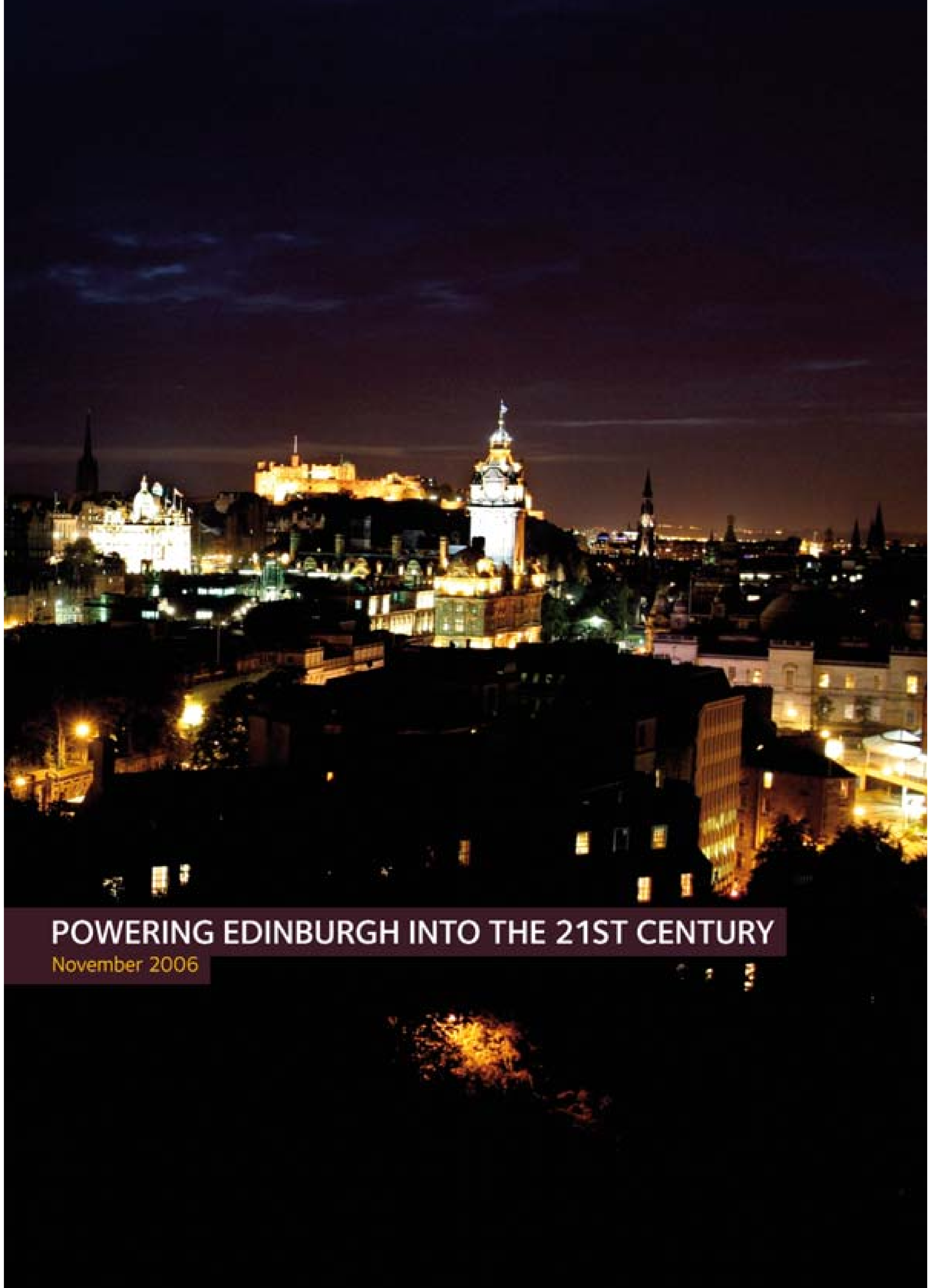

POWERING EDINBURGH INTO THE 21ST CENTURY

November 2006

This report was written by PBPower Energy Services Division for City of Edinburgh Council, WWF Scotland and Greenpeace.

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FOREWORD

Achieving a sustainable world, securing energy supplies and combating the threat of climate change will require fresh ideas and radical thinking. The city of Edinburgh cannot expect to meet the challenges of the 21st century by relying only on structures and technologies inherited from the past.

Energy generated at a local level by means of technologies such as neighbourhood combined heat and power schemes and domestic-scale renewable energy generation can make a real contribution to both reducing carbon emissions and improving energy efficiency. We live in a fast-changing world and Edinburgh, as Scotland's capital city, has a moral responsibility to lead the way on environmental progress. Other pioneering cities across the UK have already shown what is possible it terms of energy generation through initiatives such as using waste wood to fuel homes or setting up efficient renewable local sources. By joining the local energy approach Edinburgh can make a significant contribution to slashing both the city's and Scotland's carbon emissions.

This study shows how, by fully utilising energy generated locally, Edinburgh can over the next 20 years secure energy supplies, meet the energy demands of its growing population, support continued economic growth and still make substantial cuts in emissions of carbon.

Cllr Ewan Aitken,
Leader of City of Edinburgh Council.

·EDINBVRGH·
THE CITY OF EDINBURGH COUNCIL

PREFACE

With the impacts of climate change already touching our daily lives and every day seeming to bring more predictions of catastrophe and chaos, it is easy to forget that genuine solutions to climate change exist. Decentralised energy (DE) systems, integrated with renewables such as wind power, can make a major contribution to the CO_2 emissions cuts needed to tackle the problem. DE uses proven technologies which can be put to use straight away, reducing CO_2 levels within the short timeframe that we have to act in if we are to prevent irrevocable damage to our planet.

The UK Government's recent energy review concluded that nuclear power should be a major tool in the fight against climate change. The Westminster government and nuclear lobby hails nuclear power as the silver bullet that can provide energy security whilst cutting carbon emissions, yet proposed new-build of nuclear power stations could only meet 4% of the UK's overall energy needs.

The Scottish Executive's current opposition to new nuclear power stations in Scotland has put Scotland at the heart of the UK energy debate. Now Edinburgh has a role to play in proving that the real solution to climate change and security of supply lies, not in nuclear power, but in decentralised energy.

