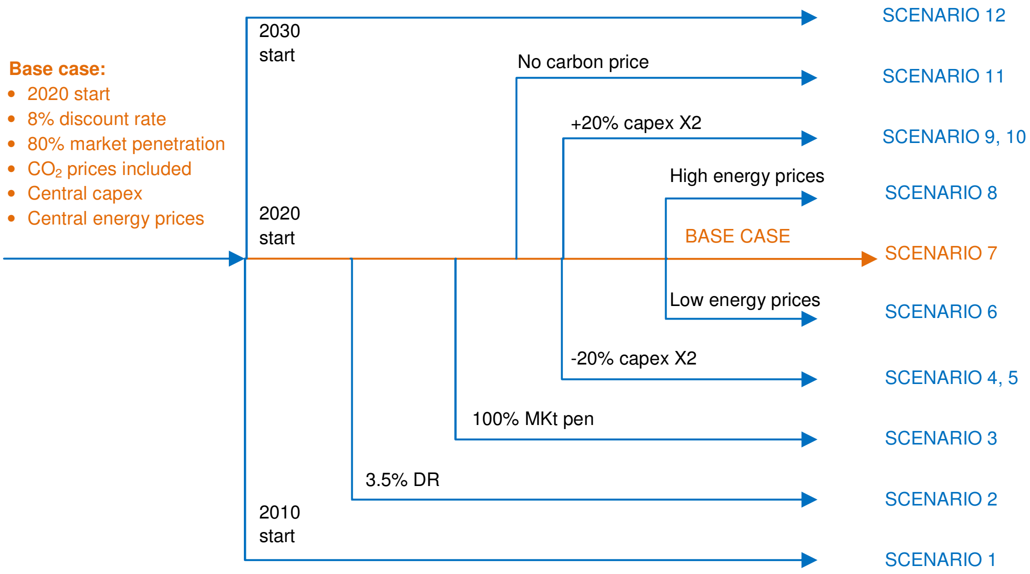

Figure 2: Schematic of the scenarios. Sensitivities are indicated around the base case.

All Technology Options: Stage 1 results

Introduction

Stage 1 of the assessment examines macro DE schemes across all CZs with access to the full WP3.3 technology library, which also includes the established technologies examined in the WP 5.1 report. This allows comparison of the developing technologies with the mature systems, and identification of the potential benefits which the developing technologies may provide, but also the barriers which must be overcome for them to compete.

It is important to note that land fill gas engines were excluded from the technology library for modelling in WP 5.3. These were selected in some model runs in WP 5.1, but it was felt that due to the extremely limited national potential combined with geographic constraint (landfill sites are generally located outside urban areas), significant uptake of landfill gas systems on macro DE schemes is both unrealistic and unlikely. The results from the landfill gas schemes are discussed in the Stage 3 part of this report.

Stage 1 – first iteration

Description of schemes

With no constraints applied to the technology selection (apart from the removal of landfill gas), Anaerobic Digestion (AD) systems were selected for every CZ in combination with gas back-up boilers. For all CZs, multiple AD systems based around 4 MWth units are optimised to provide up to 100% of the heat on the DHN, with no CZs falling below 97%.

The modular nature of the AD systems allows the schemes to operate similarly to the natural gas engine CHP schemes in WP 5.1. In essence, these schemes are very similar, but use a different fuel source. It is unlikely that a modular AD system would be used in reality, and the gas generation plant would be sized for the total load. However the gas engines taking the biogas would be modular such that each AD system may have a number of gas engines connected.

Performance of schemes

The economic and environmental performance of the AD schemes for each CZ is displayed in Figure 3 (for an explanation of the results presentation, please see the WP 5.1 report). The results clearly show the following:

- Macro DE schemes with AD can provide zero cost heat to customers if gate fees of circa £10 per tonne or more are obtained. The cost of heat from all the CZs is predicted to be less than 0 p/kWh with most schemes at around -5 p/kWh.
- The schemes are all predicted to provide negative carbon heat with an intensity of around -0.35 kg CO_2 / kWh, due to the zero CO_2 intensity of the feedstock and offset grid electricity CO_2.

The low cost of the schemes can be attributed to the operation costs which are always below zero, and which counteract the cost of the DHN. This is as a result of the gate fee which is obtained for the feedstock and brings revenue to the scheme, valued at £10 per tonne (a tonne of feedstock is equivalent to 2250 MJ on average). If this gate fee increases in value (for example, alternative waste disposal options become more expensive, creating a greater need for lower cost disposal), then the cost of heat will become even less. If the gate fee reduces as a result of alternative markets for the feedstock (effectively lower cost disposal options), then the cost of heat will increase and potentially become positive. In general, an attractive gate fee is required for schemes to remain economic, and the removal of gate fee will result in an uneconomic AD scheme. As described below, AD schemes are complex and the gate fee is only one component of the cost structure. In particular, the sale or disposal of digestate also needs careful consideration to ensure the scheme can operate in an economic manner. The gate fee requested will need to account for these other aspects.

The low CO_2 emissions are due to the feedstock being zero CO_2 rated, arising solely from bio mass sources which are generated as part of a waste stream. With a heat to power ratio of close to 1, the heat therefore is rated at minus the offset grid electricity CO_2 intensity, which is around 0.35 kg CO_2 / kWh for the 2020s. The zero rating of the feedstock means that no carbon prices are attributable to the AD fuel supply, further reducing the levelised cost.

These results suggest that where AD schemes are viable (but see the next section), AD could provide the lowest cost heat, and potentially some of the lowest carbon heat from all of the technologies.

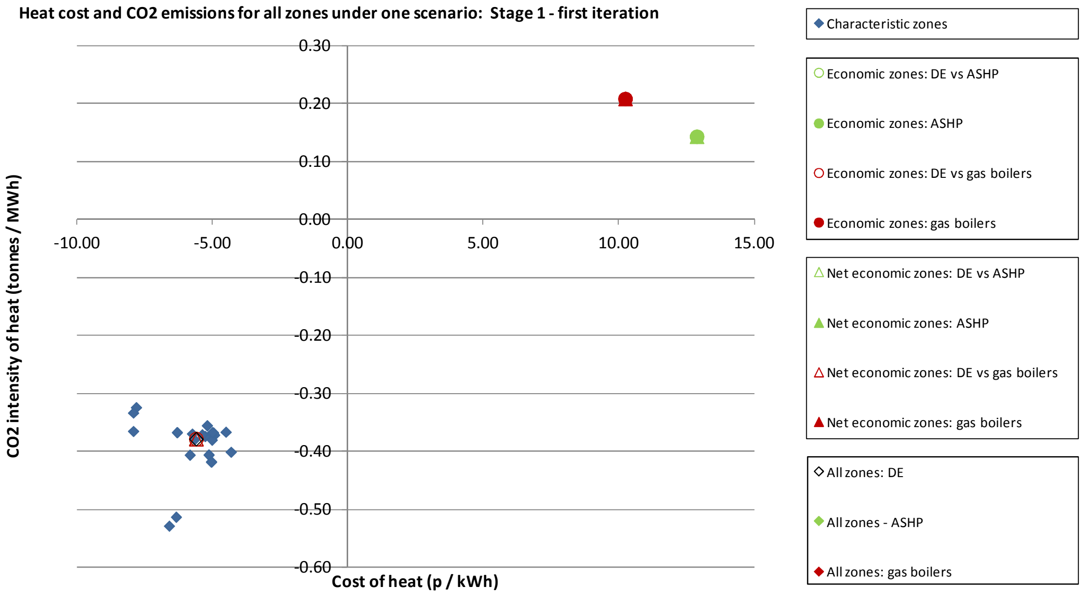

Figure 3: Stage 1 (first iteration) results for each CZ.

Realistic potential

The cost and CO_2 results for AD are very positive and demonstrate that other technology options can outperform natural gas engine CHP options in the 2020s. However before this can be seen as a viable solution, some other issues need to be considered:

- The availability of feedstock
- The robustness of the costs of heat from AD
- The practicalities of mass AD deployment for macro DE schemes
- The other aspects of AD which need considering

The first consideration of how robust these results are concerns the availability of feedstock for AD. Feedstock types can be in a variety of forms, but typically animal wastes, food waste, energy crops (for example maize), and sewage sludge are used. Un-processed wastes are higher in energy density, whilst pre-processed wastes (i.e. sewage sludge and animal wastes) are much lower. However the latter can have an important role in maintaining the consistency of the feedstock for processing. With the exception of energy crops, the other feed stocks are finite, and for items such as food waste, there are arguments for reducing their availability even further through resource efficiency. The growth of energy crops clearly requires careful consideration of competing land uses and markets.

A recent review of AD suggests that by 2020, there is a potential of between 3 – 5 TWh of electricity generation in the UK [5]. This assumes that around 70% of the total food waste is collected and digested, and between around 20% and 70% of slurry is collected and digested. Assuming that heat could also be captured from all of these schemes for macro DE at a simplistic heat to power ratio of 1:1, the total potential for heat is therefore also between 3 and 5 TWh.

In WP 5.1, the total heat demand for buildings was estimated at 458 TWh, with up to 199 TWh (43%) being cost effective for macro DE schemes. A potential optimistic contribution from AD of between 3 and 5 TWh is therefore negligible at about 1% of the total heat demand or 2% of the demand that .

The generation and use of energy from AD schemes is only one part of three key components in biogas generation and use. Firstly, the feedstock sourcing needs to be considered. In general, the types of facilities associated with food waste production are rural or edge of town industrial, and not likely to be located in dense urban areas. The transportation associated with this food waste is significant with circa 40,000 tonnes of feedstock required for a 1 MW unit. It is therefore important to minimise the feedstock transportation which generally means locating the units near the feedstock production.

Secondly, AD systems produce a large amount of digestate which must be removed. This may have a positive value as fertiliser, but needs transporting. However if local NPK levels are adequate, then the digestate can be classed as a waste with an associated disposal cost (or transportation cost to other areas).

The logistics of dealing with feedstock and digestate generally mean that AD systems are located where both are available or required. A common location may be at a large food production farm where there is on-site processing and a demand for fertiliser. The generation of energy is therefore a less important consideration.

AD schemes also generally have a large land take due to the size of the digester tanks and space required for feedstock and digestate storage and processing. The CHP engines often take up a very small fraction of the overall site. Locating AD schemes in dense urban areas will therefore be extremely challenging.

