Programme Area: Distributed Energy

Project: Macro DE

Title: Macro DE Summary Report

Abstract:

The Government's recently published heat strategy identifies two pathways for the long-term reduction in Carbon Dioxide (CO2) emissions from energy for heating buildings and provision of domestic hot water:

- the use of district heating (DH) supplied by a range of low carbon heat sources
- the use of individual heat pumps supplied by a largely decarbonised electricity grid

The Government recognises that in high density urban areas DH is likely to be more cost effective and that in rural areas DH is not a practical solution. This leaves a large proportion of the country where either option would be feasible technically but where there is considerable uncertainty as to which option is preferable from both a cost and CO2 perspective.

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 5.4.

Summary Report
Version 5 - FINAL

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Glossary of Terms

AD.......................Anaerobic Digestion

ASHP..................Air Source Heat Pump

CCGT.................Combined Cycle Gas Turbine

CCS...................Carbon Capture and Storage

CHP......................Combined Heat and Power

CO_2.......................Carbon Dioxide

CZ........................Characteristic Zone

DE....................... Distributed Energy

DH.........................District Heating

DECC.................Department of Energy and Climate Change

DHN......................District Heating Network

EfW......................Energy from Waste

Energy Centre...................Location for Heat Source(s)

ETI......................Energy Technologies Institute

EU......................European Union

GB......................Great Britain

GHG......................Green House Gas

GWh......................Gigawatt Hours

Ha.........................Hectares

km......................Kilometre

kW........................Kilowatt

MLSOA.................Medium Level Super Output Area

MW........................Megawatt

MWe........................Megawatt (electrical)

MWh..................Megawatt Hours

MWth.....................Megawatt (thermal)

NO_x.........................Nitrogen Oxide/Dioxide

p.a.................................per annum (per year)

TERMIS..................... District Energy Network Simulation Software

TWh.....................Terawatt Hours

TWth......................Terawatt (thermal)

UK......................United Kingdom

WP......................Work Package

Executive Summary

Introduction

The Government's recently published heat strategy[1] identifies two pathways for the long-term reduction in Carbon Dioxide (CO_2) emissions from energy for heating buildings and provision of domestic hot water:

- the use of district heating (DH) supplied by a range of low carbon heat sources
- the use of individual heat pumps supplied by a largely decarbonised electricity grid

The Government recognises that in high density urban areas DH is likely to be more cost effective and that in rural areas DH is not a practical solution. This leaves a large proportion of the country where either option would be feasible technically but where there is considerable uncertainty as to which option is preferable from both a cost and CO_2 perspective.

The Aim of this Project

The Macro District Energy (DE) project has been able to establish the cost of heat supply and the CO_2 emissions for a range of characteristic zones which represent the urban and suburban areas within Great Britain[2] (GB), assessing both residential and tertiary[3] demands, to help resolve this uncertainty. A consortium led by Caterpillar delivered the project with the principal members being EDF and EDF-Eifer, University of Manchester, Mooney Kelly Niras and AECOM.

Methodology

In the United Kingdom (UK) there are a number of successful District Heating Networks (DHNs) but their share of the market is low (1-2%) compared with much higher shares in some parts of Europe (e.g. Denmark at 60%).

About half of the heat demand of GB was found to be suitable for DH in principle based on a minimum threshold of heat density of 200MWh/Ha as used in Europe and elsewhere. This conclusion is in line with the Department of Environment and Climate Change's (DECC's) own analysis from heat mapping (para 3.21 in the Future of Heating). Heat demands were estimated for each of these higher density Middle Layer Super Output Areas (MLSOAs), a total of 4,660, as hour by hour profiles throughout the year as well as peak demands.

The selected 4,660 MLSOAs were then combined to form 948 'zones' which were contiguous and were still above a threshold heat density in aggregate. The maximum size of zone was limited to that suitable for a 50MWe Combined Heat and Power (CHP) plant.
These 948 zones were then analysed to establish 20 'classes' which were distinct from each other using classification parameters including: scale, heat density and the ratio of domestic heat demand to tertiary heat demand. The 20 classes contained different numbers of zones but for each class a single zone (the median zone) was selected for analysis termed the Characteristic Zone (CZ).

The costs of a DH network (DHN) were determined by designing a DHN for three CZs which together contained 16 MLSOAs of varying density. A DHN Cost Algorithm was established from this work which enabled the cost of the DHNs to be determined for each of the 20 CZs.

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[1] The Future of Heating, a strategic framework for low carbon heat in the UK, DECC, March 2012
[2] As data was not available at the same level of detail for Northern Ireland this project is limited to Great Britain (England, Scotland and Wales)
[3] Tertiary is defined as non-domestic buildings and excluding industrial energy use

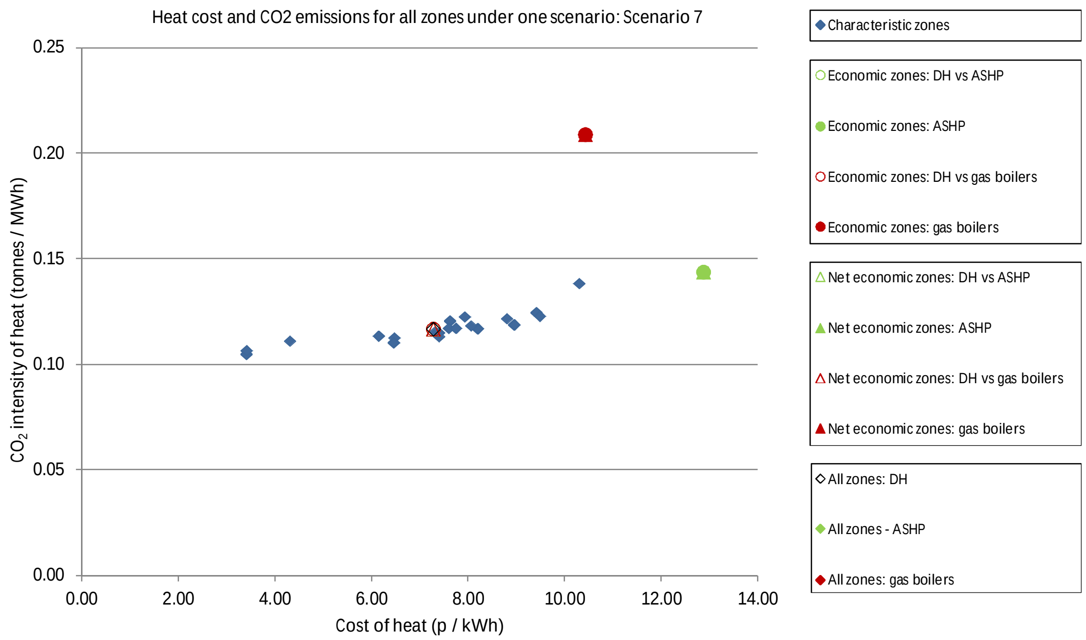
A range of technologies can be used to supply the DHNs which is referred to as the Energy Centre solution. Energy and economic modelling of an Energy Centre solution was carried out for each CZ using an optimisation tool which was able to select the lowest cost energy solution taking account of capital costs, fuel costs and maintenance costs over a 25 year period. Where Combined Heat and Power[4] (CHP) was used, electricity revenues were calculated and included in the model. A library of potential heat sources (both available now and in the future) was created for use by the model including: gas-fired CHP, large-scale heat pumps, biomass boilers, biomass CHP and Energy from Waste technologies.

The cost of heat production at the Energy Centre and the cost of heat distribution via the DHNs were combined to produce a total levelised cost of heat delivered in each CZ. The CO_2 emissions associated with this heat supply were also calculated. The cost of heat supply and the CO2 emissions were compared against two counterfactuals, gas-fired condensing boilers and air source heat pumps (ASHP).

A total of 12 scenarios were modelled for each of the 20 CZs using proven current technology for heat sources (reported in WP5.1). Further modelling was undertaken on selected CZs to investigate a range of future heat source technologies (reported in WP5.3).

Results

The results for the central scenario are presented in the 2-D plot below:



The main conclusions from the Work Package 5 (WP5): GB benefits analysis work in relation to the national benefits are:

1. Given the right regulatory and fiscal environment (to deliver an 80% market penetration and provide equitable treatment in the market for electricity generated locally by CHP plant), DHNs could be the lowest cost way of delivering CO_2 reductions in the building environment, assuming a cost of finance equivalent to that of 8% real pre-tax discount rate, and with the cost of carbon emitted applied uniformly to all sectors including domestic and equal to the social costs of carbon set by the Government.

[4] Combined Heat and Power involves the generation of electricity and heat in a single process to improve primary energy efficiency

2. There is a current economic case for building DHNs and this is likely to improve over time given forecasted energy prices rises published by DECC. Our analysis is based on a 25 year cashflow, as the life of the DHN will exceed 25 years, in the long term there will be a stronger economic case for retaining and operating the network as the capital repayments will have been made.
3. The CO_2 emissions reductions available when using gas-fired CHP are highest now but this benefit will decline over time as the electricity grid decarbonises. Provided unabated gas-fired CCGT power stations remain on the system, gas-fired CHP will continue to provide a CO_2 saving compared to individual building gas-fired boilers.
4. In the long-term (post 2030), DHN remains competitive in cost and CO_2 performance with individual ASHPs although the relative CO_2 benefit will depend on whether large-scale heat pumps to supply DHNs can access an elevated heat source such as industrial waste heat that would not be available for individual building heat pumps.

Of the future technologies analysed the most attractive for further technical and commercial development are:

Combined Cycle Gas Turbine (CCGT) CHP (<100MWe). As this technology has a higher efficiency than gas-engines the potential for CO_2 savings are greater. It is applicable for the larger zones and cities containing multiple zones which could be interconnected. Although it did not appear to compete with multiple gas-engines CHP it was not significantly more costly and further development would be worthwhile. Also, such CCGT plants may be more suitable in the future for use with Carbon Capture and Storage (CCS).