Our current, centralised energy system wastes a staggering two-thirds of primary energy input, mostly in the form of waste heat going up the cooling towers and into cooling water of large power stations. A decentralised future would rely on more, but smaller power stations close to the point of use. This approach reduces electricity transmission losses and allows the waste heat from the generation process to be piped to nearby homes so that a much greater proportion of input energy is used, resulting in far higher overall efficiency.

Alongside these Combined Heat and Power (CHP) plants, and stringent efficiency standards to reduce demand, a range of other on-site renewable technologies form an essential part of a clean decentralised system. Solar panels for hot water and electricity, micro wind turbines, geothermal heating systems, micro hydropower schemes, biomass (such as wood pellet boilers or in the CHP plants) can all contribute additional renewable heat and power locally, increasing the environmental advantages. They also have a key role to play in areas where district heating is unsuitable.

This report provides a blueprint to put Edinburgh on a pathway to surpass the UK government's 2050 emissions reductions targets, whilst providing value for money and reducing the need for imported gas. It proves that continuing our out-dated centralised energy system, either with or without nuclear, cannot come close to providing the levels of emissions cuts we need if we are serious about preventing the huge threat posed by climate change. This report is further proof that we have a clear choice. Opt for dangerous and expensive nuclear power, and still face runaway climate change, or choose clean decentralised energy and make a real contribution to tackling the greatest environmental threat the planet faces.

Greenpeace UK
WWF Scotland

EXECUTIVE SUMMARY

This report appears in the context of the UK Government's recent Energy Review and the likelihood that the Scottish Executive will have to decide whether to accept or reject new nuclear power stations. It does not provide all the answers to the many questions posed in the review, but it does demonstrate that there is at least one viable set of options for achieving the Government's key energy goals - CO_2 emission reductions, a secure energy supply, economic growth, and alleviation of fuel poverty – without the need for a new generation of nuclear power stations.

The cornerstone of this approach is decentralised energy (DE). This entails generating locally a significant proportion of the energy consumed in homes, offices and shops. The DE options modelled in this report do not require dramatic breakthroughs in technology: they rely wholly on the use of existing, technically proven solutions largely based on conventional energy sources, topped up by small-scale renewable energy generation.

The report has been written with a view to demonstrating a pathway to the UK Government's target of 60% CO_2 emissions cuts by 2050. By assuming a linear decline in emissions from the study's baseline year 2005 until 2050, the report has set a 2025 target of 26.7% cuts as the point at which Edinburgh would securely be on the pathway to meet the 2050 target.

The study which forms the basis for this report, carried out by the international energy consultancy PB Power, predicts and compares the CO_2 emissions savings which result from four different energy supply scenarios for meeting the heating and electricity needs of all the buildings in Edinburgh in 2025. Two of these scenarios assume the continuation of a wholly centralised approach to energy supply, while the other two posit different levels of DE take-up.

Briefly, the scenarios used in the study are as follows:

1. **Centralised low nuclear scenario –** existing nuclear power stations are allowed to close when they reach the end of their current lifespan and are replaced by gas-fired generation rather than new nuclear plant. By 2025 only Sizewell B remains in operation.

2. **Centralised high nuclear scenario –** new nuclear plant is installed at the rate of one 1.6GW station in 2015 and two further 1.6 GW stations by 2025.

3. **Low decentralised energy (DE) scenario –** existing nuclear power stations are allowed to close when they reach the end of their current projected life span and a mix of conventional energy generation and technically proven DE sources – mostly gas-engine combined heat and power (CHP) generation supplying community heating (CH) networks – is added to the energy supply.

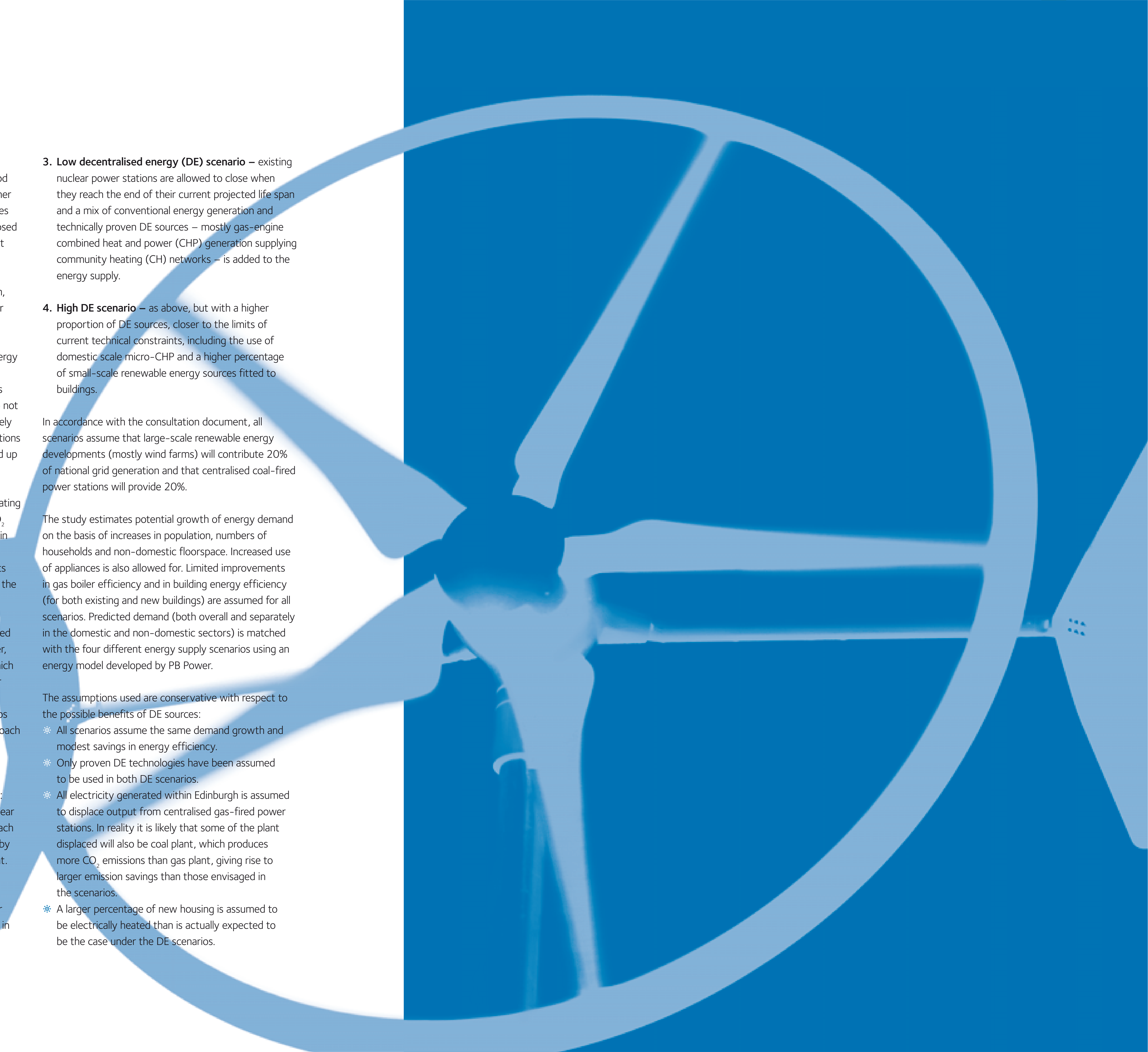
4. **High DE scenario –** as above, but with a higher proportion of DE sources, closer to the limits of current technical constraints, including the use of domestic scale micro-CHP and a higher percentage of small-scale renewable energy sources fitted to buildings.