Given these issues, the extraction of heat from AD schemes for DHNs may not be the most practical option, and preferable options may include electricity-only generation, or biogas generation for injection to the gas grid or storage for transportation. Given the typical size of the AD schemes which are viable (based on feedstock) it is highly unlikely that building lengthy DHN transmission pipes to AD systems will be viable.

The complexities around AD will also impact the costs, and therefore not all schemes may be able to generate heat at the price suggested in the modelling. In particular, transportation costs, digestate removal / disposal costs, and also feedstock cost variability need to be considered. For urban areas, land take and associated costs will also be considerable.

The most likely application will be where a reasonably high density town/city is located within an intensive agricultural area where an edge of town/city AD plant could be constructed.

Stage 1 – first iteration summary

The selection of AD as a first choice based on cost optimisation shows that where the challenges associated with AD and macro DE schemes can be overcome, there could be considerable benefits. However, the overall potential for AD on macro DE schemes is likely to be extremely limited and therefore not a major component of macro DE for GB as a whole.

Given this result, a decision was made at the end of this iteration to repeat the modelling of stage 1, with the option to select AD removed.

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[5] Anaerobic Digestion Strategy and Action Plan. Defra and DECC. 2011.

Stage 1 – second iteration

With the restriction of the technology library and removal of AD from the options, the schemes optimised in the second iteration all selected gas engine CHP systems as per the base case in WP 5.1. This demonstrates that under the assumptions made in this assessment, the only developing technology which can outperform gas engine CHP systems on a cost basis is AD, and therefore gas engine CHP still has the greatest potential in the 2020s in economic terms.

Limited natural gas: Stage 2 results

Introduction

This section examines the potential for macro DE under a scenario where the availability of natural gas is limited. Although it is likely that natural gas resources will still be available world-wide the Government's targets for an 80% reduction in CO_2 by 2050 will not be met if gas remains the dominant fuel for heating and power generation. This scenario is simulated by preventing the selection of all natural gas based technologies for macro DE schemes with the exception of gas boilers. The 5.1 results showed that gas boilers are used a negligible amount in schemes where the prime mover is modular, to provide a low cost back up.

Apart from the selection of AD in the stage 1 analysis, all the 2020 cost optimised results have relied on gas CHP and so the outcome of this stage is important in understanding the transition macro DE schemes will need to make through the 2020s and into the 2030s to maintain a low carbon heat supply.

Description of the schemes

All of the CZs selected large heat pumps as the prime thermal generation technology, backed up by gas boilers. The heat pumps selected are designed to operate with an input temperature circa 30° – 40°, typical of sources of excess or "waste" heat from industrial processes, mines water or power generation condenser circuits. The elevated input temperature allows higher CoPs to be achieved of around 3.9 (as assumed in the modelling), providing lower cost heat than the lower input temperature heat pump systems selected in WP 5.1 under scenario 12 in the 2030s. This CoP is higher than for smaller heat pumps operating from an ambient temperature source due to the smaller temperate difference between source and output. If intermediate temperatures were used, lower than the 30° – 40°, but higher than ambient, then an intermediate CoP would be expected. The performance of heat pump macro DE schemes will therefore be dependent on the locally available heat sources and it is recommended that further work examines the availability and nature of heat available for schemes.

As with many of the other technologies, the heat pumps are installed in a modular configuration, with multiple 4.75 MW (the largest size contained within the technology library) units. This configuration allows close following of the thermal loads, resulting in most schemes having around 85% to 90% of their heat from the pumps.

Performance of the schemes

The analysis of heat pumps in WP 5.1 demonstrated that by applying constraints on CO_2 emissions, it was possible to develop macro DE schemes which provided savings in excess of 50% when compared with the gas boiler counterfactual. However due to the improvements assumed in building scale ASHPs and taking account of the DHN losses, the large heat pump option (using ambient temperature sources) could not compete with building scale heat pumps on a CO_2 basis. The resultant CZ schemes were mostly uneconomic with only 6% GB heating potential in the commercial benefits case and around 20% in the net economic GB benefits case.

The results in this section show that improvements in heat pump performance, either through technology development, or through increased input temperatures (such as the excess heat simulated) could have a large impact on the economic and environmental performance of heat pump based macro DE schemes. The 4.75 MW heat pumps selected during stage 2 have a CoP of 3.9, compared to the value of 2.8 selected in the WP 5.1 schemes.

Figure 4 shows the cost and CO_2 emissions for each of the CZs alongside the average performance of the counterfactuals.

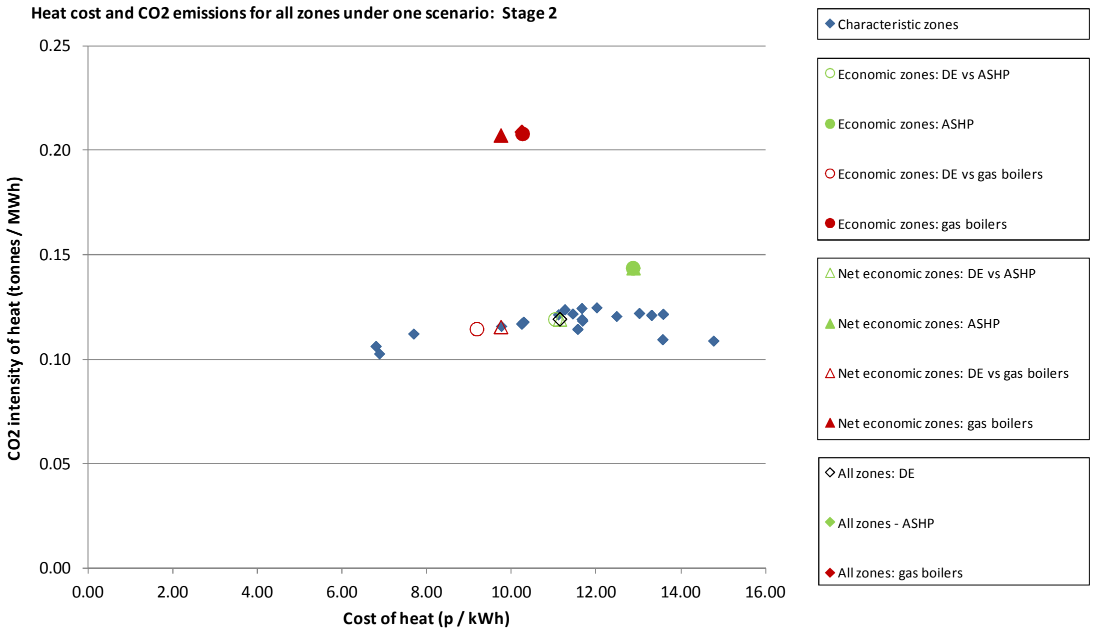

Figure 4: Performance of large heat pump macro DE schemes optimised during the stage 2 analyses.

The results demonstrate that, assuming the higher CoPs can be achieved, heat pumps can be used for macro DE schemes resulting in CO_2 savings against both gas boilers and ASHP counterfactuals. This is an important result and demonstrates that heat pumps can be used in the transition from natural gas CHP based macro DE schemes to lower carbon systems in the 2030s.

The potential for using these heat pumps at a GB scale depends on the availability of elevated temperature heat sources. However if this barrier can be overcome, and within each scheme sufficient heat sources could be found, then against the ASHP counterfactual 41% of the GB heat load is economic with macro DE, increasing to 43% (the maximum level) if cross subsidy between schemes is included (the net economic GB benefits case). This is equivalent to around £3.5 billion saving in heat costs across GB. These results demonstrate that macro DE heat pump schemes could provide lower cost and lower carbon heating than individual heat pumps in buildings if the CoPs can be improved.

The elevated CoPs modelled here either represent technology improvement and / or elevated input temperatures. If these improvements cannot be achieved, either through a lack of development, or unavailability of excess heat sources, then the CoPs will be lower. However it is likely that some level of improvement will still be achieved in many schemes (and identifying waste heat sources within all potential zones is an important starting point). Therefore whilst the economic and CO_2 savings potential across GB may be reduced, it will still lie somewhere between that identified in WP 5.1 and 5.3, demonstrating a viable future for macro DE schemes following the early phases of natural gas CHP deployment.

The modelling carried out here is based on the construction of a new macro DE scheme starting in the 2020s. If the network has already been started with a gas-engine CHP then some of the capital cost will have been recovered before a second phase of investment in heat pumps. We have not modelled this more complex situation and as a result the cost benefit of a heat pump driven macro DE scheme is likely to be better in practice.

With regard to CO_2 performance, the CO_2 benefit will remain better than individual gas boilers and broadly similar to individual heat pumps with any difference declining over time as the grid is decarbonised.

It is also possible that the grid emissions factor will not be uniform through the year as assumed in the modelling and that there will be benefits in having both a heat pump and a gas-engine CHP in the Energy Centre so that the heat pump operates at times of low emission factor (high wind generation and low demand) and the gas-engine CHP operates at times of high emissions factor (low wind output, high demand and need for peak lopping gas-fired power stations).

Individual technology analysis: Stage 3 results

Introduction

This section provides results of macro DE schemes based around using the technologies not previously selected. Most of the technologies modelled here have not been previously selected because they are not deemed cost optimal under the previous scenarios and stages. However this does not mean that they would not offer an economic solution to macro DE in some of the zones, and in some cases, they may have fewer barriers than the systems selected in the previous stages. The technologies examined here include:

- Fuel cells
- Solar thermal
- Gas turbines
- Dual fuel engines
- Combined cycle gas turbines
- Biomass CHP (gasification and steam turbine)
- Biomass boilers
- Energy from waste (incineration)

In addition to the above technologies, landfill gas engines are also examined. These were selected as part of the WP 5.1 modelling, but excluded from the analysis on the basis that a significant uptake was not viable due to resource and geographic limitations.

Assessment methodology

In Stage 4, the individual technologies are modelled on 1 or more CZs to assess their performance. To simulate uptake of the technologies (which are not cost competitive compared with other options), the technology library is restricted to promote their selection. This means that the schemes may be sub-optimal due to the selection of only a single solution (in combination with gas boilers) when in reality a combination of systems may be selected. For example, a larger technology such as energy from waste may be paired with natural gas CHP engines to improve the economic performance and allow closer load following. However in the stage 4 modelling, only energy from waste would be modelled without the additional natural gas CHP.