Energy from waste CHP. A number of established Macro DE projects in the UK (e.g. in Sheffield, Nottingham and Lerwick) utilise energy from waste as the primary heat source - normally in CHP mode. However this is still a largely untapped energy resource as there is still considerable waste going to landfill and many energy-from-waste projects are electricity-only plants recovering only around 30% of the available energy. The impact of greater recycling will reduce the volume of residual waste available. There are ongoing technological developments in advanced thermal treatment processes some of which are beneficial to operation as CHP plant. There is a need to assess the national resource available and relate it to the results of the Macro DE project in terms of the geographic match of resource to heat demand.

Power station heat. An opportunity not analysed in this report is to extract heat from major power stations where these are sited close to urban areas. This is likely to be the most efficient way to produce heat for DHNs and could be compatible with a future scenario where carbon capture and storage technology has become established, depending on the location of such power stations.

Conclusions

The main conclusions from WP5 in relation to the ETI (Energy Technologies Institute) members' benefits are:

- There is a substantial business opportunity to develop Macro DE projects across the country if the right economic and regulatory environment can be achieved. A total investment of £128billion would be required if the full potential of the technology is achieved (£35billion for the Energy Centre, £93billion for DHNs). Macro DE offers substantial CO_2 savings especially over the next decade, a benefit to the national economy of around £6.3billion p.a. and, by making more efficient use of gas, Macro DE would improve our energy security.
- The main risks are not in the technology but in the security of the heat market and a proper recognition of the carbon savings of CHP systems and the benefits of local electricity generation. Many projects will have the potential to start small and expand through organic growth of the network and the use of modular CHP plant.

The size of the GB market is such that it would justify new manufacturing plant for the various components, building on established UK industries such as reciprocating engine design and manufacture, gas turbines and steel production and pipe fabrication.

However, if fully developed, the scale of Macro DE is such that it will impact on other electricity generation technologies in which ETI members also have an interest. However, in the longer term there is the potential for large city-wide district heating networks to be developed taking heat from thermal power stations of any type, subject to the more strategic siting of power stations closer to major city heat loads.

1. 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 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 or uneconomic to make more efficient and 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 low carbon heat producing technology such as a Combined Heat and Power (CHP) system providing heat to a district heating network (DHN). The DHN consists of a series of insulated pipes distributing heat from the central source to individual buildings. The main advantage of DE is that technologies providing high energy efficiencies (such as CHP), or other sources of heat such as waste heat from industry can be utilised and distributed. A further advantage is that heat can be stored more efficiently and economically within DE schemes than at individual buildings. However the cost of installing heat networks and energy centres can be high and the viability of a DE scheme will depend on the economic performance of the DE scheme compared with other options (typically heating systems at an individual building scale).

This Macro Distributed Energy Study for the ETI aims to assess the role that DE could have in GB in providing low carbon and low cost heat to buildings. The work examines schemes of up to 50 MW aggregated loads representing large scale networks which may cover large parts 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 in GB.

The work in the Macro DE project is split into 5 distinct work packages which aim to characterise DE in GB, and develop a suite of data and a pre-prototype software based tool to allow the assessment of the potential and the 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 DE uptake. It also provides a summary review of current software supporting the design of DE systems.
- 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 20 distinct Characteristic Zones (CZs) for subsequent analysis. A set of energy demand profiles are developed and used to represent the aggregated energy demand of the CZs as an input to later modelling of DE centres in work package 4.
- WP 3: Energy Supply Characterisation. This work package develops energy supply options for the CZs based around DHN infrastructure and both new and future technologies. DHNs are 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 these designs are 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 this work package 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 CZ demand characteristics, the performance of supply technologies, lifecycle costs, and a number of other inputs. The output from the tool is the most appropriate system based on cost or CO_2 optimisation.
- WP 5: UK Benefits Case Opportunity Identification & Summary of the Individual Development Options. This work package 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.

This Report 5.4 is a summary report for the whole of the Macro DE project. Although the main conclusions are presented together with an outline of the methodology it is recommended that the reports for each WP are consulted for further detail. These are listed in the Appendix and referred to within the text as ‘Report X.X’ where X.X is the Deliverable reference number.

The report is structured by summarising the work of each WP in turn followed by an overall conclusion and recommendations section.

2. Design Practice, State of the Market, and Overview of Current DE Software (WP1)

The first part of the work of WP1 was a review of the current market and the main conclusions were:

- There is a lack of financial incentive to support district heating and gas-fired CHP in the UK even though in many other countries some financial or regulatory support has been needed for the full potential of these technologies to be realised. For example, energy from CHP in several countries has been made untaxed, and grants are in available to ease the immediate financial burden of district heating and CHP.

- The current and planned incentive schemes mainly relate to support for renewable energy generation at either an individual household level or at national level in response to the commitments to achieving EU renewable energy targets.

- There is a view within Government that district heating is a high capital cost option that would lock consumers into a single heat supply system.

- There is a growing consensus that heating will increasingly be provided by electricity resulting in reduced carbon emissions as the grid is decarbonised.

A stakeholder consultation process was held in 2010 and was conducted using both a workshop session and a series of face to face interviews. This revealed a consensus on the following 6 key points which remain valid in 2012:

- DE is an established technology in the UK and throughout Europe.

- The value chain for DE is currently too long, too complicated and with a risk:reward ratio that is not compelling for potential investors.

- There is potential to reduce operating costs and reduce carbon emissions in the near term while constructing infrastructure for future development out beyond 2020.

- DE is inherently flexible as it can both accommodate local level energy targets and complement the grid in times of peak demand.

- For DE to play a material role in the UK, strong partnerships will be required amongst public and private organisations including relevant funding institutions. It will also be essential to demonstrate a desire to deliver superior value and benefit to the customer and the local community.

- Macro Scale DE requires community rather than individual's action to maximise market penetration at an early stage. This requires a high degree of political commitment and potentially legislative action. Therefore it is not just a matter of technology and costs.

The work also investigated the barriers to deployment of Macro DE and made a number of recommendations that the ETI and other UK based stakeholders should consider:

1. **Policy:** Current policy is too often focused on promoting renewable energy instead of broader objectives around reducing CO_2 emissions and improving energy efficiency. As a result the CO_2 benefits of gas-fired CHP are not properly recognised compared to other technologies. For example there is a Renewable Heat Incentive for heat pumps but no equivalent mechanism for CHP even though the CO_2 savings are potentially higher for CHP. This puts CHP based District Heating at a disadvantage in the market.
2. **Investment:** There are clear advantages around the establishment of a "green investment" bank, whose aims are to unlock UK investment in low carbon industry and technology. This will enable investors to understand the long-term nature and benefits of a district heating infrastructure. The UK Green Investment Bank is now in the process of being set up.
3. **Allocation of risk:** The allocation of risks between private and public sectors and the significant difference in economic lifetimes of heat generation sources (typically 15 years) and heat networks (30 years or more) will need to be understood more clearly. If private sector investment is required the full economic lifetime of the DHN asset may not be recognised.
4. **Capital Cost:** The relatively high capital cost of the heat networks remains a barrier to a greater adoption of DE into the UK and there is evidence that our costs are higher than those seen on the continent. A new financial model needs to be identified recognising the long-term nature of the infrastructure such that the life cycle costs become materially more attractive. A larger market for DH in the UK may lead to lower costs and a more local manufacturing base.
5. **Business Models:** A need to develop a new and smarter set of business models that are applicable across the UK, especially with respect to system level solutions.
6. **Technology:** A focus on development in fuel flexibility and equipment modularisation could improve the adaptability and life-cycle cost of DE solutions.
7. **Grid Flexibility**: An understanding of how potential DE solutions will enable the future flexibility of the UK grid, (with respect to heat and electricity) cost effectively, while simultaneously decarbonising the future energy system. As the electricity supply system moves towards base load nuclear and intermittent wind, the use of a range of heat sources able to be operated flexibly is likely to be of increasing benefit.
8. **Heat Demand:** Mapping the whole of the UK heat demand to identify the potential role of aggregated DE in meeting the future heat needs. A national heat map has now been published by DECC.
9. **Value Chain:** Further investigation is required to simplify the existing and complex value chains to define a clear investment opportunity.
10. **Grid Connectivity:** The cost and time to connect to the grid have to be radically reduced. Regulatory consistency has to become standard practice. This issue is being addressed by the industry with projects being sponsored by Ofgem however greater collaboration with DE developers is still needed to seek out the best connection option.
11. **Behaviour and Education:** Programmes need to be developed that address the required behavioural changes and overall awareness of DE and its benefits across government, business and the general public.
12. **Voice of Customer and Market Needs:** Customers of DE vary considerably: A deeper understanding of customer requirements and needs would allow for more aligned solutions.

A summary review of DE software concluded that though there are many software packages available for the design of aspects of a DE system – e.g. the energy centre, or the DHN, at a local/site-specific level, there are no software packages available for the design and optimisation of a complete energy centre or suite of energy centres at a national/regional level. Hence this justified the need to develop such a methodology based in a software environment, to assess the potential for DE in GB.

The results of the WP1 work formed a useful background to the study as the work progressed through the various work packages.

3. Assessing the Heat Demand and Industrial Waste Heat Sources (WP2)

Annual heat demands

The WP2 team have produced an extensive database of energy demands (electricity and heat) for each MLSOA in GB. This prediction takes account of:

- The type of dwelling and its age
- The type of commercial/institutional building
- The regional climate

The approach was to establish the numbers of different types of buildings, an indicator for its energy use (e.g. floor area) and a benchmark for its energy consumption. This can be expressed in a formula as:

$$Annual\ Energy\ Demand = \sum_{Sector} \sum_{Sites} (indicator \times factor \times benchmarks)$$

Figure 3.1 also represents the approach taken.