In accordance with the consultation document, all scenarios assume that large-scale renewable energy developments (mostly wind farms) will contribute 20% of national grid generation and that centralised coal-fired power stations will provide 20%.

The study estimates potential growth of energy demand on the basis of increases in population, numbers of households and non-domestic floorspace. Increased use of appliances is also allowed for. Limited improvements in gas boiler efficiency and in building energy efficiency (for both existing and new buildings) are assumed for all scenarios. Predicted demand (both overall and separately in the domestic and non-domestic sectors) is matched with the four different energy supply scenarios using an energy model developed by PB Power.

The assumptions used are conservative with respect to the possible benefits of DE sources:

- All scenarios assume the same demand growth and modest savings in energy efficiency.
- Only proven DE technologies have been assumed to be used in both DE scenarios.
- All electricity generated within Edinburgh is assumed to displace output from centralised gas-fired power stations. In reality it is likely that some of the plant displaced will also be coal plant, which produces more CO_2 emissions than gas plant, giving rise to larger emission savings than those envisaged in the scenarios.
- A larger percentage of new housing is assumed to be electrically heated than is actually expected to be the case under the DE scenarios.



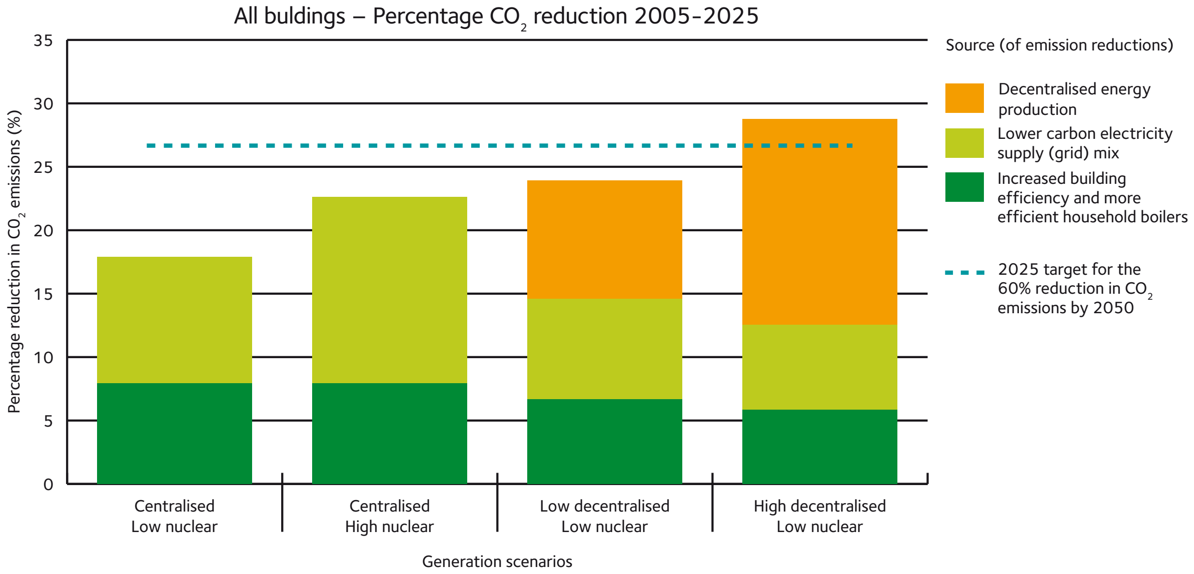
CHP (combined heat and power) plant, Copenhagen, Denmark. As a result of following a DE approach in Denmark, energy demand has remained stable, and CO2 emissions have fallen, while living standards remain high. ©Greenpeace/Christelis

On the basis of these inputs and assumptions, the study concludes that:

- **Only DE can meet the 2025 target for CO_2 emissions reductions.** By 2025, on a conservative estimate, CO_2 emissions from Edinburgh could be reduced from current levels by 28.74% through the adoption of the high DE approach, without new nuclear power stations being built.
- **Only establishing a DE pathway will allow Edinburgh to continue on to reach the 2050 target for CO_2 reductions.** Of the four scenarios considered only the two DE scenarios would be capable of putting Edinburgh on a trajectory to meet the Government's target of a 60% cut in emissions by 2050. Unlike a centralised or nuclear based scenario, DE can tackle the issues of:
  - heating homes directly;
  - accommodating future needs for switching fuels (for example utilising hydrogen technologies when they become available;
  - accommodating future technologies as they evolve (for example smaller scale biomass CHP);
  - building a strong building-integrated CHP and renewable energy sector in the UK economy able to carry on delivering through to 2050.
- **DE uses less primary energy to meet the heat and electricity demands of the city.** DE would enable Edinburgh's projected heat and electricity demand to be met using far less primary energy than the centralised high nuclear scenario – around 25% less under the high DE scenario.
- **Edinburgh's reliance on gas is reduced by following a DE pathway.** Despite the use of natural gas for CHP and the increased use of gas in power stations (to compensate for the falling nuclear contribution) Edinburgh's overall gas consumption would fall under the low DE scenario to a level 5% lower than that for the centralised high nuclear scenario. Gas consumption under the high DE scenario would be almost 15% lower than under the high nuclear scenario.
- **A DE pathway is the only one capable of accommodating switching to new fuels and rapid incorporation of new technologies.** The installation of CHP plants and of CH networks capable of distributing heat from different fuel sources (including renewables) would offer flexibility in meeting heat demand in the coming decades.
- **Security of supply is enhanced when energy is generated by a decentralised system.**
- **DE would reduce the level of electricity imports into Edinburgh, with significant potential benefits to the National Grid.**
- **Only DE can directly deliver heat, the major energy need of the city by using CHP technologies coupled to CH networks.** A major component of Edinburgh's energy demand, particularly in the domestic sector, is for heat, and DE solutions such as CHP offer the most efficient means to satisfy that demand. Any centralised scenario would have to rely on either inefficient electric heating or the continuation of individual gas boilers with the consequent dependence on a secure and affordable gas supply.