Throughout this section the combination of a technology and a CZ should only be considered as a sample scheme, and the results should not be extrapolated to a GB scale. As discussed earlier, there are many factors other than energy load characteristics which need considering when assessing the suitability of a technology, and these are not included in the definition of the classes or CZs.

Table 2 provides an overview of the assessment of the individual technologies. It details which technology options are modelled, what date they are modelled in, and the issues which need considering. The CZs are selected on the basis of the hierarchy described in the section “Methodology for assessing the potential of developing technologies”.

Table 2: Description of the assessment of individual technologies.

Technology type	Size for modelling	Decade for modelling	CZs for modelling
Fuel Cells	1400 kW and 2800 kW (300 considered too small for a CZ)	2020	CZ 7
Solar thermal	All sizes from 3.3 technology library.	2020	CZ 7. Modular nature means that performance will be independent of CZ size. In reality, the site will be heavily influenced by land availability and potentially geographic location.
Large scale CCGT	39 MWth and 55 MWth	2010 and 2020	CZ 7
Biomass CHP	All sizes	2020	Single model run across all CZs of all biomass technologies.
Biomass gasification	All sizes		
Biomass boilers	All sizes		
Energy from waste (incineration)	All sizes	2020	All CZs.
Landfill gas engines	All sizes	2010 and 2020	All CZs (from WP 5.1 modelling)

Analysis

Fuel cells

Fuel cell CHP systems provide a higher electrical efficiency than conventional thermal technologies, and therefore can provide greater electricity revenues. However this is counteracted by the high capital cost of the systems currently under development. This is demonstrated in the modelling up to stage 4, by the selection of conventional natural gas engine CHP systems over fuel cells.

Table 3 Performance of fuel cell CHP macro DE systems

CZ	Base case - gas CHP		Fuel cells		Notes
	£ / kWh thermal	kg CO_2 / kWh thermal	£ / kWh thermal	kg CO_2 / kWh thermal	
7	0.079	0.123	0.129	0.23	5.4 MWth FC CHP selected
15	0.095	0.123	0.150	0.25	0 MWth FC CHP selected

The results in Table 3 demonstrate the relatively poor performance of fuel cell CHP macro DE schemes in comparison with the base case of natural gas engines. The optimised schemes for fuel cells have a levelised cost of heat over 50% greater, and a CO_2 emission factor for heat of almost double.

These results are representative of the cost optimised schemes. For CZ 7, three fuel cell units were selected totalling 5.4 MWth. This compares with a total peak heat demand of 152 MW for the CZ, and thus the fuel cells are only providing a small fraction (around 10%) of the overall heat demand. The fact that some units have been selected demonstrates that they can be more cost effective than boiler-only schemes, but the small capacity means that they will only be selected where the base load allows almost continuous operation to gain maximum revenue. The low proportion of heat from the fuel cell means that the CO_2 emission factor of the heat is largely determined by the gas boilers, with only a slight reduction due to the fuel cells. If the scheme had a greater uptake of fuel cells with a correspondingly higher amount of heat from the fuel cells, the net emission factor for heat would reduce due to the grid electricity offset.

In the smaller CZ (CZ 15 which has a peak load of 16 MWth), no fuel cell units were selected, leaving the scheme powered entirely by boilers. This means that the costs and CO_2 emissions are only from the boiler operation. The lack of fuel cell selection can probably be attributed to the load profile of the smaller CZ not providing an adequate baseload to justify the installation of a fuel cell CHP unit.

Under these conditions, the fuel cells are slightly more cost effective than the ASHP counterfactual (but not gas boiler counterfactual), but do not provide CO_2 savings against either.

These results offer an important insight on the potential of fuel cells in macro DE schemes. The rationale for using fuel cells is the higher electrical efficiency and larger CO_2 reductions. However significant capital cost reductions are required for them to become cost effective, which will take development time. Fuel cells may effectively form a transition technology between gas engines and non-gas systems, and therefore the technology development and cost reductions need to be achieved in a short period before this technology will be superseded. If this improvement cannot be achieved in time, there may not be a major role for fuel cells in macro DE.

There may be other attributes which allow the uptake of fuel cells in certain circumstances. In particular the capture of CO_2 from fuel cells is relatively simple due to the reaction producing water and CO_2. Therefore fuel cells could offer a lower cost Carbon Capture and Storage (CCS) process. For this to be viable, the schemes would need to be relatively large to bring the costs down for the capture and piping / storage of CO_2. Therefore they would effectively become fuel cell power stations with heat off-take for the macro DE schemes.

There are also alternative fuel options for fuel cells including biogas and hydrogen (H_2). The uptake of biogas fuel cells will be limited by the availability of biogas, and as the discussion on AD demonstrates, this is a limited resource. H_2 is an alternative source, and there has been extensive discussion and analysis of H_2 as an energy vector, and even an 'H_2 economy' in many research and strategy studies. The economic and environmental performance of H_2 fuel cells will depend on the source of the H_2. Electrolysis using renewable electricity is one method by which low or zero carbon H_2 can be generated, but this is relatively inefficient (with losses in the electrolysis and compression stages, combined with distribution infrastructure requirements) and therefore could require significant increases in electricity generation. It does however offer the potential to store excess renewable electricity as H_2. Thus the use of H_2 needs considering in the wider context of energy, and in particular renewable electricity generation.

Solar thermal

Solar thermal can contribute to macro DE schemes by providing zero carbon heat but mainly in the summer months. The schemes clearly have low ongoing costs with no input fuel requirements, but have a relatively high capital cost and require a significant land take. Although solar thermal could be installed on the roofs of major buildings this is typically more costly than ground mounted panels and the area is limited to the roof area availability. Roof-top installations will also mean that the overall system is distributed, which may increase operation and maintenance costs, alongside consideration of legal implications of using third party roofs.

The land take will mean that sites will typically need to be edge of city or small towns, where neighbouring open land is available and where there are low land values. For urban schemes, sufficient low value land, or undevelopable land will be required. The overall potential is therefore likely to be closely linked to this factor.

Table 4: Performance of solar thermal macro DE schemes.

CZ	Base case - gas CHP		Solar thermal		Notes
	£ / kWh thermal	kg CO_2 / kWh thermal	£ / kWh thermal	kg CO_2 / kWh thermal	
7	0.079	0.123	0.115	0.2260	52.5 MWth solar thermal selected

In the optimised scheme for CZ 7, 52.5 MWth of solar thermal collectors were selected. This compares with the peak demand for the zone of 152 MWth). Assuming a simple conversion of 0.7 kW / m^2, this is equivalent to an area of around 4 hectares. Despite the large capacity, the solar thermal system only provides around 11% of the annual heat demand. This is relatively low and limited by the supply-demand mismatch with high solar thermal output in the summer months when the demand is low.

The resulting scheme has cost and CO_2 savings of around 10% from a gas boiler-only macro DE scheme, but is higher in cost and CO_2 than the gas boiler counterfactual. It therefore offers no benefit for macro DE.

If the solar thermal systems were oversized, it would be possible to increase the proportion of heat delivered, and therefore the CO_2 savings, but this is fundamentally limited by the supply-demand mismatch. Therefore the capital cost would increase considerably with smaller revenue increases. Another option is to adjust the supply-demand profile through the incorporation of long term storage. Inter-seasonal storage can be used to store thermal energy from the summer into the winter period, but the costs, technical viability and efficiencies of the process need to be considered.

In summary, solar thermal in isolation from other low carbon heat sources is not considered an appropriate solution for cost-effective macro DE schemes in GB, due to providing no benefits over the gas boiler counterfactual or gas CHP macro DE schemes, and having land availability constraints. A scheme that combined solar thermal with a biomass boiler would be potentially of interest subject to suitable land being available.

Combined cycle gas turbines (CCGT)

CCGT systems provide higher electrical efficiencies than engine based CHP systems, but are generally only built at a larger scale. Therefore whilst there may be potential for more efficient, and lower cost operation, the scale of technology for heat led schemes may limit the applications. The systems are considered a mature technology, although generally deployed at a larger scale (100MWe to 1000MWe) for industrial CHP schemes or centralised power generation. The use of small-scale (c50MWe) CCGT systems connected to DHNs is less mature although there are examples from Denmark e.g. Viborg.

The higher electrical efficiencies may allow CCGT plants to be used as a transition technology, connecting to macro DE schemes in the 2010s and 2020s. In this section, CCGT systems from the WP 3.3 technology library of 39 MWth and 55 MWth are investigated.

The performance of the CCGT optimised schemes is shown in Table 5 below. It is important to note that the optimisation assumes that the systems are operated in heat led mode. For smaller CCGT systems which are optimised for CHP operation at a macro DE scale, as investigated in this report, this is a reasonable assumption, although a small amount of heat dumping may be allowed. However if larger CCGT systems were used for more centralised electricity generation, with a heat off-take for macro DE schemes, it is more likely that the system would be electricity led, and therefore potentially provide a greater fraction of the heat on the DHN, albeit with additional heat dumping.

Table 5: Performance of CCGT macro DE schemes

CCGT size	Base case - gas CHP		CCGT		Notes
	£ / kWh thermal	kg CO_2 / kWh thermal	£ / kWh thermal	kg CO_2 / kWh thermal	
2010s					
39 MWth	0.061	-0.005	0.099	-0.016	93% of heat from CCGT
55 MWth	0.061	-0.005	0.082	0.023	80% of heat from CCGT
2020s					
39 MWth	0.079	0.123	0.089	0.116	93% of heat from CCGT
55 MWth	0.079	0.123	0.085	0.149	80% of heat from CCGT

The results show that the optimised schemes deliver similar CO_2 reductions to the base case of gas engine CHP systems. The emissions are higher for the larger CCGT, but this is a result of increased boiler use arising from the CCGT being unable to meet as much of the baseload as the smaller unit without heat dumping.

The levelised costs are lower from the larger CCGT system despite the reduction in heat provision. This is due to the 2 percentage point improvement in efficiency over the smaller unit, and 10% reduction in capital cost per kW. However costs are higher than the gas-engine solution.

The results demonstrate that in CZ 7, CCGT systems provide CO_2 reductions and cost savings compared with both gas boiler and ASHP counterfactuals in both the 2010s and 2020s. Careful optimisation of the schemes in terms of CCGT system size could allow for greater thermal contribution and therefore higher CO_2 savings. However the risk is that selecting smaller systems will reduce efficiency and increase unit costs. A more appropriate solution may be to aggregate zones into larger schemes which can connect to larger CCGT systems or extract heat from CCGT systems designed for centralised electricity generation.