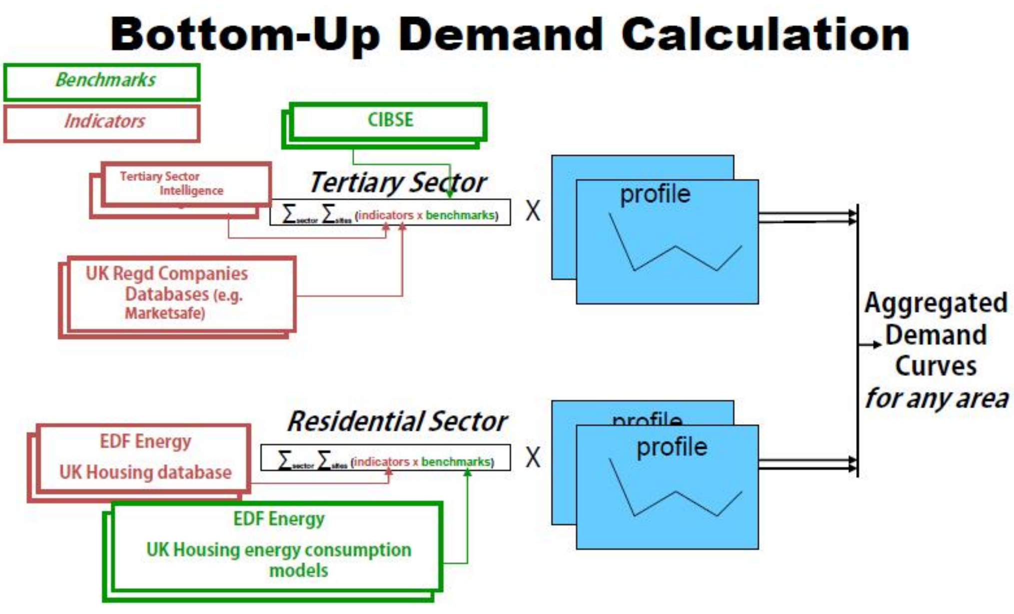


Figure 3.1 – Energy Demand Calculation

Daily profiles were also generated for the heat and electricity demands using a range of data sources. Some verification was carried out against a particular group of buildings in London for actual weather data and good agreement was found (see Figure 3.2).

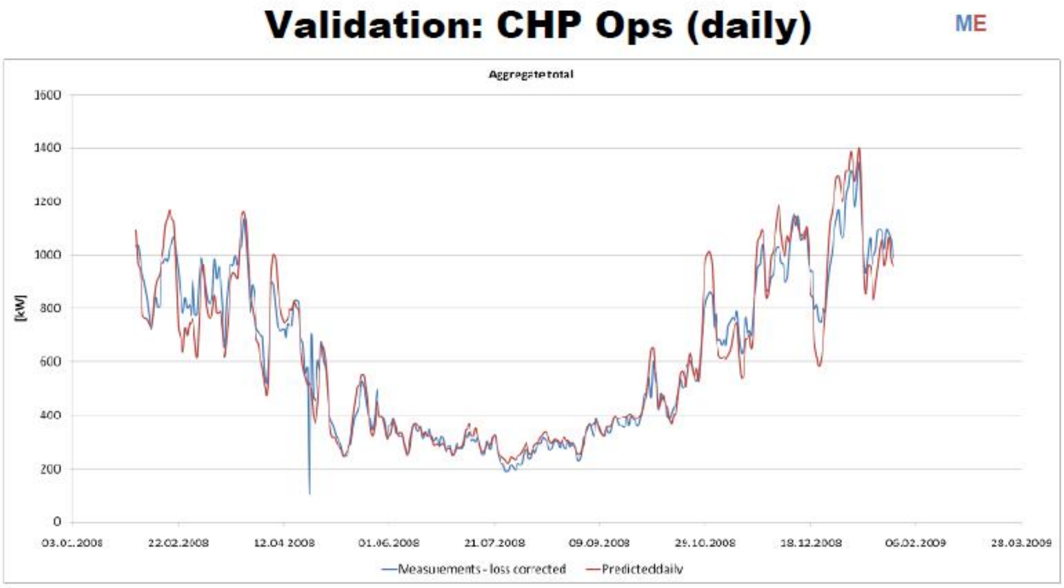


Figure 3.2 – Comparison of predicted and actual heat demands for a site in London

Defining the areas suitable for macro DE

From the heat demand estimated it was possible to determine the area heat density[5] for each MLSOA. A heat density of 200MWh/Ha was used as the threshold and MLSOAs with a heat density below this figure were not taken forward as potential areas for Macro DE. The figure of 200MWh/Ha was based on published studies investigating viability of district heating in various countries. Of the 8,429 MLSOAs, 4660 MLSOAs were above the threshold representing 56% of the heat demand in GB and covering 4% of the total land area.

Creation of zones

A major objective of the Macro DE project is to explore how projects can be delivered at a scale larger than typically implemented currently and therefore beyond the scale of an individual MLSOA. A methodology was developed to combine MLSOAs to form distinct zones in each urban area. This was achieved through a combination of merging adjacent MLSOAs, subject to limits on maintaining an overall heat density, and then subdividing the large zones on the basis of a total heat demand limit in any zone of 500GWh p.a. this limit was related to the maximum CHP capacity of 50MWe set by the study's brief. A small number of single MLSOAs were found to have a demand greater than 500GWh, typically for central business districts in major cities especially London and these were treated as special cases.

The result of this work was to create 948 zones across the country. These zones represent the maximum number of individual district heating projects that could be realised if there was a limit on size of heat source. A separate report has been produced by WP2 with maps of each class and aerial pictures of each CZ.

[5] This is defined as annual heat demand (MWh) divided by geographic area (Ha)

Classification of zones and characteristic zones

Clearly it would be arduous to analyse each of these 948 zones so the next step was to classify these zones into 20 distinct classes using a statistical approach. Firstly the most significant of the 42 parameters in the dataset available for each zone were determined and the following were selected:

- Parameters that indicate the scale of the scheme: Total heat demand, Total tertiary demand.
- A parameter that indicates likely cost-effectiveness: Area heat density.
- Parameters that characterise the heat demand profile: Ratio of base demand to peak demand, Load Factor (annual demand/(peak demand x 8760)).

Using these parameters and a series of iterations the zones were classified into 20 classes which were both distinct from each other and contained zones with similar characteristics.

One zone within the class that was considered the most representative (closest to the centroid) was chosen as the Characteristic Zone for that class which was then used as the basis for the detailed analysis of both the Energy Centre solution and DHN costing.

Industrial waste heat

Although there are examples from across Europe of the use of industrial waste heat to supply district heating schemes this is not common in the UK. A standalone study was used to identify the potential heat source available.

The energy consumption for each industrial site was derived from the EU Emissions Trading System National Allocation Plan published by Defra. The waste heat ratios i.e. how much of the heat input is available as waste heat from the industrial process was determined based on research by University of Bath and EDF's own results from industry audits. From this data the waste heat available was derived and presented both in a spreadsheet and on a map. Only heat sources above 100°C were included. Lower grade heat sources may also be available but would require the use of heat pumps to deliver to a DH scheme.

It was found that CO_2 emissions are dominated by the iron and steel, oil refineries and chemical sectors (see Figure 3.3),

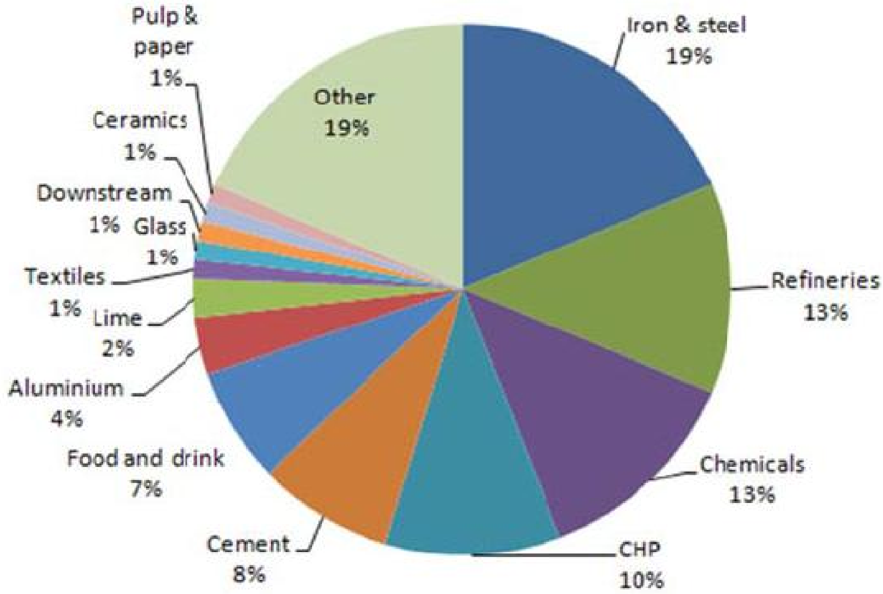


Figure 3.3 Direct CO_2 emissions from UK industry

A total of 586 sites were evaluated. Oil refineries were excluded as these are complex sites which need to be considered on a case by case basis. The total waste heat available is estimated at up to 2754 MWth or about 24TWh p.a. This compares with the heat demand of those MacroDE schemes found to be economic of about 200TWh p.a.

4. Technologies for Heat Supply (WP3)

Current technologies

The task of WP3 was to compile a technology library providing information on the performance and cost of a range of heat producing technologies that could be used in various combinations in an Energy Centre to supply a DHN.

A range of sizes were identified for each technology based on actual equipment that was commercially available and the following parameters were established for each technology:

- Heat capacity
- Type of fuel
- Capital cost
- Annual maintenance cost (fixed and variable)
- Efficiencies at full-load and part-load
- Maximum operating hours
- Annual availability
- CO_2 emissions from fuel used
- CO_2 content from manufacture

The technologies included under the current technology section were:

- Gas-fired boilers (from 500kW to 10MW)
- Spark-ignition gas-engines
- Gas turbines
- Diesel engines
- Landfill gas engine
- Biodiesel engine
- Heat pumps using near ambient heat source (c15C average)
- Thermal stores

These technologies were used in the modelling for assessing the GB benefits case for Macro DE described below in WP5.1. Biomass and Energy from Waste technologies were excluded from this list as potentially they have supply capacity constraints or raise air quality issues and so cannot necessarily be applied in every CZ.