DE solutions are highly suited to meeting the energy requirements of densely populated urban areas such as Edinburgh and this report shows that DE is the only system which can meet the 2025 CO_2 emissions cuts target.

Furthermore, DE technologies are available now. By putting them in place, Edinburgh can begin making CO_2 savings straight away. The fact that DE sources can be added to or replaced means DE is 'future-proof', and therefore the only scenario which can put Edinburgh on a trajectory to meet the 2050 CO_2 targets and make a meaningful impact in the fight against climate change.



CO_2 emissions reductions from 2005 levels by 2025 for the four scenarios.
Only the high decentralised energy pathway enables sufficient CO_2 savings to put the Scottish capital on a trajectory to meet the UK CO_2 emission reduction target of 60% by 2050.

1. INTRODUCTION

1.1 THE CONTEXT OF THIS REPORT

The UK Government has recently completed an Energy Review, re-examining energy strategies with a view to delivering the four energy policy goals set out in the Energy White Paper (EWP) issued in 2003 (DTI, 2003). These are:

- to put the country on a path to cut the UK's CO_2 emissions by 60% by 2050
- to maintain reliability of energy supplies
- to promote competitive markets
- to ensure that every home is adequately and affordably heated.

Greenpeace, WWF Scotland and City of Edinburgh Council (CEC) have commissioned the present report from PB Power in order to inform the ongoing policy debate. The report demonstrates that there is at least one viable set of options for achieving these four energy policy goals without the need for the new generation of nuclear power stations suggested in the review.[1]

The objectives of this report are:

- to show that Edinburgh has a choice as to how it meets its future energy demand
- to illustrate how a decentralised energy (DE) strategy for Edinburgh could be developed
- to estimate the reduction in Edinburgh's CO_2 emissions that would result from such a strategy
- to assess the implications for wider energy supply issues such as the demand for natural gas.

The report does not detail all the actions required if Edinburgh were to go down a DE route e.g financial modelling, marketing evaluation and policy changes. These would all require further work and development.

The report examines the impact by 2025 of four scenarios on the key areas of a) CO_2 emissions and b) energy security, for the city of Edinburgh (defined as areas submitting Census data to city of Edinburgh Census Offices).

The first two scenarios assume a centralised approach to future energy supply and look at the impacts of choosing either a low nuclear approach (in which there is no new build of reactors) or a high nuclear approach (with some new build of reactors). The second two scenarios are based on adopting a decentralised approach to future energy supply. Both assume a future in which there is no new nuclear build to allow the contrast with the nuclear new build approach to be analysed. The first is a low DE scenario, that assumes a relatively low uptake of DE consistent with moderate political support for the technologies and a legislative and regulatory framework similar to the current situation. Finally there is the high DE scenario, which assumes a higher uptake limited only by technological constraints, and therefore a more proactive framework for supporting distributed low and zero carbon technologies.

The report only considers the CO_2 emissions associated with energy use in buildings, representing around 53% of energy consumed in Edinburgh, and does not consider emissions arising from transport or industrial processes.

1.2 STRUCTURE OF THE REPORT

The report begins by forecasting the 2025 energy demand of Edinburgh's buildings (both domestic and non-domestic) on the basis of existing published data and literature. It then sets out some assumptions about the future centralised power station mix that will supply electricity to Edinburgh[2], and suggests means by which the forecast level of demand could be met, comparing the impacts of four different energy supply scenarios.

1. *Centralised low nuclear scenario* – The current schedule of nuclear reactor closures is assumed with no extensions to plant life and no new reactors being built. Lost nuclear generation is displaced by gas. By 2025 only Sizewell B is scheduled to remain in operation.

2. *Centralised high nuclear scenario* – New nuclear plant is installed at the rate of one 1.6GWe station in 2015 and two further 1.6GWe stations by 2025.

3. *Low DE scenario* – Comprises a mix of technically proven decentralised energy sources and conventional centralised energy generation, mostly using gas-engine combined heat and power (CHP) plant supplying community heating (CH) networks. Centralised electricity supply is as per the low nuclear scenario.

4. *High DE scenario* – Includes a higher proportion of decentralised energy sources, closer to the technical limits of CHP capacity, the use of domestic 'micro'-CHP; and a higher percentage of building-integrated renewables. Centralised electricity supply is as per the low nuclear scenario.

The approach to delivering the two DE scenarios is explained in relation to the understanding of a distribution of heat demand for Edinburgh. The workings of the model – which brings together the single projected energy demand figure and the four supply scenarios – are briefly explained before its results are illustrated and discussed. Finally, a series of conclusions is drawn out from these results.

1.3 TECHNOLOGIES SUITED TO A DECENTRALISED ENERGY SYSTEM

The following section provides a brief overview of the technologies assumed to be employed within the DE scenarios. Further information is available from the relevant trade associations. The report by Greenpeace, Decentralising Power: *An Energy Revolution for the 21st Century* (Greenpeace, 2005), also provides descriptions of the technologies involved.