Overall the CCGT CHP option does not appear to offer a significant benefit over the use of multiple gas-engines which are better able to track the variable heat load.

Biomass technologies

The use of biomass offers the opportunity for large CO_2 reductions as the fuel is considered as renewable. The CO_2 emitted when combustion takes place is assumed to be equal to the CO_2 recently absorbed from the atmosphere during the growth phase. There are additional CO_2 emissions associated with treatment and transport of the fuel and increasing concern around the potential impacts from a change of land use where biomass crops are concerned. A CO_2 emissions factor of 0.029 kg CO_2 / kWh is assumed in line with other ETI studies.

A number of different technologies exist for biomass based around heat-only systems and CHP systems. This assessment takes the approach of being technology neutral and simulating macro DE schemes across all CZs, limited to biomass technologies of all types (and gas powered back up boilers). The question being answered is therefore “what is the most effective use of biomass for macro DE”.

Biomass boilers were the only biomass technology selected in all of the cost optimised CZs. The boilers are selected in a modular manner with a total capacity of typically 30% - 40% of the peak thermal demand of the CZ, with higher capacities in some zones of up to 50%. These capacities mean that between 80% and 90% of the heat distributed by the DHN originates from the biomass boilers, with the remainder from the back up boilers.

The results from each CZ in Figure 5 show a spread in levelised cost from the biomass schemes with some being economic and others being un-economic against the two counterfactuals. The emissions of the biomass schemes are around 0.08 kg CO_2 / kWh and around half of the ASHP emissions, and a third of the gas boiler counterfactual. The range in levelised cost is similar to the gas CHP schemes (see the WP 5.1 report). The biomass systems are all very similar, using the same capacity boilers in a modular manner, with similar capacities and outputs, and therefore the component of levelised cost from the biomass heat source component is likely to be similar. As a result, the cost variation seen is primarily due to the variation in DHN costs.

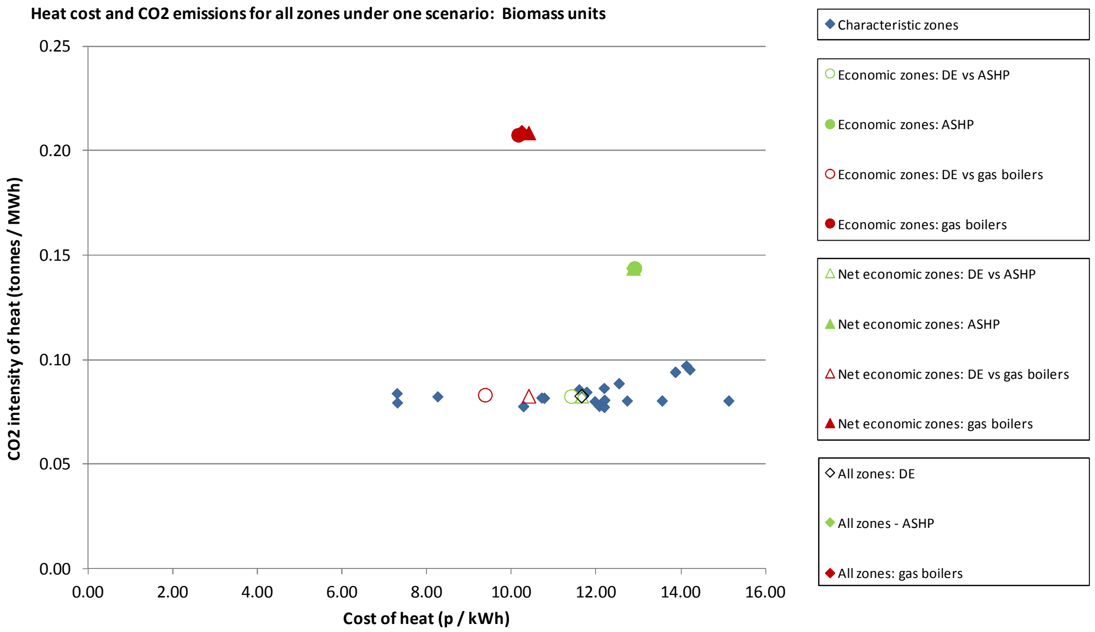

Figure 5: Economic and environmental performance of biomass macro DE schemes. All systems selected for all CZs are biomass boilers. (Please note – the averages presented here are shown for GB uptake. These are shown for illustration only and do not imply that biomass macro DE schemes can be implemented across the whole of GB).

The two MAC curves in Figure 6 and Figure 7 are shown to illustrate the impact that biomass boilers could have on CO_2 emissions, and where the most appropriate locations may be in terms of costs.

Biomass feedstock is a finite resource, and therefore it will be important to use the resource efficiently. Bio energy resources currently provide around 2% of the UKs energy supplies (of which around two thirds is from biomass i.e. solid wood-derived fuel) [6]. Research by the Carbon Trust in 2005 estimated the current biomass use at around 41 TWh per year, with a potential to increase to 80 TWh per year if other existing resources were captured and there was a significant uptake in energy crops[7]. Whilst there is a considerable uncertainty in these numbers, they represent only a small fraction of the GB heat demand of 458TWh and the 199TWh heat demand included in the zones analysed. Biomass can of course be imported, but this opens questions of sustainability in relation to sourcing and transportation, and also international market demands influencing price and availability. Even with a native resource, there are competing uses which means the market is uncertain.

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[6] Bioenergy Review. Committee on Climate Change. 2011.

[7] Biomass Sector Review. Carbon Trust. 2005

The results across all CZs demonstrate that if a quarter of all the potential macro DE schemes (circa 50 TWh heat provision) used biomass, this would require the majority of the identified UK biomass resource. This assumes that all resource is used on macro DE schemes. With other options available which can deliver similar costs and CO_2 savings, such as gas CHP in the earlier years, and later more efficient heat pumps, one has to question whether using biomass in the macro DE schemes is its optimum application.

Firstly the biomass may be better suited to industrial heat use or buildings in lower density areas which cannot be connected to a macro DE scheme, and which may not be suited to the lower temperature output of heat pumps. However the Committee on Climate Change (CCC) have recommended that bio-energy should only be used for stationary power or heat applications as a last resort, with other more CO_2 efficient uses such as for construction materials, fuels for aviation and shipping, and that biomass should be used for power generation only where there is CCS[8]. Therefore whilst biomass may show potential for macro DE, this should only be considered in the broader context of other uses.

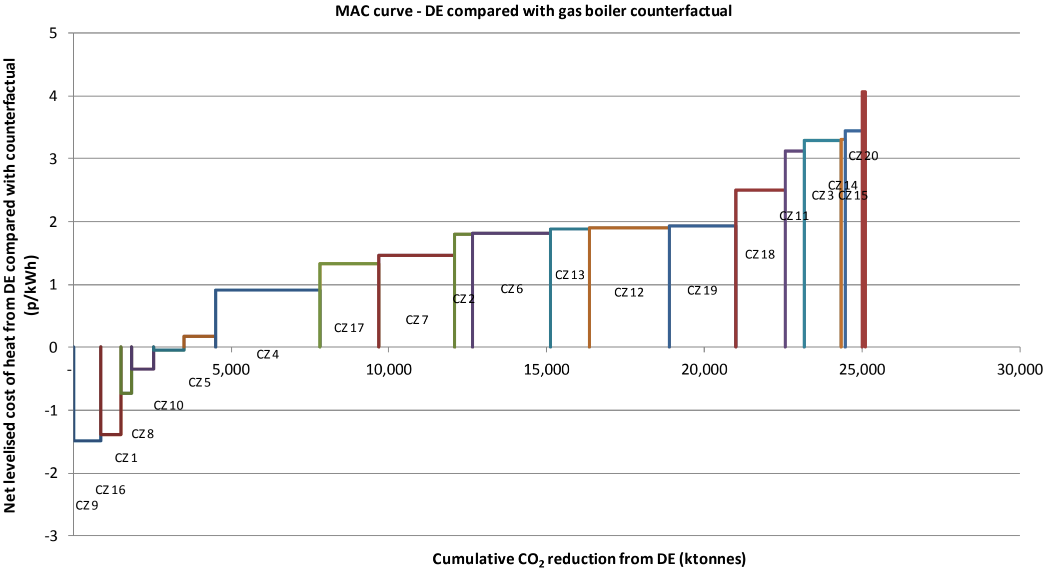

Figure 6: MAC curve for biomass macro DE schemes compared with a gas boiler counterfactual. (Please note - these are shown for illustration only and do not imply the potential for biomass macro DE schemes across GB).

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[8] Bioenergy Review. Committee on Climate Change. 2011.

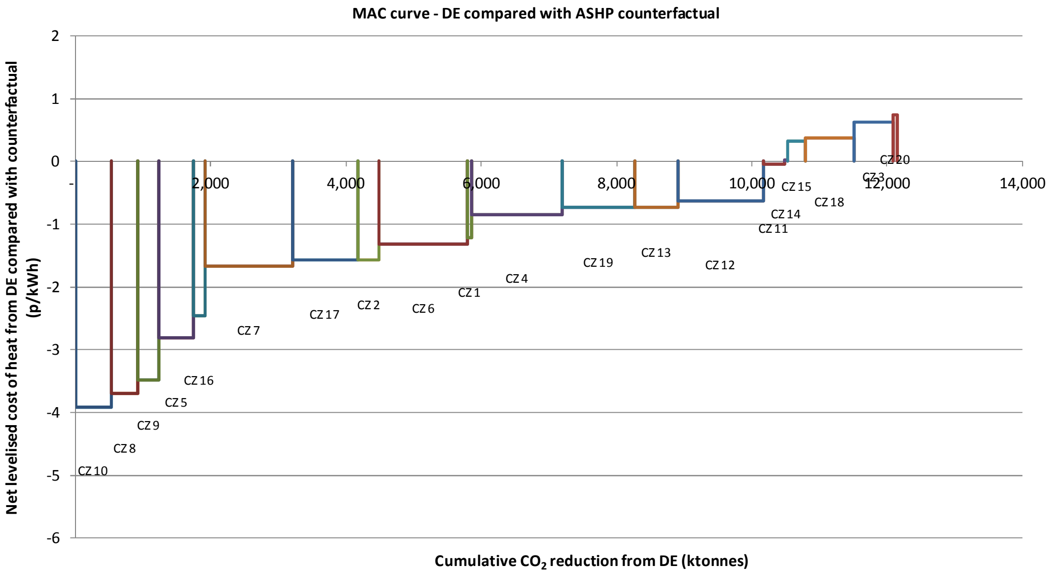

Figure 7: MAC curve for biomass macro DE schemes compared with an ASHP counterfactual. (Please note - these are shown for illustration only and do not imply the potential for biomass macro DE schemes across GB).