Future technologies

WP3 also included a second library of future (2030s) technologies, updating the cost and performance data of the current technologies library and including newer technologies yet to be commercially proven. These were identified by examining recent trends in established DE markets such as Denmark.

The same underlying economic and energy price parameters were used as for the current technologies. The future technology list comprised:

- 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)

5. The Cost of District Heating Schemes (WP3)

Introduction

It is recognised that DHN is a capital intensive infrastructure. Once installed maintenance is minimal and mainly associated with maintaining good water quality. It is important to obtain accurate estimates of DHN costs for the economic evaluations of schemes to be meaningful. Whilst costs can be estimated accurately from full design drawings and specifications it is more difficult to carry out estimates on a national basis or in the case of the Macro DE project for the 20 CZs which are being studied in detail.

The final approach taken for the project after several revisions was:

- To select 3 CZs containing a sample size of approximately 15 MLSOAs that were representative of a range of heat densities but excluding extremes of high or low density.
- To prepare DHN designs for these areas using an established DHN software tool to select routes and pipe sizing.
- To establish a cost book for the elemental cost of pipework and other equipment (e.g. cost per metre for each pipe diameter).
- To develop mathematical relationships between various input parameters and the cost estimates made for the 3 CZs analysed.
- To use these relationships – termed the DHN Algorithm, to estimate capital costs for all of the CZs.

Two separate reports have been issued which describe this work in detail.

DH cost book

This report provides an overview of the technology and components of a DHN and provides the elemental prices that are used in conjunction with the DHN algorithm.

DHN Algorithm

Although many of the zones created contain a number of MLSOAs the calculation of DHN costs is based on the data for each MLSOA being as representative as possible.

The costs were divided into three parts:

- The transmission mains – installed within the streets and linking back to the Energy Centre.
- The distribution mains between the street main and the building.
- The building connection, often termed a hydraulic interface unit and including the heat meter.

For the transmission mains, the costs were determined using

a) The road lengths which had been derived by the ETI from published road statistics and a correction factor which was related to area heat density.

b) A cost per meter which was determined from a relationship with heat demand per meter of trench.

For the distribution mains the main parameter was the type of dwelling, typically semi-detached and detached houses are located further from the road centreline than terraced houses and will therefore have a longer length.

Figure 5.1 presents the total costs for the DHN including transmission mains, distribution mains and building connections for the 15 sample MLSOAs considered and plotted against linear heat density (the simplified approach was used in the early stages of the project and as it over-estimated costs in dense areas compared to costs experienced on UK schemes it was rejected). The revised cost line is derived from applying the algorithm and the TERMIS (district energy network simulation software) results show the costs calculated from the actual designs produced. The costs for the remaining MLSOAs in each CZ were calculated using the algorithm derived.

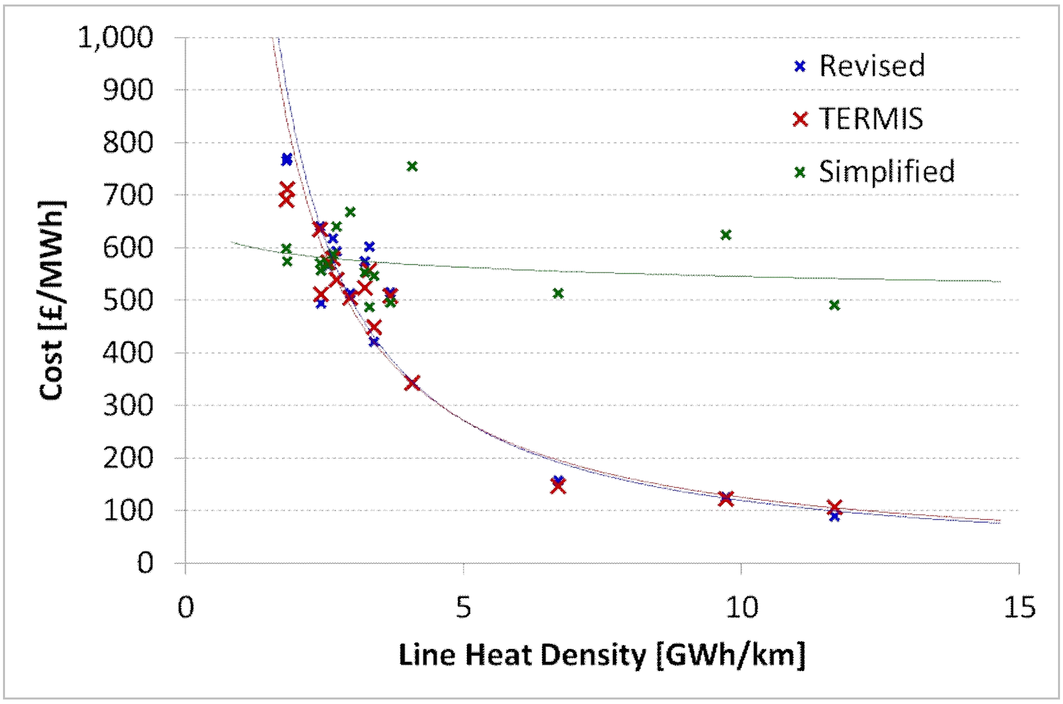


Figure 5.1 – Total costs for DHNs in 15 sample MLSOAs (100% market penetration case)

As expected, Figure 5.1 shows a relationship where higher heat density areas have lower costs than lower density areas. The variation is particularly significant between around 2GWh/km and 4 GWh/km where the costs vary by a factor of two.

6. Optimisation of the Heat Supply (WP4)

Introduction

WP1 identified the need for an optimisation tool rather than just a model which analyses a given design. The approach taken was to use mixed integer linear programming within an Excel environment.

Description of the optimisation tool

The tool takes as its inputs the heat demands of a given area expressed as 39 demand points derived from:

- 3 seasons (winter, summer and intermediate)
- 7 time bands in each weekday,
- 6 time bands in each weekend day

Although there is some approximation created by reducing the full hour by hour dataset to 39 points this was shown to be relatively small.

The tool also uses energy prices and electricity selling prices as well as the performance and cost data from the technology libraries.

The economic analysis is based on minimising the annualised cost of heat production.

There are two ways in which the model can be used:

1) To select plant that gives the lowest annualised cost, with the economic benefit of CO_2 savings calculated by assuming energy prices that include the social cost of carbon as published by DECC
2) To select plant to deliver a given CO_2 emissions reduction

Report 4.1 describes the development of the tool in detail and Report 4.2 describes how the tool was used within the project.

A typical set of operating results from the model is shown in Figure 5.1. This shows heat being supplied by gas-engines and boilers, and also periods when the heat production exceeds the demand – when heat is delivered to the thermal store, and periods when heat produced is zero when the demand is supplied from the store.

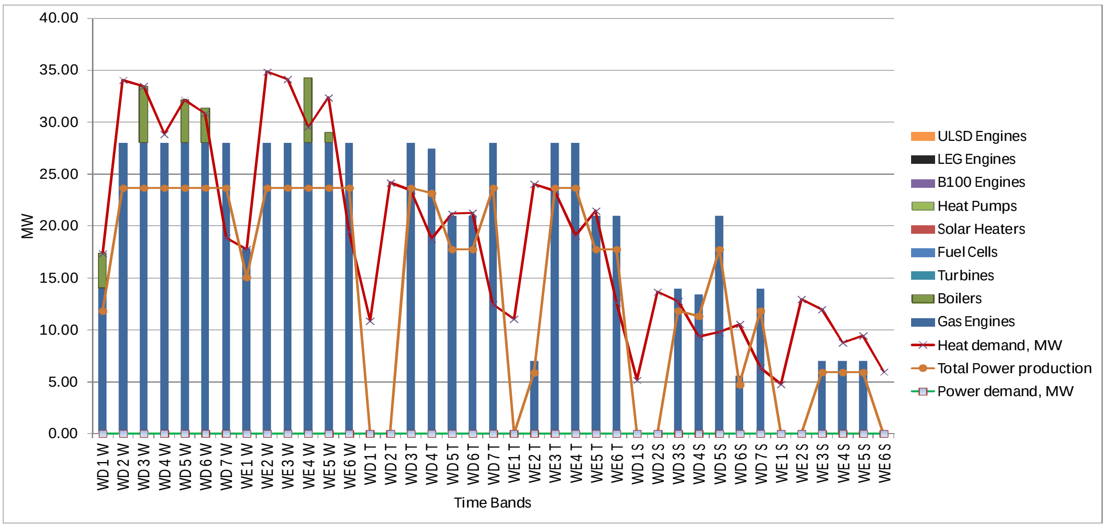


Figure 5.1 – Typical model output, Key for x-axis: WD = weekdays, WE = weekends, W = winter, T = intermediate, S = summer, the numbers are the timebands from midnight.

Thermal store

An early analysis carried out showed that the use of a thermal store was always beneficial in both economic and emissions terms. As a result all of the analyses were carried out assuming that a thermal store was included in the scheme.

Energy prices

The optimisation model relies on fuel and electricity prices for the cost of energy required to produce the heat. The prices used have been taken from the DECC projections following the Interdepartmental Analysts Group Guidance[6].

Carbon prices

The cost of CO_2 emissions from the various fuels and electricity have been included with the carbon prices given in (6) being used to calculate the price uplift. This approach ensures that the correct economic signals are given in the optimisation process. Effectively this also means that the economic results automatically take account of the value of CO_2 saved by adopting say CHP.

Levelised costs

Levelised costs of the supply of heat to customers have been calculated as the key economic output of the model, expressed in £/MWh heat supplied. The project life has been taken a 25 years and a discount rate of 8% real for most scenarios. The levelised cost takes account of capital costs, replacement of plant at the end of life and fuel, electricity costs, electricity revenues from CHP generation and maintenance costs.

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[6] 'Valuation of energy use and greenhouse gas emissions for appraisal and evaluation, and associated guidance Tables 1-24, DECC/HMT, October 2011'

The social cost of carbon has been included in the prices for the fuel used for the DH the electricity displaced by CHP generation and the gas or electricity used by the counterfactuals.