1.3.1 Combined heat and power (CHP)

The benefits offered by CHP make a major contribution to the CO_2 savings estimated for the DE scenarios and some explanation of the principles of CHP is therefore included here. Generation of electricity in conventional thermal power stations requires the combustion of fuel sources in order to generate heat. This heat is then used to raise steam at a high pressure, which in turn drives a turbine that generates electricity. Some of the heat

Scotland's largest array of building-integrated photovoltaic tiles on the William Rankine building, University of Edinburgh, demonstrates how zero-emission technologies can be integrated harmoniously into new buildings.
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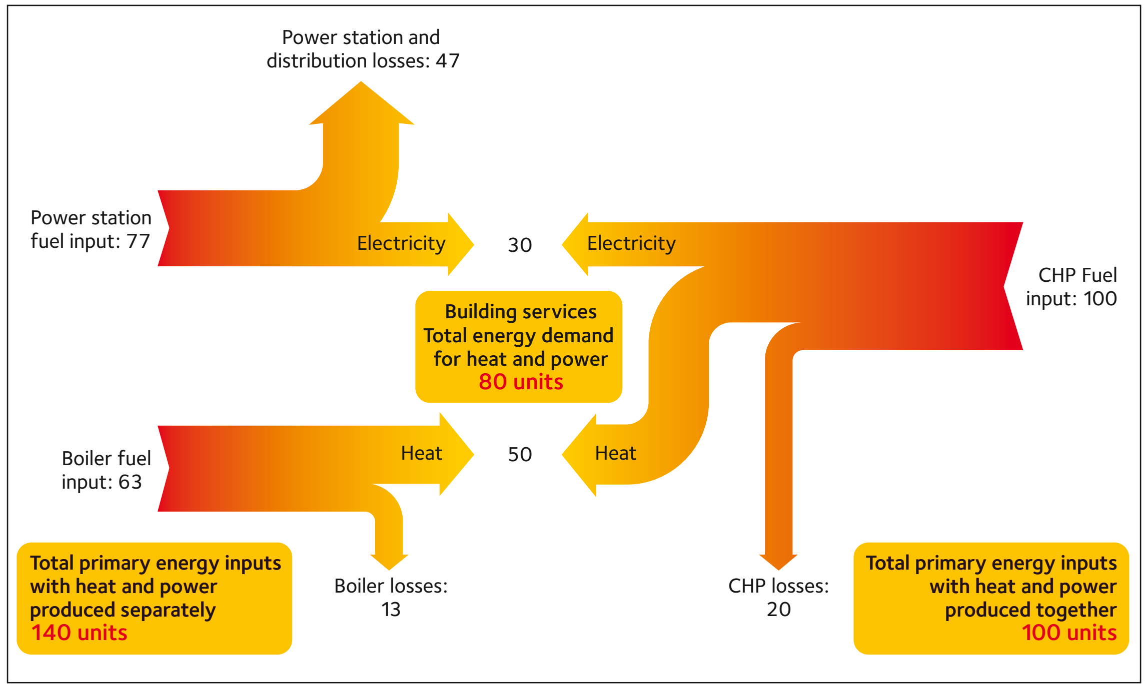


Figure 1.1: Principles of CHP energy efficiency

energy is lost in this process and is no longer hot enough to generate electricity. In conventional power stations, this waste heat is emitted either to the air via cooling towers or to the sea or rivers in discharged cooling water. All thermal power stations discharge substantial quantities of this waste heat to the environment. This fundamental constraint limits the efficiency[3] of the energy generation process to about 50% even for the most efficient gas-fired stations. CHP is a technology which captures this waste heat rather than allowing it to be lost. The available waste steam is extracted at a higher pressure than in conventional power stations, maintaining a higher temperature, enabling the waste heat to be used either for industrial processes or supplied to CH (community heating, often called district heating) networks which in turn supply buildings. There is a small drop in electricity production as a result, but the overall efficiency of CHP plants can reach in excess of 90% compared to the 50% of centralised electricity-only thermal power plants.

For the purposes of this model, however, we have assumed a typical CHP efficiency of 80%. The technology is well proven, but in the UK the main application has been on industrial sites. Elsewhere, especially in Scandinavia, it is normal practice to build power stations using CHP technology and in locations where the heat generated can be used to supply large-scale CH networks. The cities of Copenhagen and Helsinki are heated in this way. Any major thermal power station, whether coal, oil, gas or biomass-fired, can in theory operate as a CHP plant, as only a small modification to the steam turbine system is required. However, since the UK's major power stations have historically been built remote from population centres, it has not been practicable to use their waste heat for buildings. Now, though, it is possible to generate electricity from thermal combustion at a range of scales, making it more suited to sites located much nearer to centres of demand, or even to location within buildings as part of their heating system. Figure 1.1 illustrates the energy saving that can result from a CHP system. The building's demand is for 80 units of energy (30 for electricity and 50 for heat). The conventional centralised method of delivering this requires 140 units of primary energy. However, to deliver it via a CHP unit takes just 100 units, representing a 28.6% saving of input energy.

1.3.2 Community heating (CH) networks

Although dedicated CHP units are already available for larger buildings, the technology is not yet ready for commercialisation at a small or domestic scale. Consequently, to obtain the greatest benefit from CHP it is at present necessary to distribute the heat either from a conventional power station or a more local CHP system by means of a CH network. The heat is transported in the form of hot water through well-insulated pipes, buried in the ground like those for utility services. The circuit forms a closed loop with a flow pipe and a return pipe and typically transfers heat to a building's heating system through a heat exchanger. This technology has been well proven over the last 20 years, particularly in northern, eastern and central Europe, but UK examples also exist, including the Sheffield city centre scheme and the system supplying the Pimlico estate in Westminster, London, which commenced operation in 1950. Schemes have recently been established in Aberdeen and Lerwick[4] connecting to existing domestic and non-domestic buildings. Smaller schemes connecting CHP to domestic properties are currently operating in Bonnyrigg, Midlothian and multiple tower blocks in Glasgow. Small-scale biomass boiler fired community heating schemes are currently operating in the Highlands in Oban and Aviemore.

1.3.3. District cooling

CHP systems can also supply a cooling demand by using absorption chillers. This technology uses heat as the driving energy for the cooling process and can reduce CO_2 emissions if the heat is produced by a sufficiently low-emission source, such as high-efficiency CHP or renewable energy. The present model has not considered cooling, and there are therefore no CO_2 emissions reductions included for this type of system. However, it is clear that climate change will bring with it the requirement to develop low carbon cooling alternatives to air-conditioning, a solution that is likely to further support the installation of CHP by increasing the heating load factor on systems on which they were included.

1.3.4. Decentralised energy generation technologies

The generation technologies that are suitable for DE include:

Gas-engine CHP supplying CH networks
Biomass CHP supplying CH networks
Building-based CHP - (only applicable to the non-domestic sector)
Biomass boilers
Fuel cells[5]
Geothermal[6]
Building-integrated low and zero-emission technologies, including:
  Domestic CHP
  Renewable heat – solar thermal
  Renewable electricity – micro-wind turbines and photovoltaics.