Biomass technologies – Biomass CHP

With the model allowed to optimise schemes from all biomass technologies, biomass boilers were selected as the least cost option as discussed above. However biomass CHP systems could provide greater benefits through the higher overall efficiencies offered from the CHP operation. In addition, larger scale biomass CHP systems could potentially be fitted with carbon capture equipment in line with the CCCs recommendations. On this basis, a second model run was conducted examining biomass CHP systems in CZ 7 for comparison with boilers. The comparison with biomass boilers and gas CHP is shown in Table 6.

Table 6: Comparison of biomass CHP optimised macro DE scheme with the biomass boiler optimised macro DE scheme (data shown for CZ 7)

System	**Base case - gas CHP**		**Biomass option**		**Notes**
	£ / kWh thermal	kg CO_2 / kWh thermal	£ / kWh thermal	kg CO_2 / kWh thermal	
Biomass Boilers	0.079	0.123	0.107	0.087	83% of heat from biomass boilers
Biomass CHP	0.079	0.123	0.123	0.232	6% of heat from biomass CHP

The scheme optimisation selected steam turbine-based biomass CHP which demonstrates that it provides an economic advantage over a gas-boiler only scheme. However the capacity of circa 6 MW is only around 4 % of the peak load, and therefore the CHP system only provides a small fraction of the overall heat load. This small contribution results in overall CO_2 emissions and costs which are similar to a boiler only scheme, and offer no advantage over the counterfactuals.

The poor performance of the biomass CHP system can be attributed to the poor electrical efficiencies of small steam turbine biomass CHP units. The high capital cost and low electricity revenues associated with this system result in poor overall economics.

Gasification biomass CHP units are also included in the technology library but were not selected. Despite having a lower cost per kWe, and higher electrical efficiencies, the units in the library are larger in terms of thermal capacity than the steam turbines, and with a higher cost per kWth. The overall efficiency of gasification units is also much lower than steam turbine base systems due to the losses in the gasification process. These factors combined caused the tool to find steam turbine systems more optimal.

These results suggest that small scale biomass CHP systems are not suited for operation on macro DE schemes. If concerns over the use of biomass can be overcome then the option of larger-scale biomass CHP should be taken forward as a development opportunity given its strong CO_2 performance and the potential for using CCS.

Energy from waste (incineration)

Incineration based energy from waste (EfW) systems are used in some existing macro DE schemes in the UK, including those in Nottingham and Sheffield. In a similar manner to AD schemes, energy is only one component of EfW schemes, and of prime importance is the waste management aspect. This means that the energy products from schemes will be largely determined by the waste inputs and availability.

This study examines EfW systems on a heat led basis, and assumes that the process can be used as required by the DE schemes. On large macro DE schemes, this is a reasonable assumption where the EfW plant can operate against the thermal baseload.

Due to the status of EfW as a technology which is currently used on some existing schemes, and the large scale of the technology, the modelling has simulated all CZs. The results are shown in Figure 8.

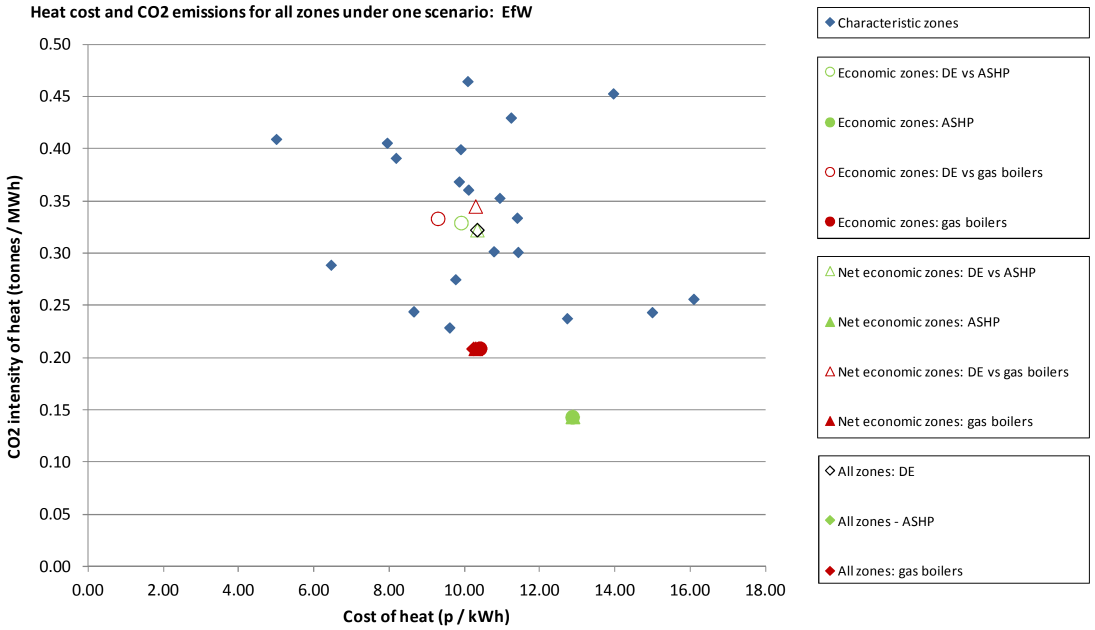

Figure 8: Economic and environmental performance of EfW schemes. (Please note – the averages presented here are shown for GB uptake. These are shown for illustration only and do not imply the potential for biomass macro DE schemes across GB).

The most obvious observations from the results are the wide ranges of both levelised cost and CO_2 intensity. The costs are distributed such that some CZs are economic and others are not, although this range in part can be attributed to the DHN costs. It is also important to note that for three of the CZs, EfW systems were not selected due to the small size of these schemes and their load profiles resulting in no optimised solutions. These zones are therefore based on gas boilers and all have CO_2 intensities around 0.25 kg CO_2 / kWh, but costs equivalent to or higher than the ASHP counterfactual. The CO_2 emissions factor from these schemes is higher than for the counterfactual gas boilers due to the additional thermal losses in the DHN.

From a cost perspective, the potential for EfW macro DE schemes appears large. Assuming that there was sufficient waste availability and EfW plants are viable in each of the CZs and the zones which they represent, then 20% of the GB heat load is economic (the commercial GB benefits case). If ASHPs are considered the counterfactual, then virtually all schemes are economic. This result is not surprising and is backed up by the significant current use of EfW plants on DHNs in the UK and in Europe.

Despite the fact that many schemes are economic, the overall costs are considerably higher than the AD schemes assessed in Stage 1, which is surprising considering that the gate fee assumed for EfW is £45 per tonne, higher than the £10 figure assumed for AD. One reason for this is that carbon prices are applied to the waste for the EfW scheme based on its CO_2 content (see below) which counteracts the gate fee increase.

The CO_2 intensity of the schemes also varies considerably. This is primarily due to the amount of heat supplied to the DHN from the EfW plant which ranges from 16% to 100% (excluding zones with no EfW). This range of heat provision is due to the relatively large size of the EfW systems in the technology library, resulting in very little modularity or ability to optimise the capacity of the energy centre. In reality, EfW plants would be optimised around both the waste availability, but also the DE scheme.

The most important observation about the CO_2 emissions is that they are all higher than the counterfactuals, with schemes having the highest contribution of heat from the EfW plant having the highest emissions. This is due to the emissions factor for waste, assumed to be 0.209 (provided by the ETI and consistent with other ETI studies) and the relatively low electrical efficiency (circa 20%) for the EfW plants.

The analysis of CO_2 as presented is based on the CO_2 content of the waste stream, which in turn depends on the constituent components (some of which are bio-degradable, and others such as plastics fossil fuel based). However these CO_2 emissions are not all avoidable, and other forms of waste treatment will also incur CO_2 emissions whether through recycling (if possible), other forms of waste treatment, or landfill. In the ultimate extent, if there were no alternatives such as landfill available and the waste was simply incinerated, then the same emissions will be produced for no energy benefit. In Denmark, heat from EfW schemes is classed as zero carbon for this reason, thus promoting the use of the technology. Therefore the CO_2 content of energy from EfW schemes needs to consider these alternative treatment options and the associated emissions. This may result in lower emissions for the macro DE schemes which may provide an improvement over the counterfactuals. A detailed analysis of avoided waste treatment CO_2 emissions is beyond the scope of this study but considered as part of the ETI Energy from Waste work.

The potential of EfW is clearly linked to the availability of waste. Detailed forecasts of waste generation are beyond the scope of this work, but it is important to understand the magnitude of the potential. In 2010, circa 290 million tonnes of waste in total was generated in the UK. This includes waste from all sectors, including streams which are inert, re-useable, or recyclable. Out of this total, 32 million tonnes of waste was collected by local authorities from household waste, of which around 50%, or 16 million tonnes was landfilled [9]. Assuming that an energy intensity of circa 10 GJ/tonne for MSW, and thermal efficiency of around 60%, this household waste which is currently landfilled (assuming it could all be incinerated) gives a potential of 26 TWh heat. This is around 6% of the total UK buildings heat demand, or 13% of the Macro DE heat provision potential.

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[9] Defra statistics. http://www.defra.gov.uk/environment/waste

The above calculation shows that even using only household waste, incineration could be used to meet 13% of the total macro DE potential. In reality, additional waste streams could be available from commercial and industrial sources, and this figure could significantly increase. Therefore whilst these calculations are very approximate, they indicate that EfW macro DE schemes could have an important role to play if the waste can be accessed for energy recovery. It is also important to note that there are strong synergies between the waste resource and macro DE schemes (unlike for biomass or AD), with waste generation linked to areas of high density such as towns and cities.

Finally, a common argument in the UK against EfW is that waste generation should be minimised and residual waste recycled as much as possible, thus limiting the amount of waste available for EfW schemes. It is true that the waste hierarchy of reduce, re-use and recycle should be followed, but this is not incompatible with EfW. In countries where high recycling rates are achieved, such as the Scandinavian countries, there is also a much greater uptake of EfW schemes, usually connected to DHNs. For example, Sweden, Denmark, Germany, and the Netherlands all have recycling rates much higher than the UKs, but also incinerate (largely for energy from waste) up to around 50% of municipal waste, compared with 11% currently incinerated in the UK.