CO_2 emissions

CO_2 emissions are calculated from the annual energy flows predicted using emissions factors taken from (4). The emissions factors were averaged for the decades in question and are best seen as representing the CO_2 saved on average in the first 10 years of the project's life.

7. The GB Benefits Case (WP5)

Introduction

WP5.1 aims to identify the potential for DE across GB with a range of currently available and mature technologies. The cost of heat supply and associated CO_2 emissions are calculated for each of the representative CZs to allow comparison with the individual building heating systems (termed counterfactuals). Then by aggregating and scaling the data for the zones in the 20 classes to a GB level using the representative CZs, the overall impacts for GB can be calculated in terms of the penetration of DE into the heat market, the overall economic impact, and the potential for CO_2 reduction across GB.

The following assumptions are implicit in all the analyses:

- Large 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 in a given area will connect to the scheme (see further discussion below).
- There is sufficient electricity network capacity to accommodate a high proportion of decentralised generation. For the cases where all zones are viable the amount of electricity generation is estimated at 185TWh or about 62% of the UK electricity demand. It is likely that the grid will become 'smarter' in the future to allow a greater range and scale of electricity generators to connect however any costs associated with grid enhancements have not been estimated. Similarly for the individual air source heat pump counterfactual no account has been taken of the costs associated with upgrading the electricity distribution system.
- The current electricity market distortions which do not favour decentralised electricity generation are removed and CHP operators will receive a fairer value for all the electricity they produce. Our model assumes an uplift of about 20% compared to the typical prices currently obtained for small-scale (<5MWe) CHP in the market. This implies changes to the licensing regime to allow operators to sell some electricity directly to customers without undue costs, and for the value of local de-centralised generation to be more highly valued reflecting embedded benefits. The process to make these changes is already underway with DECC promoting the 'License Lite' regime proposed by Ofgem[7].

80% market penetration assumption

Although high levels of market penetration are seen in some cities e.g. central Copenhagen where 95% is achieved, an 80% penetration is seen as more reasonable. The best economic return for a Macro DE scheme will be achieved if there is a rapid take-up as some elements of the capital investment will be required initially. The modelling has not attempted to model the building up of heat customers over time and so presents an optimistic picture. A rapid take-up could be achieved through regulation to mandate connection within a certain time period. This may not be feasible politically as it runs counter to the principle created by the competitive markets established for gas and electricity where customers have freedom to choose suppliers. An alternative would be to provide subsidies in favour of Macro DE schemes where they are considered economic and subsidies for other options e.g. ASHPs where they are not. However, subsidies could prove expensive and a mandatory approach may be more acceptable if there are appropriate safeguards offered regarding the price of DE compared to

[7] See para 5.19 of 'Planning our Electric Future – a White Paper for secure affordable and low carbon electricity', DECC, July 2011 and 'Final proposals and statutory notice for electricity supply licence modification' Ofgem, February 2009

the alternatives in the market. Most consumers in fact have very little choice in energy supplier given the predominance of natural gas in the urban areas, the relatively small number of suppliers and more importantly the increasing dependence on world markets for the supply of gas to the UK. In this respect the Macro DE offer could be a welcome improvement in the diversity of heat supply. For larger DE schemes, there could be a number of heat sources feeding a city-wide grid and some level of competition in a heat market could result in the longer term.

Scenarios Analysed

A number of scenarios were analysed as defined in Figure 7.1 below:

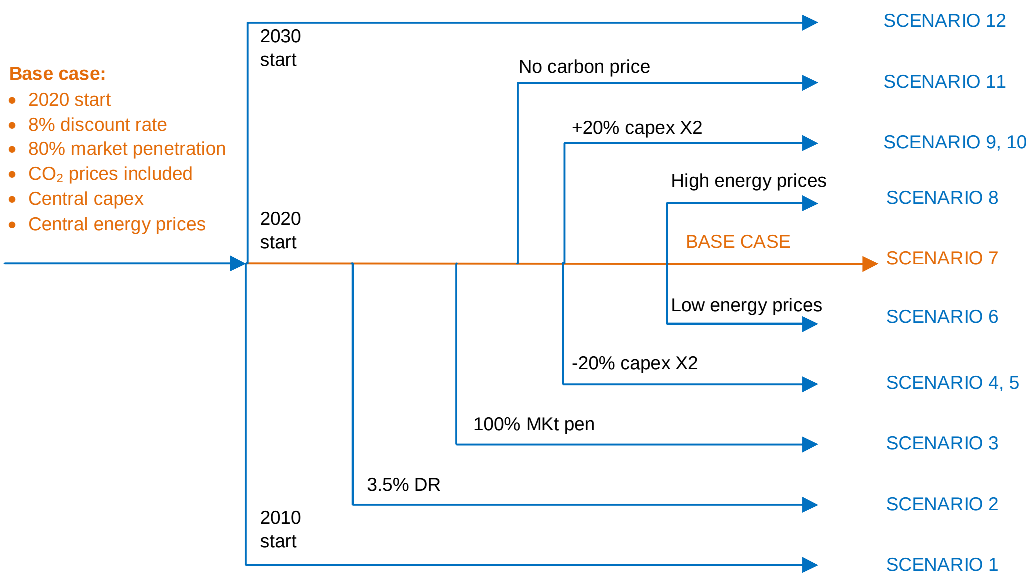

Figure 7.1 – Scenarios analysed

Heat provision

The modelling performed has demonstrated that in the base case scenario (scenario 7) 43% of the current GB-buildings heat market can be connected economically to macro DE schemes, resulting in significant overall cost savings. This represents 12.4 million homes and 2.9 million non-domestic connections, all of who will benefit from lower heating costs. Figure 7.2 shows the results for each CZ plotted for the central scenario and compared with the individual gas boiler and air source heat pump (ASHP) counterfactuals.

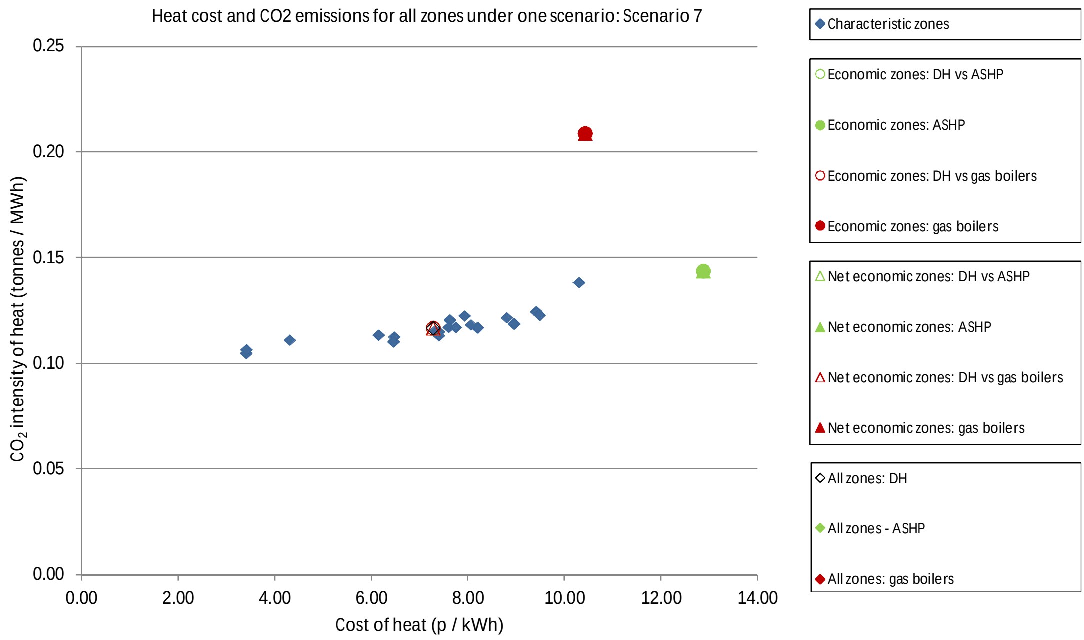

Figure 7.2 Results for each CZ for central scenario (2020s)

The results have also been plotted as Marginal Abatement Cost Curves which for the central scenario are all negative cost i.e. an economic benefit. The shape of the curve shows a relatively small part of the market is significantly more cost-effective and equally a small part of the market is more marginal. The majority of the market has very similar costs. All of the CZs are of a size where large-scale gas-engine CHP is selected so there are only small differences in the heat supply costs. The main variations occur in relation to the DHN costs. Although these will tend to increase with lower density areas, the reduction is small as there are some fixed costs and lower density areas are also associated with higher heat demands for individual buildings so that there are compensating factors when calculating the cost per unit of heat supplied.

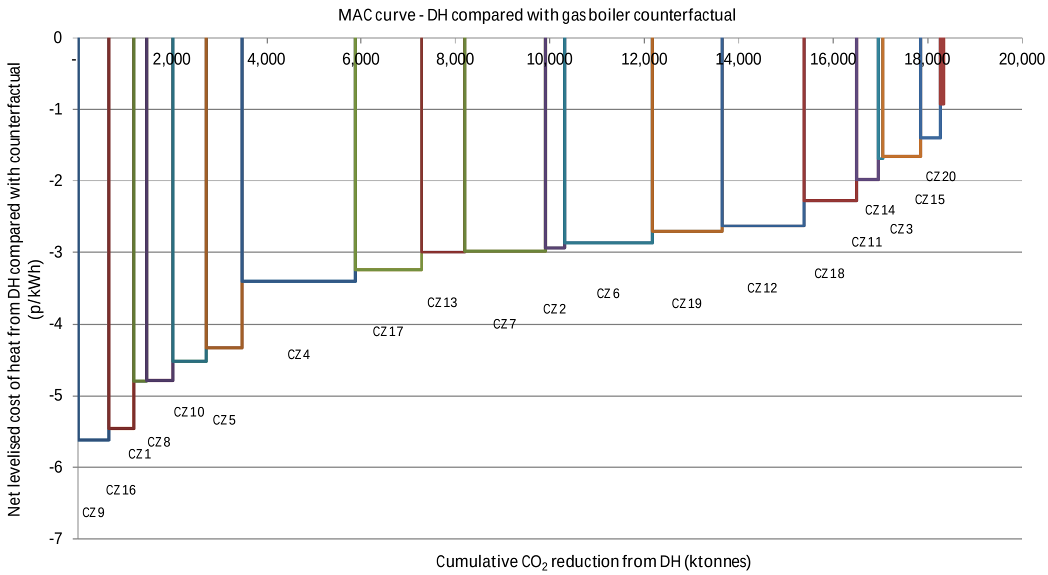

Figure 7.3 Marginal abatement curve for central scenario (2020s) compared to individual gas boilers

Reduction in CO_2 emissions

The efficiency improvements facilitated by macro DE enable CO_2 savings to be made when compared to the counterfactuals. The CO_2 savings depend on the type of technology (and fuel) selected, the optimised solution, and the CO_2 intensity of the energy being displaced. In this study, the counterfactuals are gas boilers (which do not change in CO_2 intensity over time), ASHPs and grid electricity (which do change over time).