These technologies (with the exception of fuel cells) are described in more detail in Appendix C. It can be seen that an important characteristic of DE is the ability to integrate a range of different energy sources and systems, including renewables. CH networks in particular permit much greater flexibility in terms of energy source than the present use of individual heating boilers, with their high dependency on natural gas. The potential fuel diversity, coupled with the ease with which energy sources can be changed, in turn offers improved security of supply with a high degree of future proofing.

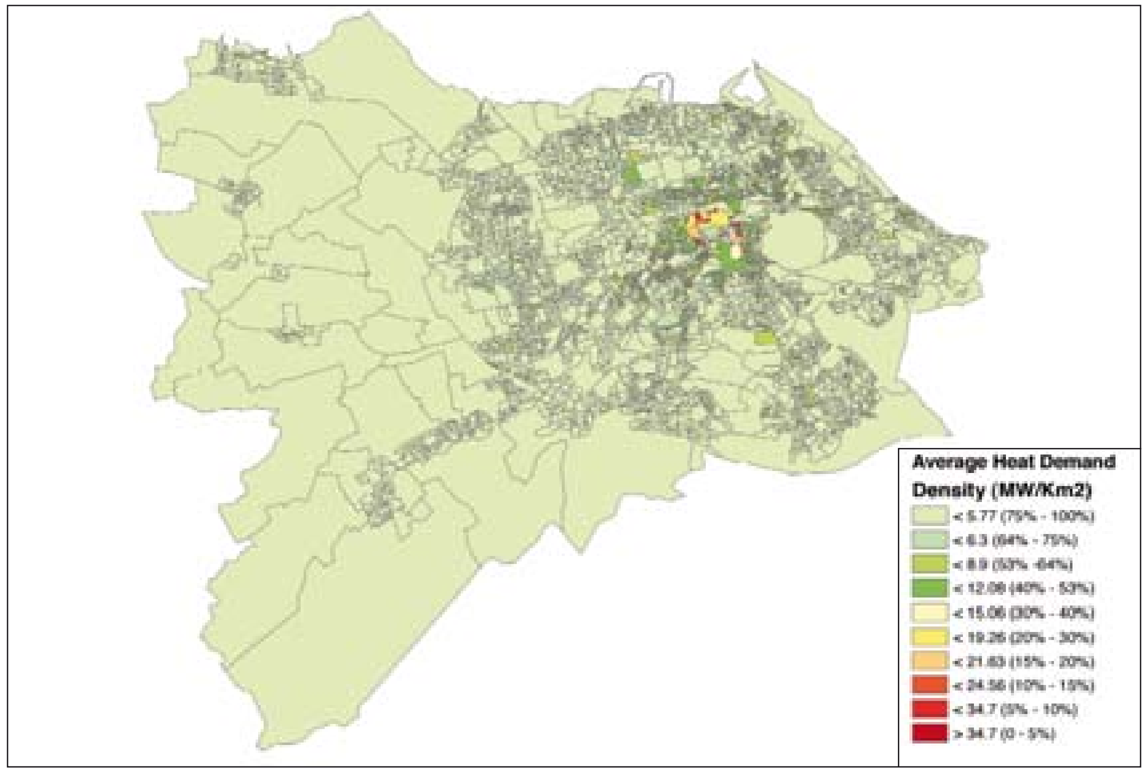
1.4 HOW DECENTRALISED ENERGY TECHNOLOGIES CAN BE USED IN EDINBURGH

The energy Edinburgh demands for its buildings is required in two forms – heat and electricity. Understanding heat demand is essential to planning an integrated energy supply strategy. Heat transport is possible over an entire city (as can be seen in various European cities such as Copenhagen and Gothenburg) this is a longer term objective – so far in the UK CH has only been implemented at district level. The cost of heat distribution with CH networks depends on the distance between the supply point and customer and on the heat density, which is the heat demand divided by the area of the 'zone' in question. If the volume of heating water being supplied is great enough, then heat can be transported over significant distances, as is the case in Copenhagen. However the main costs are in the local distribution pipes and lower costs will be incurred in areas of highest heat demand density.

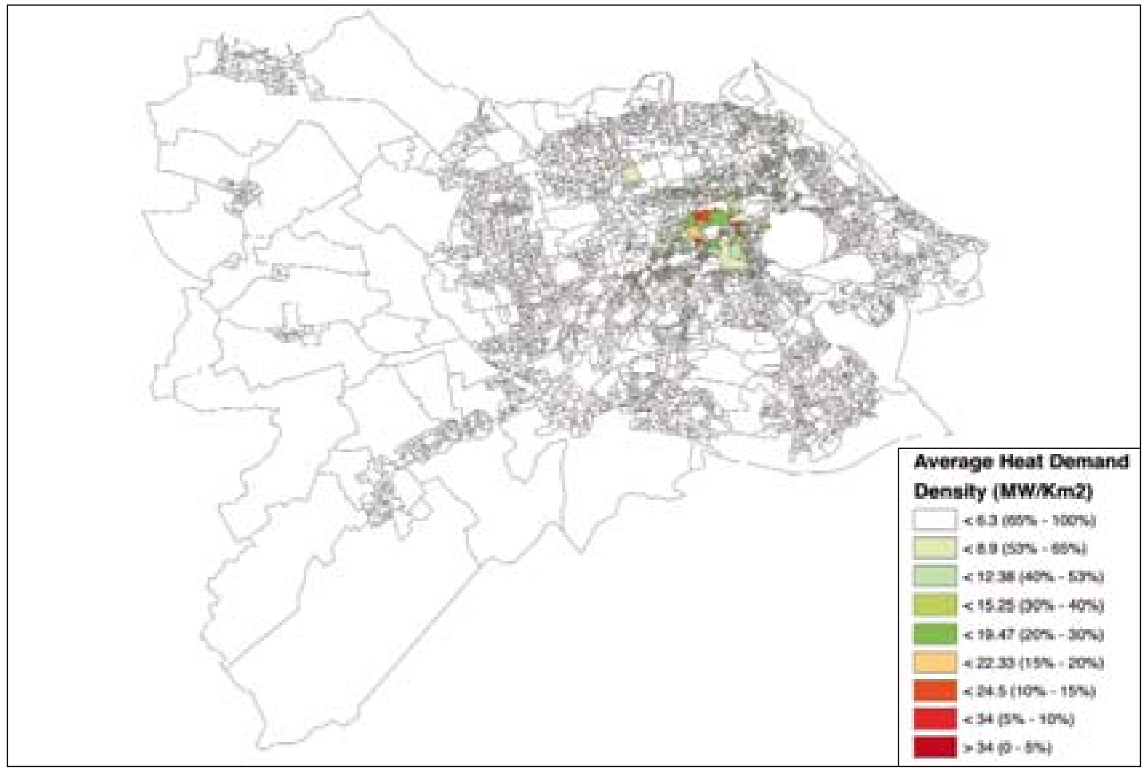
Map 1 below is a heat map that broadly reflects the density of the heat demand within the city. It can be seen that it is the most densely developed areas in Edinburgh that demand the most heat, although there are other small centres that also have substantial demand. This pattern of demand informs and guides the allocation of CHP and community heating in the two DE strategies proposed in this report. In both DE scenarios two complementary approaches for technology deployment are used. In areas of high-density heat demand it is proposed that CH networks are established and that these are connected to newly installed (and initially gas-fired) CHP technologies. In areas of lower-density heat demand where CH networks are less viable, a range of building-integrated low- and zero-emission energy generation technologies is envisaged. These twinned strategies are applied in the two DE scenarios in the following manner:

The low DE scenario is illustrated in Map 2. It draws a tight line around the highest-density heat demand areas. The relatively small areas of high-density heat demand highlighted amount to around 23% of Edinburgh's total heat demand. The low DE scenario suggests that this level of demand can be met by simply installing CH networks and adopting existing decentralised technologies such as CHP and biomass CHP on a moderate scale. Outside the highest-density heat demand areas a moderate level of building-integrated low- and zero-emission energy generation technologies is envisaged. It is anticipated that this level of DE penetration would be possible within the current regulatory framework

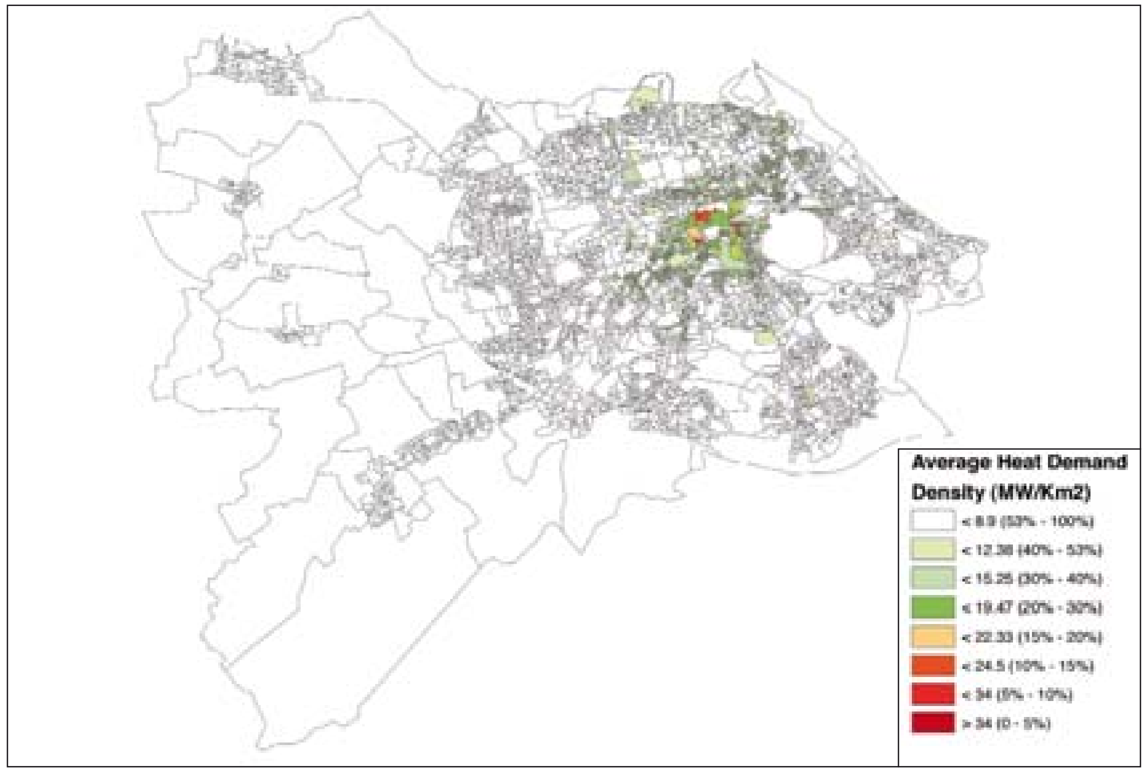
The high DE scenario is illustrated in Map 3. It identifies a broader area to be considered for DE, albeit still one with relatively high-density heat demand. At the same time it assumes a much more extensive application of existing DE technologies, and anticipates that around 35% of the heat demand for the whole of Edinburgh can be met through this approach. Outside the core zone for CH networks it also assumes a more extensive deployment of building-integrated low and zero-emission generation technologies. Such a level of DE penetration would likely require a degree of political will and legislative support from the City of Edinburgh Council and the Scottish Executive.



Map 1 – A heat map for Edinburgh. It shows the density of the heat loads within the city.



Map 2 – The relatively small areas of high-density heat demand in Edinburgh are highlighted here: they amount to 23% of the city's total heat demand.



Map 3 – A more extensive application of community heating networks and the associated CHP technologies would meet around 35% of Edinburgh's total heat demand.

2. METHODOLOGY

The methodology is firstly to establish the energy demand for heat and electricity from all buildings (both domestic and non-domestic) in Edinburgh, and the associated CO_2 emissions, for the baseline year of 2005. The corresponding heat and electricity demand for 2025 is then predicted (see Section 2.3). Finally, the predicted demand is balanced against each of the four supply scenarios described above and the resulting primary energy requirements and CO_2 emissions are calculated. A brief description of the method and the principal assumptions used in the study follows below.
A full discussion of the assumptions is included in Appendix B.