Landfill gas

Landfill gas is collected at most landfill sites using a network of pipes into the waste deposit to collect the methane. The capacity of the system is linked to the size of the site, but capacities of up to a few MW are typical. In total the UK currently has around 1 GWe of landfill gas capacity (DECC Restats data). The systems are based around electricity generation with little or no heat off-take.

As a conventional technology, landfill gas was included in the WP 3.2 technology library and modelled in the WP 5.1 simulations. However due to the extensive uptake, a decision was taken to remove it from the available technologies for the following reasons:

- The technology is location dependent, and in general located in edge of town areas or rural areas, away from likely macro DE schemes. The potential is therefore likely to be influenced by geographic factors.
- Landfill gas systems generally have a relatively short life of circa 15-20 years, based on the gas generation lifetime. As less waste is projected to be sent to landfill in the future, the combination of reduced generation from existing sites in combination with a smaller number of new sites will mean the resource becomes smaller. Therefore as the uptake of macro DE schemes may increase in the 2020s, the landfill gas resource will become more scarce.

In the WP 5.1 modelling, all schemes in the 2010s (scenario 1) were optimised with natural gas CHP engines. No landfill gas systems were selected suggesting that they are not as cost-effective as natural gas engines.

All schemes in the 2020s included landfill gas engines, up to around 14 MWth per scheme. This level of uptake is considered unrealistic, and on the smaller schemes which are probably associated with smaller urban areas (for example part or all of a smaller market town), the landfill capacity, if located adjacent to the macro DE scheme, is likely to be significantly smaller. In addition it is likely that landfill gas generation will reduce by the 2020s.

The results showed that the inclusion of landfill gas in the schemes resulted in a relatively small CO_2 reduction from the baseline natural gas CHP schemes of around 0.02 – 0.03 kg CO_2 / kWh.

In summary, landfill gas could contribute to macro DE schemes where the resource is in a suitable location. However the change in resource over time, combined with limited availability means that macro DE schemes should not be designed or optimised around the availability or location of the resource given the limited impact.

Summary

The analysis during stage 4 of this study demonstrates that some of the developing technologies could assist with the deployment of macro DE schemes, including providing energy supply options in the 2030s post natural gas CHP deployment.

However some of the technologies whilst providing economic and environmental benefits are likely to be limited by resource availability, and/or other constraints such as location or land availability.

The following table provides a high level summary of the potential and barriers for each technology.

Table 7: Summary of technologies assessed during stage 4 of the analysis.

Technology	Performance – costs	Performance – CO_2	Resource constraints	Other constraints	Overall potential
Fuel cells	Higher cost than gas CHP – limits uptake of technology.	Limited by low levels of uptake. However offers opportunity for CCS when deployed in fuel cell power stations.	Limited to natural gas availability for NG units. Renewable H_2 fuel will require sufficient additional electricity generation for electrolysis. Short to mid term technology.	None	Limited. Unless significant cost reductions are made in the short term, fuel cells do not appear to offer benefits to macro DE.
Solar thermal	Limited cost reduction due to low thermal %	Limited CO_2 reduction due to low thermal %	Resource and demand load mismatch	Large land take required. Roof mounted systems will require sufficient roof space, and potentially be less cost efficient plus legal / ownership issues.	Very low due to technical and physical constraints and high cost.
CCGT	Large cost reductions from counterfactual.	Similar CO_2 savings to natural gas CHP.	Relies on natural gas. Could be part of longer term peak load plant on the electricity grid.	None	Good potential. Connections to larger CCGT grid base plant could improve potential further.
Biomass - boilers	Cost effective in many CZs against both counterfactuals.	Large CO_2 reductions due to low carbon fuel	Biomass resource and competing markets.	Air quality, transportation.	Limited by resource and competing, more valuable uses.
Biomass CHP	High cost – limits uptake	Large CO_2 reduction, but less than for biomass boilers due to reductions in electricity grid CO_2 intensity	See above	See above.	Very limited economic potential. Limited by resource and competing, more valuable uses. Possible large-scale CHP with CCS
EfW	Economic in a number of CZs – up to 20% of GB heat demand.	No CO_2 reduction due to carbon content of waste. Requires further examination of alternative waste management options.	Waste resource limits uptake, but significant potential remains.	Location of EfW plants in relation to air quality and transportation. Existing systems have been suitably located in UK and abroad.	Good potential based on economic performance and resource.
Landfill gas	No reduction in cost in 2010s, but additional economic benefit in 2020s over gas CHP.	Reduction circa 0.02 kg / kWh for schemes is typical.	Limited resource availability, with projected reduction over time.	Location of landfill sites in relation to macro DE schemes unlikely to be suitable.	Low. Could be included where viable, but unlikely to be a major component.

Of all the systems not selected in stages 1 and 2, EfW and CCGT appear to offer the best potential for applications in macro DE schemes based on performance and resource availability. Further work is required to examine the GB potential of these including the mode of operation for CCGT (heat led versus electricity led), and the calculation of carbon emissions from EfW schemes. The identification of these two technologies is supported by their use in existing schemes globally, and the established nature of the technology.

Of the other technologies, fuel cells are potentially the most flexible, offering a more efficient alternative to internal combustion engines, and extending the period within which natural gas CHP may provide CO_2 savings. However if they are to have potential, significant cost reductions are required through technology development in the near term, otherwise the window for which fuel cells may be viable will be lost.

Conclusions

The analysis of developing technologies in this report demonstrates that there is a strong role for macro DE providing heat in urban areas into the future. In the 2010s and 2020s, the results demonstrate natural gas engine CHP schemes will remain the most economic solution out of all the technologies for large scale deployment.

The original aims of this study were to examine how less mature and novel technologies could support the future development of macro DE. The analysis in this report covers many areas with wide ranging conclusions, but specifically in relation to the project aims, succinct conclusions can be drawn:

Aim 1: Establish the role which novel technologies may take and the importance of novel technologies for DE nationally.

The analysis demonstrates that in the shorter term (2010s), there is a small role for some novel technologies but based on cost and performance combined with fuel and resource constraints, gas-fired CHP is likely to be the preferred technology enabling widespread deployment of up to 43% of the heat market. In the 2030s, the reducing CO_2 intensity of the electricity grid means that the CO_2 savings from gas CHP will become marginal, and the role of novel technologies becomes more important.

The most economic technology identified, suited to wide scale deployment, other than gas-engine CHP is large scale heat pumps provided an elevated temperature heat source (c30℃) is available. These provide a more cost and carbon efficient solution to individual building Air Source Heat Pumps (ASHPs), demonstrating that in a future with limited natural gas use, the combination of macro DE with large heat pumps offers the optimal solution for urban areas, being cost effective for most zones. The performance of the heat pumps depends on the availability of elevated temperature sources which could include industrial processes, mines water, or power generation condenser circuits. The modelling demonstrates that through using elevated temperature heat pumps (which make use of waste or excess heat), alongside gas CHP with an emission constraint of 50% reduction from the gas boiler counterfactual, virtually all CZs remain economic. It is recommended that further work examines the potential of these sources and their locations in relation to the zones.

Large heat pumps, both at an elevated temperature and at temperatures closer to ambient (from WP 5.1 analysis) provide a transition option from gas engine CHP schemes, towards a long term option. They also could potentially operate in tandem with gas CHP systems to allow optimisation of generation technology with the heat pumps operating when there is surplus low carbon electricity on the grid, and the gas engines when there are low levels of renewable grid generation in combination with peak demand periods. It is recommended that further work is conducted to examine how these 'smart heat grid' macro DE schemes could operate.

Out of the remaining technologies, Combined Cycle Gas Turbine (CCGT) CHP and Energy from Waste (EfW) offer the most economic solutions with the greatest potential. CCGT systems can be used in heat led modes with smaller systems, or with heat off-take from larger schemes, which may also be suited to Carbon Capture and Storage (CCS). Given the long term UK Government predictions for CCGT on the electricity grid, and the potential for using CCS, it is recommended that heat off-take options are examined in more detail. Where smaller CCGT units are used in a heat led macro DE scheme, the lack of modularity and load following means that there is only a marginal benefit over gas engine schemes even though the electrical efficiency is slightly higher..

Aim 2: Identify the key novel technologies for future technology development and commercialisation which may have a large impact on the macro DE potential.

The analysis in this report shows that the most suitable 'novel' technologies are in fact systems which have a large degree of maturity, and which are already used in some macro DE schemes.

Heat pumps in particular offer a flexible option, especially when a higher than ambient temperature source is available allowing improved Coefficient of Performance (CoP). There are no direct fuel or feedstock constraints, although, clearly, access to electricity will be important and widespread deployment will increase the need for low carbon grid generation. On the other hand, the increase in load provided by the heat pumps could provide a useful sink in times of excess renewable generation, which would be enhanced if storage in the form of heat is included. Heat pumps with large-scale storage would also enable heating demands to be managed over the day to avoid high peak demands on the grid. It is therefore recommended that further work examines the technology development of heat pumps, alongside the technical design and operation protocols of District Heating Networks (DHNs) to allow operation at lower flow temperatures with the aim of improving overall CoPs of large units,. It will also be important to identify and assess the viability of waste / excess heat sources for use with heat pumps.

Energy from Waste has also been identified as a technology which could have an impact on the macro DE potential. A detailed study of waste resource was outside the scope of this study, but the high level data analysed suggests that a useful fraction of the overall macro DE potential can be met using energy from waste systems with household waste alone. A key consideration of EfW is the calculation of CO_2 emissions, in the context of alternative waste management and disposal options and further work needs to consider this. The EfW systems examined in this work are based around incineration, and alternative treatment forms could offer additional benefits and should also be considered in future work.

Aim 3: Understand the high level impacts of the novel technologies on existing and new supply chains, in particular in relation to feedstock and waste outputs.

Anaerobic digestion (AD) systems could provide a more cost optimal solution where the opportunities exist. However the feedstock is extremely limited in relation to the heat demand, and the location of feedstock and digestate disposal needs considering in addition to proximity to heat loads. In reality, these constraints, combined with land take requirements, may mean that more localised DE deployment of AD is likely to be more practical, potentially not connected to DHNs. Future work should examine how access to feedstock can be maximised, and whether there are opportunities for growing dedicated feedstock, but the overall feedstock constraint will remain significant.