The total CO_2 emissions associated with heating buildings in GB are currently estimated to be 113 Mtonnes p.a. Table 7.1 provides a summary of the potential CO_2 reduction available against this total from the scenarios modelled in work package 5.1.

Table 7.1: Summary of annual CO_2 reduction potential from macro DE across GB. All figures in Mtonnes. (note values are shown to 2 decimal places to allow observation of small changes between scenarios)

	Compared with gas boiler counterfactual			Compared with ASHP counterfactual		
	Commercially driven uptake	GB economy based approach	Maximum CO_2 reduction	Commercially driven uptake	GB economy based approach	Maximum CO_2 reduction
2010s						
Scenario 1	42.98	42.98	42.98	42.96	42.96	42.96
2020s						
Central – scenario 7	18.33	18.33	18.33	5.38	5.38	5.38
Minimum (scenario)	17.79 (6)	18.03 (2)	18.03 (2)	5.22 (6)	5.23 (4)	5.23 (4)
Maximum (scenario)	23.08 (3)	23.08 (3)	23.08 (3)	6.89 (3)	6.89 (3)	6.89 (3)
2030s						
Scenario 12.2 (50% reduction constraint)	3.22	11.0	22.97	-1.05	-2.94	-6.17

The results for the 2010s (scenario 1) show that the savings from macro DE are almost identical compared to both the gas boiler and ASHP counterfactuals. This is due to the similar CO_2 intensities of heat from both these technologies. The savings are equivalent to a 38% reduction in CO_2 emissions associated with heating buildings.

In the 2020s, the savings against gas boilers are much larger than against ASHP due to the reduction in grid electricity CO_2 intensity. The minimum savings in the 2020s are only slightly less than the central case.

In the 2030s, it will be possible for macro DE to produce CO_2 savings compared with the gas boiler counterfactual by including heat pumps in the then existing DE systems if a CO_2 constraint is imposed (up to 50% of gas boiler equivalent emissions as modelled). The maximum savings are similar to the 2020s, but this would require investment in schemes which are uneconomic. If a cross subsidy approach is used, the CO_2 savings are 11 Mtonnes (or 10% of heat emissions), compared to 3.22 Mtonnes for the zones which are economic zones. It is not predicted that macro DE will make savings in the 2030s compared to the ASHP counterfactual with the technologies available in the model.

Economic benefits

This report assesses the change in GB heat costs with the adoption of macro DE. These benefits are effectively the reduced heat cost to homes and businesses across GB, and not necessarily a net national economic benefit. Where savings are made through the adoption of macro DE, other sectors, such as individual boiler manufacturers, may lose trade. Therefore a full impact assessment is required to assess the true value to the GB economy.

Table 7.2: Summary of annual economic benefit from macro DE across GB. All figures in £ billions.

	Compared with gas boiler counterfactual			Compared with ASHP counterfactual		
	Commercially driven uptake	GB economy based approach	Maximum CO_2 reduction	Commercially driven uptake	GB economy based approach	Maximum CO_2 reduction
2010s						
Scenario 1	5.6	5.6	5.6	15.4	15.4	15.4
2020s						
Central – scenario 7	6.3	6.3	6.3	11.1	11.1	11.1
Minimum (scenario)	3.4 (6)	3.3 (6)	3.3 (6)	8.3 (6)	8.3 (6)	8.3 (6)
Maximum (scenario)	9.4 (3)	9.4 (3)	9.4 (3)	17.4 (3)	17.4 (3)	17.4 (3)
2030s						
Scenario 12.2 (50% reduction constraint)	0.4	0.0	-2.0	0.4	0.0	-1.8

The results presented in Table 7.2 demonstrate that the savings in heat cost with the adoption of macro DE schemes are higher against ASHPs than the gas boiler counterfactuals for both the 2010s and 2020s. By the 2030s, the savings are significantly reduced, and similar against both counterfactuals.

A simple calculation suggests that the savings for a domestic customer are circa £62 per year per £1 billion saving, and for non-domestic customers £79 per year per £1 billion saving[8]. This means that in scenario 1, the average home connected could save approximately £350 per year annualised cost against gas boilers and £950 per year annualised cost against ASHPs.

[8] The optimisation of the macro DE schemes is based on the total energy loads and therefore it is not possible to accurately calculate the savings for each customer. The figure presented here allocates the overall savings based on the split between total domestic and non-domestic heat loads, and the number of each type of customer.

8. The Potential for Technology Development (WP5.3)

Introduction

This section provides results and analysis from work package 5.3 which aimed to identify how technology developments can support the potential for DE across GB. In particular, it examines the following:

- The role which future technologies may take and the importance of future technologies for DE nationally.
- The key future technologies for development and commercialisation which may have a large impact on the macro DE potential.
- The high level impacts of the future technologies on existing and new supply chains, in particular in relation to availability of biomass and waste.
- 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 WP5.3 were described in section 4 above.

The assessment was split into stages, which were 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 and peak boilers are retained on the basis that their contribution will be relatively small and that this approach will be the most cost-effective rather than using higher cost plant for this function. .
- **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 demonstrates that there is a strong role for macro DE providing heat to urban areas into the future. In the 2010s and 2020s, the results demonstrate natural gas engine CHP schemes will remain the most economic solution of all the technologies for large scale deployment. Anaerobic digestion (AD) systems could provide a more cost optimal solution where the opportunities exist, but the feedstock is extremely limited, 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.

The most economic technology suited to wide scale deployment after natural gas engines is large scale heat pumps, where an elevated temperature heat source (c30°C) is available. These provide a more cost and carbon efficient solution to individual ASHPs, demonstrating that in a future with limited natural gas availability, 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. It is recommended that further work examines the potential of these sources and their locations in relation to the zones.

Large-scale heat pumps, whether with elevated temperature heat sources or using ambient temperatures (from WP 5.1 analysis), provide a viable option for Macro DE to move away from gas engine CHP schemes, when the grid has decarbonised. In the transition period heat pumps could potentially operate in tandem with gas CHP systems to allow optimisation of heat generation technology; the heat pumps would operate when there is surplus low carbon electricity on the grid, and the gas engines when there are low levels of renewable grid generation and peak electricity 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, CCGT 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 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. However, 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.

Energy from Waste systems are used in existing GB schemes, and extensively in Europe demonstrating their viability. In GB, between 20% (against the gas boiler counterfactual) and 43% (against the ASHP counterfactual) of the GB building heat load is economic for macro DE EfW schemes. A high level analysis of waste availability suggests that a large proportion of schemes could have access to sufficient resource although further work is recommended on examining the potential waste resources in more detail. Under the assumptions used, the CO_2 performance of EfW schemes is poor, but this does not account for the emissions associated with alternative waste processing options and the constraints on future landfill; in other countries the heat from EfW is classed as zero carbon. There is also evidence from other countries e.g. Sweden and Denmark that EfW is compatible with better waste management and higher recycling rates dispelling concerns in GB about using this technology. Those countries with high recycling rates also typically have high levels of energy recovery.

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, there are significant concerns over the fuel potential, fuel sustainability, and practical issues such as transportation and air quality. The Committee on Climate Change has also highlighted that stationary heat and power applications are perhaps the least useful application of the limited biomass resource. The modelling demonstrated that current biomass CHP systems are much less cost effective than boilers and small scale systems have a very limited benefit. However much larger biomass CHP systems with heat off-take could be more efficient and be equipped with CCS to increase the benefits.

Of the other technologies, fuel cells may provide some potential for schemes as their higher electrical efficiencies will allow the continued use of gas for longer as the grid decarbonises. However the increase in economic lifetime of small scale gas-fired CHP offered by fuel cell technology over gas-engines is limited in duration, and significant cost reductions and therefore technology improvements are required in a very short time to enable fuel cells to contribute significantly to macro DE.

9. ETI Members Benefits

This section describes the benefits of Macro DE in terms of the set of ETI criteria provided.

Emissions of Greenhouse Gases

Macro DE offers the opportunity for significant reductions in CO_2 emissions, and as gas-engine CHP is the most prevalent technology these reductions are highest in the near term when the grid efficiency is low and coal-fired power stations remain on the system. In the medium term (2020s), gas CHP will be competing with large-scale CCGT and although emissions savings from Macro DE are realised these are reduced and similar to that achieved by individual ASHPs.

Affordability

For the assumptions made in this report, the supply of heat from Macro DE would offer a saving compared to the alternatives of either gas-fired boilers or individual heat pumps. This economic benefit is likely to be shared between Macro DE developers and customers. The national benefit amounts to around £6.3 billion p.a. compared to gas-fired boilers. In contrast, the ASHP option is more costly than gas-fired boilers with an additional cost to the economy of £5.8 billion.

Energy Security

Energy security can be improved if there is less reliance on imported fuels. The more efficient use of natural gas through the use of CHP will reduce the need to import gas. The greater use of alternative heat sources such as energy from waste, indigenous biomass, heat recovery from industry will also contribute to a reduction in imported fossil fuels. A major driver for the development of DH in Denmark was to improve national energy security after the oil price rises of the 1970s. In addition, the use of decentralised energy potentially results in improved security as there is less dependence on the electricity transmission system.