Biomass is not predicted to be a significant component of macro DE schemes in GB. Whilst boilers can be used to develop economic and low carbon schemes in the near term, there are significant concerns over the potential fuel available for macro DE and the sustainability of the supply chain in the longer term. The Committee on Climate Change has highlighted that stationary heat and power applications are one of the less useful applications for the limited biomass resource available[10]. Their preferred applications are industrial heat and aviation and shipping. Our modelling demonstrates that current biomass CHP systems are much less cost effective than biomass boilers and small scale systems have a very limited benefit. However much larger biomass CHP systems with heat off-take would be more efficient and can be equipped with CCS to increase the benefits.

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[10] Chapter 4, Bioenergy Review, Committee on Climate Change, December 2011

Aim 4: Identify whether expected improvements in performance or reductions in costs of existing technologies could materially alter the conclusions from the WP5.1 results

The analysis in this report suggests that technologies which offer the best potential for macro DE other than gas CHP are large heat pumps, EfW, and CCGT heat off-take. All of these technologies are relatively mature and used in both the UK and other countries. Therefore the barriers appear not to be technological development and cost (although reductions in cost will improve economic viability), but many of the other barriers discussed in WP1 and WP 5.4 which prevent their use or uptake. Therefore further technical improvements are unlikely to improve their uptake further and efforts should be concentrated on overcoming the other barriers. Examples include identification and securing of waste feedstocks and waste heat, addressing public perception issues around the location of technologies (EfW), ensuring that the technologies are suitable located (for example, that all new CCGT systems with CCS are built near urban areas with potential for DHNs) and potentially introducing regulation which enables strategic decisions to be taken around the co-location of technologies with DHNs.

For technologies where the level of maturity is lower, the potential for use in macro DE appears to be relatively limited. In the case of biomass technologies, in particular CHP systems, there is widespread acceptance that the current smaller systems are immature and not performing as desired. However, even with extensive development, the feedstock availability constraints will remain, fundamentally limiting the uptake of macro DE.

Fuel cells are another example of a technology which is relatively immature and where there is further scope for technical development. However, the increase in economic lifetime of small scale gas-fired CHP offered by fuel cell technology over gas-engines is limited, and significant cost reductions and technological improvements are required in a very short time to enable fuel cells to contribute to macro DE before the grid is decarbonised and the benefits of gas-fired CHP are lost. If alternative fuels such as hydrogen are to be used, then there are wider issues around the development of new energy vector fuel supply chains and infrastructure, and the efficiencies of generating hydrogen and corresponding increase in electricity demand.

Appendices

Appendix 1 – Input assumptions to scenarios

The modelling in work package 5.1 and work package 5.3 is based around twelve assessment scenarios. These scenarios are used to define the input assumptions used in the optimisation model, and allow the assessment of sensitivities which may impact the potential for DE across GB.

The scenarios are illustrated in Figure A1.1 below.

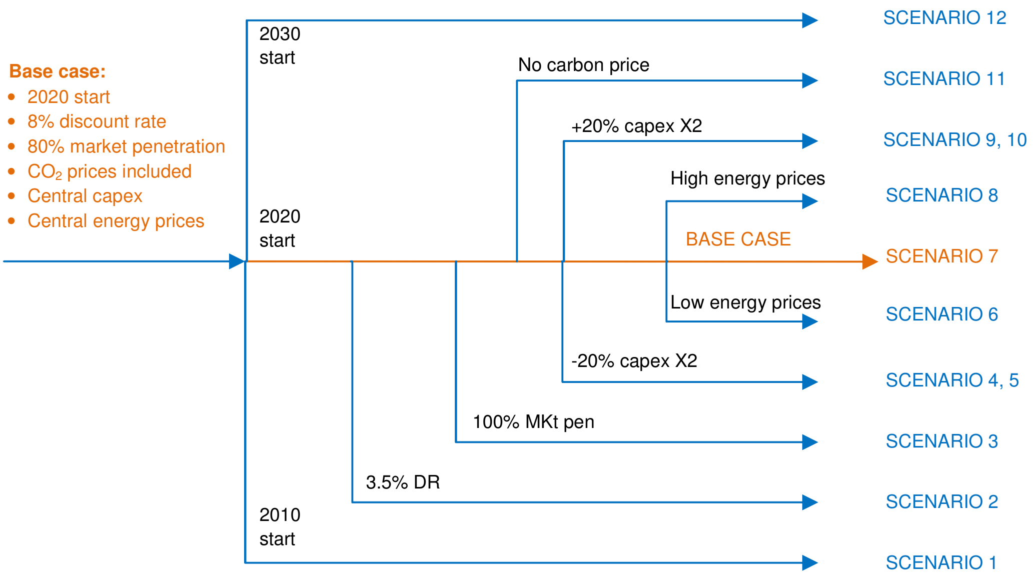

Figure A1.1: Schematic showing the various assessment scenarios.

The following sections provide further information on the inputs used to form the scenarios.

Decadal analysis

A number of the input parameters change over time, in particular the projected costs and revenues from energy, and the CO_2 intensity of grid electricity. The CO_2 benefit of gas-engine CHP will reduce over time as the grid is decarbonised. It is therefore important to reflect this in the analysis of the CO_2 emissions. The modelling uses a 25 year period of operation (to reflect the design life of the DH network) for the lifecycle costing analysis. Three scenarios are formed with starting years of 2010, 2020, and 2030. The 2010 case represents a project that might be initiated now, demonstrating how macro DE schemes may perform in the earlier stages of mass deployment. The 2020 period represents schemes that are implemented in the peak deployment period envisaged by ETI. After 2030 some predictions (Climate Change Committee) indicate that the grid will be fully decarbonised by this time and so the position would be similar in any year after this date.

Market penetration

The model as constructed assumes that 80% of the heat market in any one zone will be supplied from start-up and that this is reflected in: the energy data, the Energy Centre design optimisation and the heat network. This provides a realistic approach where the possibility of no regulation requiring connection, and acceptance that some buildings may find it difficult to connect even in the presence of regulation, limits the maximum penetration. The outcome of this reduction in penetration is:

- The energy centre and transmission network are sized for 100% penetration
- The distribution and connections are sized / costed for 80% penetration.

The ongoing costs and revenues from the generation and sale of energy are reduced in line with the reduced heat demand. However the excess capital cost associated with the energy centre and transmission being sized for 100% results in a higher overall levelised cost.

The 80% market penetration case is a central assumption and used in the majority of the scenarios. A sensitivity scenario is also modelled where penetration achieves 100% (for example through regulation and mandatory connection) and the levelised costs are reduced.

The market penetration defined here is within the zone and should not be confused with the overall national penetration of DE which could vary from 0% to 45% approximately depending on the cost-effectiveness calculated for each CZ.

Financing costs

As a Macro-DE project is capital intensive, the cost of financing is crucial in the analysis. This is modelled by selecting a discount rate and period of economic analysis when calculating the annualised cost of heat supply. The selection of discount rate is partly a function of whether the project is expected to be developed within the private sector or the public sector and if in the private sector the degree of risk associated with the business opportunity. If the project is de-risked through regulation for example guarantee of the heat market then the private sector would be able to raise capital at lower rates of return as typically seen for other utility services.

It is also important to consider the cost of finance for the comparator heat supply options to ensure that the Macro-DE project is not unduly favoured. Whilst the electricity and gas sectors are privatised the distribution businesses are regulated as natural monopolies and thus have relatively low financing costs.

To examine the impact of financing costs the assessment assumes a base case of an 8% discount rate (in real terms) to represent a typical private sector return and, as an alternative scenario, a 3.5% discount rate to represent a public sector project. These same discount rates are used throughout for the comparator heat supply options. An 8% return has been adopted for other ETI projects and is therefore consistent with these other studies.

The economic calculations derive annualised costs for the Energy Centre equipment and DHN based on its typical economic life. The lifetimes vary depending on the technology with the DH network assumed to have a 25 year life for the economic assessment. In reality, the life is likely to be longer and therefore replacement generation technologies after this period will have a more attractive rate of return.

Capital costs

This study uses a sensitivity test of +/-20 % on the costs of the district heating network and separately +/-20% on the cost of the prime mover. There are a number of uncertainties around capital costs, from the cost of the actual equipment, to site specific factors such as connection costs and construction requirements. Rather than examine each in detail, the simpler percentage adjustment route allows investigation of the potential outcomes.

Energy prices

Macro DE schemes are an example of a capital investment resulting in an energy saving. Hence when energy prices are high, there will generally be a greater rate of return from macro DE schemes. The modelling is based around mid energy price projections for the central case, with high and low sensitivity cases. All three sets of projections are based around the price *scenarios* published by DECC in the IAG guidance. Although the economics of CHP is influenced both by electricity and gas prices these are not independent parameters as part of our electricity is produced from gas. It is also important that any future price scenarios used are also consistent with the CO_2 emission factors that are assumed for the electricity supply, and the use of IAG marginal electricity emission factors ensures this consistency.

These future price scenarios or sensitivities are applied to both the macro-DE cases and the counterfactual options.

Energy prices for biomass are based on research by AEA[11]. The low price scenario is taken from the AEA analysis and effectively remains constant. The high price projections are based on trends from the CCC and include the market demand effects driving up prices [12]. The mid projection is a mid-way projection between the two. These projections are shown in Figure A1.2.

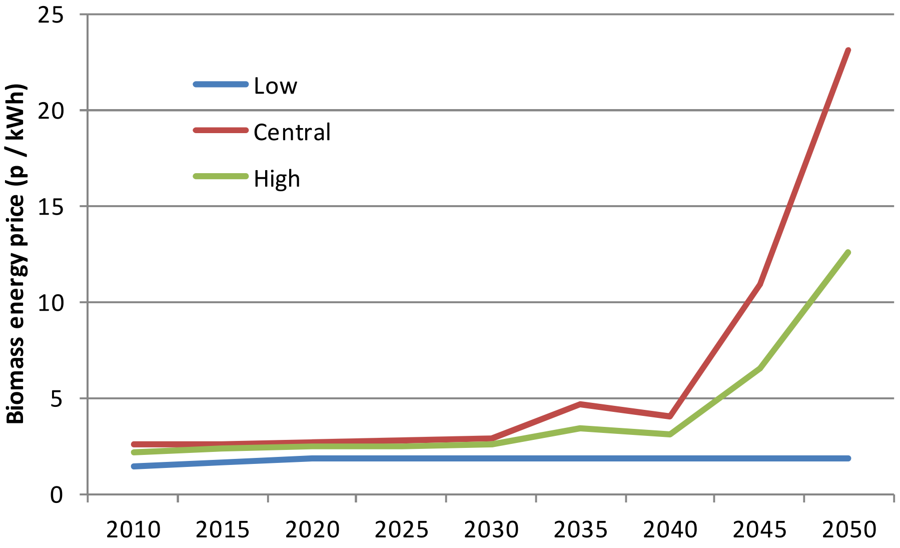

Figure A1.2: Biomass energy price projections.