Business Risk

There are risks with developing a Macro DE project as with any major energy investment.

> **Technical Risk.** The Macro DE project is technically robust in that the technology is all well-proven. It is possible to build in redundancy within both the heat network and the Energy Centre plant so that reliability levels can be very high.
>
> **Planning.** Although planning permission is required for the Energy Centre, with the main concerns: visual impact, noise and local air quality, the planning risk is relatively low, indeed many planning authorities including London positively encourage Macro DE projects for new developments.
>
> **The security of the heat market.** It is likely that some form of regulatory incentives will be needed to encourage connection or there will be a need for mandatory connections to achieve high levels of market penetration. Although buildings tend to have a long life there is the potential for demolition or refurbishment to improve the fabric and thereby reduce heat sales in the future. There are risks with new build

developments in the rate at which a project will be built. In the long-term, climatic changes may also act to reduce space heating demands.

The energy price risk. Gas-fired CHP is at risk if gas prices rise faster than electricity prices. Given that electricity is likely to be generated increasingly from gas in the next decade this risk is perceived as low in the short-term. However in the longer-term the electricity market is less certain and will be influenced by changes to the market mechanisms to encourage decarbonisation. At present the value of heat sales is assumed to be determined by individual gas boilers but this value could be undermined if there were significant subsidies under the Renewable Heat Incentive to promote individual heat pumps in areas where DH was also being developed in a market based approach. Our modelling has assumed that the value of carbon saved by gas CHP is reflected in the energy prices of fuels in a consistent manner. At present this is not the case as domestic fuel is exempt from carbon taxes. In addition we have assumed that Macro DE developers will be able to participate fully in the electricity market and achieve a higher value for electricity generated compared to current levels associated with very small volumes.

Scalability

Macro DE projects can be developed at a wide range of scales to suit the size of the community served. It is common for schemes to grow incrementally and for the Energy Centre plant to be expanded in a modular way. The results from this project support that approach with most of the zones being large enough to be supplied by a number of CHP modules.

GB Economy Benefits

The term ‘economic benefit’ has been used in this report to describe the reduction in overall heating costs to GB consumers. However the widespread adoption of DH will provide additional support/growth to the GB economy through the need for supply chains of DE components.

The costs of technologies and DHN components are discussed in the work package 3 reports in detail, and by aggregating these schemes’ specific costs to a GB level, the market size can be identified.

Using the central case as an example to understand the order of magnitude of the market size, the following figures are obtained:

- The total investment potential in energy centres is circa £35 billion. This includes the plant (and replacement during a schemes lifetime), energy centre building, and associated services.
- The total investment potential in DHNs is circa £93 billion.
- The total potential for installed CHP capacity is circa 47 GW thermal.

These values show that the potential market for macro DE equipment and services is significant and could support extensive up-scaling of relevant industries in GB if a local manufacture and supply chain were developed.

Achieving this potential requires many of the barriers to macro DE to be overcome, not least achieving the desired levels of uptake. For a GB industry to be able to respond to this investment potential, there will need to be confidence that the market will develop, and it will be crucial that long-term policy is developed which supports, or even regulates, the development of macro DE schemes.

Export potential

Much of the technology for DHNs has been developed in Denmark initially to supply their domestic market which has reached 1.6m dwellings connected. Denmark were then able to export this technology on a worldwide basis.

This compares with the potential market share in the UK identified in this report of 12m dwellings connected. It is clear that there is the potential for the UK to be a major manufacturer of DH equipment and this could be achieved given our current manufacturing base. This could lead to a strong position in export markets. Growth areas for DH are likely to be in China, Russia and Eastern Europe.

Relationship with UK energy policy

The Macro DE concept is in line with the Government's recently published heat strategy which sees a significant role for Macro DE in urban areas. The Government's strategy does envisage that gas-engine CHP is a transition technology that would enable DHNs to be established and that future low carbon heat sources not based on natural gas should be identified before embarking on the significant investment in DHNs.

The use of energy from waste and biomass are the immediate possibilities but both will be constrained by the availability of fuel. The technology that would be most widely available would be large-scale heat pumps but these will only offer an advantage over individual building heat pumps if they can access heat sources at elevated temperatures such as industrial waste heat. If the DHNs grow to a sufficient size heat could be provided from major power stations whether nuclear or coal CCS or gas CCS provided these are sited sufficiently near major cities.

However the Government has yet to put in place policies that will support either gas-fired CHP (other than micro-CHP) or the development of DHNs, in contrast to the support that is provided to renewable electricity generation or renewable heat. In this respect it is inconsistent for support to be offered through the Renewable Heat Incentive for heat pumps but not for CHP when both technologies are currently dependent on fossil fuels and are similar in thermodynamic terms[9]. Heat pumps are supplied from the grid which is currently dominated by gas and coal power stations although this mix will change over time[10]. Our analysis shows that using DECC's projections for the future marginal electricity emissions factors gas-fired CHP continues to provide greater CO_2 savings than individual air-source heat pumps through to 2030 (see Figure 7.2). A further inconsistency is that there is support through the feed-in-tariff for domestic scale micro-CHP but not for larger-scale CHP even though the latter is more efficient in primary energy terms.

The other key policy requirement for DHNs is to develop an approach that will deliver high market penetration quickly in areas that are suitable for DH and DECC have indicated that they will bring forward policies in this area in 2013.

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[9] Combined heat and power considered as a virtual steam cycle heat pump, Professor Robert Lowe, University College London, Energy Policy 39 (2011) 5528-5534

[10] Estimating marginal CO_2 emissions rates for electricity systems, A.D. Hawkes, Imperial College, Energy Policy 38 (2010) 5977-5987

Technology Readiness Level

One of the key advantages of Macro DE is that the technologies used are well established and would be rated at a Technology Readiness Level 6.

Pre-insulated pipe systems for DHNs have been developed since the 1970s and are covered by EN standards. Spark-ignition gas-engines are also well established being derived from reciprocating engines for vehicle or marine applications. Other components for use in building connections, heat meters, plate heat exchangers and control valves have also been progressively developed for the DH market over the last 30 years or so.

The areas for further development are likely to focus on reducing costs of installation of DH pipework and more sophisticated control systems to optimise both the operation of the Energy Centre plant and the control of heating systems within the dwellings.

Costs of DHN pipework could be reduced through the greater use of twin pipe systems and plastic carrier pipes and the integration of the pipe installation with other buried services or with the fabric improvements needed for older buildings.

It is likely that the Energy Centre plant will become more complex with a mix of heat sources and greater use of thermal storage so as to offer benefits to the electricity grid of rapid demand response. Small but important improvements in plant efficiency and reductions in NOx emissions are also possible.

In the longer-term, the use of gas-CHP without carbon capture and storage would be constrained and the use of large-scale heat pumps would be preferred to maintain the low carbon heat supply. These will be most efficient where there is the opportunity to use elevated temperature heat sources and further work to identify these, especially industrial waste heat would be another area of research.

The other major long-term heat source for DHNs will be from large-scale power plant which use nuclear or renewable fuels or which are fitted with carbon capture technology. For these plants to supply DHNs in the long-term there is a need for strategic siting of new power stations near to urban areas rather than the sites being solely driven by proximity to fuel and CCS infrastructure.

10. Conclusions

WP1 – The Context of the DH market

WP1 reviewed the current state of the DH market and concluded that there was little financial support for District Heating or gas-fired CHP in contrast to the renewable electricity and heat sectors. There was a need for policy to be developed that recognised the CO_2 saving potential of Macro-DE and for a financing approach that suited the potential long-term nature of the infrastructure. For Macro-DE to be developed on a wider scale there would need to be policy measures that encouraged connections so that a high market penetration was achieved. Generally these issues need to be addressed by policy makers and were not analysed further within the Macro DE project.

WP1 also established that there was no suitable software tool available that would provide an automated method to optimise the design of an Energy Centre.

WP2 – The energy demands, creation and classification of zones, industrial waste heat

WP2 concentrated initially on estimating heat and electricity demands on an hourly basis for a typical year for all types of buildings and assembled these for each MLSOA. About 56% of the heat demand was considered suitable in principle for District Heating with an area heat density above 200MWh/Ha. The individual MLSOAs were combined to form zones with a maximum size approximately equivalent to a 50MWe CHP plant, resulting in 948 Zones. These zones were then classified into 20 classes and a Characteristic Zone (CZ) identified for each. These CZs were used in WP4 and WP5 as the basis for assessing the GB benefits case for Macro DE. Maps were created to show the locations of each of the classes and the CZs.

WP2 also estimated the potential heat available for industrial heat sources above 100°C and concluded that about 2.75GW of heat could be available on a continuous basis, representing more than 10% of the heat demand for the total market available for Macro-DE. These industrial waste heat sites were also mapped.

WP3 – The Energy Solution Component Library and the Cost of DH Networks

WP3 produced two libraries of components for use in the optimisation work of WP4, defining energy performance and capital and operating costs for a range of heat sources. The first library contained details of equipment that was considered current proven technology, the second contained technologies which were either under development or were possible enhancements to existing technologies.

WP3 also carried out a significant study of the costs of installing DH networks, developing cost algorithms based on implementation of DHNs at scale and by developing detailed designs of heat networks for three sample areas. These cost estimates were then taken forward into the work of WP4 and WP5.

WP4 – Optimising the Energy Centre Design

WP4 developed a design tool to optimise the selection of the Energy Centre heat production plant, with the optimisation being based on either minimising annualised costs of heat production or minimising CO_2 emissions, using the WP3 component library. The model was used firstly to assist in the classification of zones and secondly to analyse a range of scenarios to provide the results needed for the GB benefits case presented in WP5. It was found that spark-ignition gas-engines installed on a modular basis together with thermal storage and gas-fired peak and standby boilers resulted in the lowest cost solution for a wide range of scales of zone and for most scenarios.