Other energy prices, including gate fees for AD and EfW are projected to change in line with the IAG gas projections, assuming that these will be subject to market forces.

Carbon Prices

The central case will assume that carbon emissions have an associated cost at the non-traded level in the IAG guidance. This reflects the fact that some sectors currently are liable for carbon costs through the CRC and EU-ETS, and that this situation is likely to continue with an expansion. The Carbon Price floor proposed in the electricity market reform is one sign that carbon prices will become more widespread and affect more sectors.

As a sensitivity, a scenario is presented without the carbon prices applied to examine the impact of carbon pricing on technology selection.

CO_2 emissions

The calculation of CO_2 emissions can be complex, especially in relation to offsetting grid electricity. Whilst the grid has an ‘average’ emissions factor over a year based on the amount

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[11] UK And Global Bioenergy Resource. AEA. Report for DECC. 2010.

[12] Bioenergy Review. Committee on Climate Change. 2011.

of electricity generation, and different fuels used, reducing or increasing demand on the grid will require a decrease or increase in certain generation types, which has an associated emissions factor called the 'marginal' factor. Thus the assessment effectively needs to be made against the marginal factor because it is the marginal plant which will be affected.

The marginal factor will change over time and depends on the market conditions and type of generation. Intermittent renewable technologies such as wind will not be marginal because they cannot be simply turned on and off. Low carbon nuclear will also not be marginal due to the low emissions and base load characteristics. Therefore the marginal factor is likely to be influenced by fossil (CCS and non CCS) for the foreseeable future.

There are also two aspects to marginal generation – 'operational marginal' which reflects the operation of existing power stations on the system and 'build marginal' which considers which types of plant would be built or not built as demand changes.

This study uses marginal emissions factors from the latest (October 2011) DECC IAG guidance. This means that the CO_2 projections are consistent with the future energy price assumptions also used in this modelling. This marginal factor represents 'build marginal' and therefore suited to large scale displacement of grid generation through significant uptakes of macro DE.

It is important to note that the grid electricity CO_2 emission factors are independent of the level of macro DE uptake, and further work should examine the impact that large scale macro DE may have on the grid generation mix.

Table A3.1 shows the CO_2 emissions factors assumed for grid electricity and other fuels included in the work package 5.1 technology library.

Table A3.1: Summary of CO_2 emissions factors used in the WP 5.3 modelling.

Fuel type	Year	Emissions factor (10 year average)
Natural gas	Na	0.199
Landfill gas	Na	0.000
Grid electricity	2010	0.485
	2020	0.351
	2030	0.160
Biomass	Na	0.029
Landfill gas	Na	0.000
Municipal waste incineration	Na	0.209
Wet waste / AD feedstock	Na	0.000
Low sulphur diesel	Na	0.240
Biodiesel	Na	0.144

Scenario inputs

Full details of the inputs used for the scenario modelling are shown on in table A3.2. All time variable factors such as energy costs and carbon costs are shown as an annualised figure over the 25 year economic assessment period.

Table A3.2: Summary of inputs used in the scenario modelling.

Scenario Number	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10	SC11	SC12
Year	2010	2020										2030
Macro DE inputs												
1. Discount rate	8%	3.5%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%
2. Fuel prices, p/kWh												
a. Natural gas	4.76	5.61	5.42	5.42	5.42	4.35	5.42	6.53	5.42	5.42	3.74	6.45
b. Diesel	10.93	12.38	12.09	12.09	12.09	9.24	12.09	15.06	12.09	12.09	9.93	13.56
c. Biodiesel	12.71	14.03	13.82	13.82	13.82	10.22	13.82	17.55	13.82	13.82	12.53	14.87
d. Landfill gas	5.06	5.43	5.39	5.39	5.39	3.84	5.39	7.00	5.39	5.39	5.39	5.54
3. Electricity tariff, p/kWh	11.90	12.97	12.91	12.91	12.91	10.76	12.91	14.11	12.91	12.91	10.88	13.07
4. Grid emission factor, kg/kWh	0.485	0.351	0.351	0.351	0.351	0.351	0.351	0.351	0.351	0.351	0.351	0.160
5. Market penetration	80%	80%	100%	80%	80%	80%	80%	80%	80%	80%	80%	80%
6. DHN capex	-		-	-	-20%	-	-	-	-	20%	-	-
7. CHP capex	-		-	-20%	-	-	-	-	20%	-	-	-
Counterfactual inputs												
Domestic												
Natural gas price p/kWh	6.93	7.81	7.62	7.62	7.62	6.18	7.62	9.11	7.62	7.62	5.94	3.91
Electricity tariff p/kWh	20.77	23.30	23.24	23.24	23.24	19.42	23.24	24.45	23.24	23.24	21.21	13.05
Commercial												
Natural gas price p/kWh	5.34	6.21	6.02	6.02	6.02	4.81	6.02	7.27	6.02	6.02	4.33	7.05
Electricity tariff p/kWh	17.05	19.06	19.04	19.04	19.04	15.55	19.04	20.19	19.04	19.04	17.00	19.03

Appendix 2 – Counterfactual assumptions

The following tables provide a summary of the inputs used for the counterfactual calculations

Table A2.1: Counterfactual inputs for gas boilers

Gas boilers					
	Units	**Value**			**Reference and notes**
Domestic		**2010**	**2020**	**2030**	
Capital cost	£ / dwelling	£2,500	£2,500	£2,500	ETI
Annual Maintenance	£ / dwelling	£200	£200	£200	Typical annual contract (note 3)
Efficiency	%	85%	85%	85%	C
Lifetime	years	15	15	15	A
Fuel input	type	Gas	Gas	Gas	D
Fuel cost	IAG rate	Retail domestic	Retail domestic	Retail domestic	D
Commercial					
Capital cost	£ / kW	79	79	79	A (see note 1)
Annual Maintenance	£ / kW.yr	£2	£2	£2	A (see note 1 and 3)
Efficiency	%	90%	90%	90%	B
Lifetime	years	15	15	15	A
Fuel input	type	Gas	Gas	Gas	D
Fuel cost	IAG rate	Retail commercial	Retail commercial	Retail commercial	D

Table A2.1: Counterfactual inputs for air source heat pumps.

Air source heat pumps					
	Units	**Value**			**Reference and notes**
Domestic		**2010**	**2020**	**2030**	
Capital cost	£ / dwelling	£7,500	£4,500	£3,500	ETI - central. Assume nominal 10 kW
Annual Maintenance	£ / dwelling	£100	£100	£100	ETI (note 3)
Efficiency	%	208%	219%	229%	ETI (note 5)
Lifetime	years	15	15	15	ETI
Fuel input	type	Electricity	Electricity	Electricity	D
Fuel cost	IAG rate	Retail domestic	Retail domestic	Retail domestic	D
Commercial					
Capital cost	£ / kW	£449	£269	£210	B (see note 1 and 2)

Annual Maintenance	£ / kW.yr	£7.30	£7.30	£7.30	B (see note 1 and 3)
Efficiency	%	375%	394%	413%	B (see note 1 and 4)
Lifetime	years	20	20	20	A
Fuel input	type	Electricity	Electricity	Electricity	D
Fuel cost	IAG rate	Retail commercial	Retail commercial	Retail commercial	D

References

A NERA / AEA. UK Supply curve for Renewable Heat. 2009. DECC.

B AEA review of technical information on renewable heat technologies. 2010. DECC

C Getting warmer: A field trial of heat pumps. 2010. Energy Saving Trust.

D Valuation of Energy Use and Greenhouse Gas Emissions for Appraisal and Evaluation. 2011. DECC and HM Treasury.

Notes

1 Values are provided for large and small installations for commercial/public. A mid range value is selected to represent medium installations.

2 The learning rates for commercial ASHP are assumed to be similar to the ETI figures for domestic.

3 Assumes that maintenance is labour dominated and therefore unlikely to change.

4 Efficiencies assumed to increase in line with ETI assumptions.

5 Based on ESME values of 208% for 2010 and 250% in 2050. Linear interpolation gives 218.5% for 2020 and 229% for 2030.

Glossary

Base Case: :This is the central scenario used for all modelling, around which sensitivities are investigated.

Baseline: The baseline is a scheme where DH is not adopted and alternative individual dwelling technologies are used. For the 2010 case, the baseline is conventional individual gas boilers. In future years, the baseline includes the use of heat pumps.

Benefits Cases: Three benefits cases are considered for GB, covering commercial potential (only economic schemes), economic potential (allowing more economic schemes to subsidise un-economic schemes with a neutral cost impact on GB), and maximum CO_2 savings (all schemes).

Characteristic Zone (CZ): This is the “central” zone within a Class selected for use in modelling the DE schemes and representative of all of the zones with the Class.

Class: A class is a collection of zones that has been shown to be distinct from other Classes and where the zones are sufficiently similar to other zones in the Class.

Market Penetration: The uptake of customers and connections on a DH network is termed market penetration. The best case is that 100% market penetration is achieved with all potential customers connected. In reality, the value will be lower with uptake happening over a number of years to the maximum level.

National Penetration: The uptake of DE across the GB expressed as a percentage of heat provided by heat networks, or the percentage of non domestic and domestic customers.

Scenario: A set of conditions under which the schemes are modelled for each CZ. A total of 11 scenarios are proposed.

Zone – A group of MLSOAs ....

Acronyms

ASHP: Air source heat pump

CHP: Combined heat and power

CoP: Coefficient of performance .

CZ: Characteristic zone. A zone which represents all other zones in a class and is statistically selected based on a number of criteria describing energy consumption of the zones.

DE: Distributed Energy

DHN: District heating network

GSHP: Ground source heat pump

IAG: Interdepartmental Analysts Group

MLSOA: Middle Layer Super Output Area.

NPV: Net present value of a discounted cashflow.

WP: Work package.