WP5 – The GB Benefits Case

The following assumptions are implicit in all the analyses:

- Large 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 in a given area will connect to the scheme.
- There is sufficient electricity network capacity to accommodate a high proportion of decentralised generation. For the cases where all zones are viable the amount of electricity generation is estimated at 185TWh or about 62% of the current UK total electricity demand. It is likely that the grid will become 'smarter' in the future to allow a greater range and scale of electricity generators to connect however any costs associated with grid enhancements have not been estimated. Similarly for the individual air source heat pump counterfactual no account has been taken of the costs associated with upgrading the electricity distribution system.
- The current electricity market distortions which do not favour decentralised electricity generation are removed and CHP operators will receive a fairer value for all the electricity they produce. Our model assumes an uplift of about 20% compared to the typical prices currently obtained for small-scale (<5MWe) CHP in the market. This implies changes to the licensing regime to allow operators to sell some electricity directly to customers without undue costs, and for the value of local de-centralised generation to be more highly valued reflecting embedded benefits. The process to make these changes is already underway with DECC promoting the 'License Lite' regime proposed by Ofgem.

WP5.1 examined the economic case for Macro-DE in GB using established technology. For the central case for schemes developed in the 2020s, a discount rate of 8% pre-tax real and an 80% market penetration it was found that all of the potential zones would be economic compared to individual gas boilers, resulting in a financial benefit of £6,300m p.a. and a CO_2 saving of 18m tonnes p.a.

Such schemes would result in significant electricity generation from the provision of CHP, around 62% of the annual national electricity demand for buildings (i.e. excluding industrial demand) and this level needs to be considered in the light of alternative low carbon electricity generation sources and the potential for rising electricity demand for heat pumps and electric vehicles. Macro-DE schemes would deliver a smaller CO_2 saving when compared to individual air-source heat pumps at 5.4m tonnes but would be significantly cheaper – a saving of £11,100m p.a. is predicted compared to ASHPs. In the 2030s it is predicted that gas-fired CHP will need to be phased out and replaced with large-scale heat pumps to continue to deliver low carbon heat.

The above results depend on Macro-DE receiving a higher value for electricity generated than currently achieved in the commercial market where it is generally recognised that market distortions exist[11]. The value selected is equal to the variable element of industrial electricity as given in the IAG projections[12]If an electricity export price 20% lower is used, to represent the value currently achieved in the <5MWe market for CHP generation the economic Macro-DE share drops from 43% to 22%. If, in addition, the value of carbon saving is also removed the economic Macro-DE share drops from 43% to 8% (this is more representative of the current market position for macro DE schemes).

WP5.3 compared a number of new and developing technologies to see if there was a potential for significant improvements compared to the gas-engine technology.

It was found that under current assumptions Anaerobic Digestion of waste to generate fuel for CHP would be the most attractive technology however this technology will be constrained by the availability of suitable organic wastes.

Where an elevated temperature heat source is available at around 30°C the use of large-scale heat pumps represent a viable long-term heat source for Macro-DE offering lower costs and greater CO_2 savings than individual air-source heat pumps.

The use of energy from waste plant as a heat source is also favourable as expected given that the established schemes in Sheffield and Nottingham are linked to waste plants.

Combined Cycle Gas Turbine plant in heat led mode could provide higher CO_2 savings than gas-engines but are currently a more costly and less flexible solution. A better option would be to extract heat from major power station CCGT plant but this depends on locating power stations nearer to heat loads.

[11] See para 5.19 of 'Planning our Electric Future – a White Paper for secure affordable and low carbon electricity', DECC, July 2011 and 'Final proposals and statutory notice for electricity supply licence modification' Ofgem, February 2009

[12] Valuation of Energy Use and Greenhouse Gases Emissions for Appraisal and Evaluation, DECC, October 2011

11. Recommendations for further work.

A number of issues were identified during the course of the study which were not possible to explore fully within the budget and time constraints. These are described below and are recommended as areas for further work by the ETI.

Impact of lower future heating demand as a result of retrofitting to improve thermal performance

If a retrofit programme proceeds after the installation of a Macro DE scheme in a given area, heat revenues may reduce and the financial viability of the scheme will be impacted adversely. However, if a package of thermal upgrades are offered as part of the scheme, then the finances will be based on the lower heat revenues but also the scheme capital costs will be lower as the lower peak demands can be taken into account when designing the network and Energy Centre.

Assessment of impact of electricity generation on the electricity system

If the full potential of Macro DE is implemented then the impact on the electricity system would be very significant. In some cases there would be more electricity generated within a city than required and this would need to be transported to other more rural areas. This could mean that flows in the transmission and distribution system are reversed. There may also be issues with the impact on the local distribution system such as fault levels which mean that the amount of generation is constrained. It would also have a major impact on the need for new power station capacity and for associated transmission system upgrades as the power would be generated more locally.

Analysis of gas CHP followed by heat pumps

Gas CHP and large-scale heat pumps have been analysed as two separate technologies and placed in three scenarios for 2010s, 2020s and 2030s. A more complex economic analysis but one which is probably more realistic is to model a scheme which uses gas-engine CHP for the first 15 years of its life and then uses heat pumps thereafter.

Analysis of gas CHP in conjunction with heat pumps – the smart heat grid

Grid decarbonisation will happen over a considerable timescale and there will be a period when the marginal electricity emissions factor will not be a constant as assumed in our analysis but vary significantly. For example, during periods of high wind output and low demand the emissions factor would be near zero and at time of low wind output and peak demand the emissions factor would be high reflecting the use of older unabated gas CCGT operating in a load following mode. As a result an Energy Centre operating with both gas CHP and heat pumps to exploit this difference, in conjunction with thermal storage, would potentially be a more viable solution – termed the 'smart heat grid'[13]. Economic and emissions

[13] Smart Heat Grids – the potential for District Heating to contribute to electricity demand management, Paper C92EIC029, Energy in the City Conference, Paul Woods and Andrew Turton, London South Bank University, June 2010

modelling of this arrangement for the 2030s would probably be more realistic than the scenario modelled within this project.

Extraction of heat from major power stations

This project constrained the size of the CHP plant to 50MWe (increased from the original 10MWe). The work showed that in our major cities there would be a number of projects of this size to meet the city level heat demand. As a result, the constraint on CHP size could be questioned. The alternative approach to deploying multiple gas-engine CHP projects would be to use a single large power station and a city-wide heat network. Although this would not be classed as Macro DE it could be the most cost-effective energy solution and provide the lowest CO_2 emissions[14]. In the longer term CCS could be fitted to the power station. It is recognised that it would be necessary to build up heat networks using smaller gas-engine CHP but if the final end-game is to use power station heat then this has major implications for the siting of power stations. Work to understand what sites might be available, how they could be utilised in the future for supply to DH and what the cost penalties are for choosing these sites would be of value.

Energy from waste issues

The estimate of emissions associated with using energy from waste plant is complex and requires a knowledge of emissions associated with alternative waste disposal routes. This was outside the scope of this project however a parallel project by the ETI may have established the necessary information. It would therefore be useful to examine the results of the two projects and how they inter-relate. It would also be useful to establish more clearly the quantity of likely waste arising and their energy and CO_2 content and how this resource relates to the potential for macro DE.

An ETI Demonstration Project

It is understood that the ETI may consider carrying out a demonstration project. It would be important for this to be more innovative than simply a gas-fired CHP and a DHN. There are many examples both in the UK and abroad of this approach and there is no need to demonstrate the technology. The type of scheme that would benefit from a demonstrator would involve the following characteristics which have yet to be seen in the UK at any scale:

- A mix of heat customers including private residential to establish consumer acceptance and market reaction.
- A mix of built forms including older terraced houses and pre- and post-war semi-detached houses to understand DHN costs for lower density areas.
- The incorporation of appropriate fabric upgrades to improve thermal performance of the buildings as an integral part of the project.
- Novel DH installation techniques such as using external wall insulation as a route for DH pipes, using shared connections where possible, installing mains in loftspaces etc to reduce costs of DHNs significantly.
- The use of low temperature district heating and achieving low return temperatures in a retrofit installation to maximise the efficiency of heat production from power stations and heat pumps.

[14] See ‘A comparison of distributed CHP/DH with large-scale CHP/DH’, Report 8-DHC-05.01, International Energy Agency, District Heating and Cooling Project Annex VII

- Heat recovery from industrial processes or datacentres as a low carbon heat source for DH (using heat pumps if necessary).
- Heat extraction from major power stations as a heat source (may not be possible for a small demonstrator and will depend on having a suitable power station local to the scheme but could include a biomass power station).
- The use of large-scale heat pumps in combination with gas CHP to offer demand response services to the grid to simulate the operation of such schemes in the longer-term (smart heat grid).
- The extensive use of thermal storage to cover more than 24 hour periods, linked to the grid response service concept.
- The use of inter-seasonal storage (drawing on ETI's other research).
- The use of deep geothermal heat including mines water either directly or as a heat source for a large-scale heat pump.
- The use of other heat sources for heat pumps such as rivers and sewage flows.
- The use of large-scale solar thermal (linked to interseasonal storage).
- The integration of a district cooling system with district heating to deliver additional energy savings.
- There is the potential to build on local manufacturing skills to develop a local supply chain for equipment and installation.

There are a few locations in the UK where most of these opportunities exist but a detailed comparison of possible sites would be required.

Appendix

List of Deliverable Reports

WP1

1.2 Design Practice Characterisation

WP2

2.3 Energy Demand Calculation

Outliers Appendix

Industrial Heat Demand (Chapter 6)

Heat maps for Characteristic Zones

WP3

3.2 DE Equipment Characterisation - Current Technologies

3.3 DE Equipment Characterisation - Future Technologies

District Heating Construction Costs in the UK

District Heating Network Design and Algorithm Verification Rev 5 May 2012 (MKN)

WP4

4.1 Report on the development of the optimisation tool

4.2 The application of energy centre design tool to characteristic zones

WP5

5.1 Report on results for current technologies

5.3 Report on results for future technologies

5.4 Macro DE Summary report