2.1 TIME HORIZON AND CO_2 REDUCTION TARGET

The study aims to show that over the next 20 years Edinburgh can meet its various growth and sustainability objectives simultaneously – satisfying the energy demands of its increasing population, continued economic growth, and substantial cuts in the emission of CO_2 – by adopting a decentralised energy approach, and all without the need for new nuclear power stations. The timescale of 20 years from 2005 has been used as the study baseline, since by the end of this period most existing UK nuclear power stations, with the exception of Sizewell B, will have been retired. Moreover, in the 2003 Energy White Paper, the UK Government established a target of a 60% reduction of CO_2 levels by 2050 (compared to 1990 levels), and the recent Energy Review asked for substantial progress towards this target to be demonstrated by 2020, well within the timescale of the present study. It is assumed here that there is a linear reduction in CO_2 emissions between now and 2050, which requires a reduction of 26.7% from 2005 levels by 2025. It is also assumed that the target for building-related emissions is the same as the target for overall emissions, including those from transport and industry. Therefore a 26.7% reduction in CO_2 emissions from the 2005 base level has been used as the standard against which the four modelled supply scenarios are compared. The estimates of the technical and economic limits of the DE scenarios are based on PB's experience in the CHP and community heating sectors and substantial research undertaken for London on behalf of the Greater London Authority and Greenpeace (GLA 2005). The approach used, which involved mapping heat demand densities across the city using GIS mapping techniques and Census 2001 data has also been followed here, although a slightly different methodology has been used to calculate energy demands of non-domestic buildings and their associated potential contribution to carbon dioxide reductions.

2.2 ESTABLISHING BASE DEMAND IN 2005

The model divides building energy demand into four sectors: existing dwellings (as of 2005), new dwellings (built 2005 to 2025), existing non-domestic buildings (as of 2005) and new non-domestic buildings (again, built 2005 to 2025). For each of these sectors energy demands as heat and electricity are estimated. Full details of individual elements incorporated within calculations can be found in Appendix A. Base 2005 domestic energy demand is estimated using Scottish Census 2001 data. The average annual heat demand per dwelling is estimated at 9,562kWh and electricity for lights and appliances at 3,300kWh[7]. The proportion of electrically heated houses is assumed to be 16% (Scottish House Condition Survey, 2004), the conservative estimate for electric heating in Edinburgh[8] and significantly lower than the Scottish national average at 20%. Average boiler efficiency of 70% (BRE 2005) is assumed. Base 2005

Micro wind turbine serving Dunedin Canmore Housing Association residential buildings at Fraser Court, Haymarket, Edinburgh. These turbines are produced by Edinburgh-based company Renewable Devices. © Greenpeace/Davison

demand for the non-domestic sector is derived from gross floorspace across commercial sectors for each Census Output Area in Edinburgh. This is calculated by applying broad rules of thumb in respect of worker intensity per sector (English Partnerships, 2001) to Census 2001 worker data. Energy benchmarks are then applied to the resulting floorspace for each Census Output Area giving energy demand and heat demand density. Existing floor space of 8.18 million m^2 is taken to have a heat demand of $120kWh/m^2$ and electricity demand of $154kWh/m^2$, assuming 50% of floorspace is air-conditioned and 20% is electrically heated. Boiler efficiency of 80% is assumed.

2.3 PREDICTED GROWTH IN ENERGY DEMAND TO 2025

Domestic demand

According to projections provided by City of Edinburgh Council, Edinburgh is expected to undergo a significant increase in population and a consequent increase in new dwellings (CEC, 2006) – an estimated additional 41,000 dwellings will be needed by 2025.[9] In addition, demolitions have been assumed at around 680 per annum – which equates to around 13,600 over the next 20 years – an estimate based on the *40% House* report (ECI, 2005). This results in a net number of around 27,200 new dwellings in 2025. It is assumed that in the same period there will be a modest 10% reduction in heat demand in existing dwellings due to improved insulation, and that the proportion of existing dwellings which are electrically heated will remain the same. Average domestic boiler efficiency is assumed to increase to 86%, consistent with the minimum requirement suggested in the 2007 Scottish Building Regulations Consultation. Electricity demand per dwelling for lights and appliances is assumed to remain the same. For new dwellings it has been assumed that heat demand per unit will be considerably lower at 3,000kWh per annum, consistent with proposals in the incoming Part 6 of the Scottish Building Regulations for 2007, and that electricity demand for lights and appliances will be 20% less than for existing dwellings at 2,700kWh per annum. Average domestic boiler efficiency for new dwellings is assumed to be 92% in accordance with A grade appliance ratings.

Non-domestic demand

On the basis of City of Edinburgh Economic Projections (CEC, 2006) an increase in development resulting in a 13% increase in required non-domestic floorspace together with replacement of 5% demolitions has been assumed, resulting in nearly 1.48 million m^2 of new-built floor space. It is assumed that there will be a 25% reduction in annual heat demand compared to the current level for 'Good Practice' offices as given in the CIBSE Guide F (CIBSE, 2004), giving heat demand of $54.2kWh/m^2$. It is also assumed that there will be a 30% reduction in electricity use, excluding electricity used for heating, compared to 'Typical Practice' benchmarks also given in CIBSE guide F, giving $79kWh/m^2$. It is assumed that the proportion of electrically heated floorspace will fall to 10% in new buildings and that the proportion of new air-conditioned offices will remain at 50%. Boiler efficiency of 80% for existing buildings is assumed on the basis of the Scottish Building Regulations 2004[10] and installation of condensing boilers in new buildings (92% efficiency) is assumed as a minimum requirement for energy efficiency and sustainability.

Energy efficiency assumptions

In the 2003 EWP the role of energy efficiency was identified as central to the UK's chances of meeting our long-term CO_2 emission reduction targets. Although there is anecdotal evidence that implementation of DE technologies may incentivise significant demand-side energy savings (for example through the use of smart metering within domestic households, the more widespread installation of domestic generation technologies, and the establishment of Energy Service Companies), no empirical evidence has yet been found to suggest a cause and effect relationship between the implementation of DE technologies and reduced energy demand. It is however reasonable to assume that in planning a new infrastructure such as CH networks or private wire electrical networks there would be an added incentive to reduce peak demands through conservation prior to designing and installing such networks in order to reduce the necessary capacity. It is therefore likely that a DE approach would provide impetus for demand side energy efficiency, but as it is difficult to quantify its effect and to maintain a conservative approach we have not taken this into account. For this reason, the impact of demand-side energy efficiency improvements in 2025 has been assumed to be the same for all scenarios.

A summary of the assumptions made regarding annual energy demands is given in Table 2.1 below.

Table 2.1: Energy demand assumptions

	Units	2005	2025
Dwellings			
Existing dwellings in 2005		204,683	—
Dwellings demolished 2005-2025		—	13,600
Existing dwellings remaining in 2025		—	191,083
Dwellings constructed 2005-2025		—	40,799
TOTAL DWELLINGS		204,683	231,882
Existing dwellings			
Proportion of electric heating	%	16	16
Individual gas boiler efficiency average	%	70	86
Heat energy efficiency improvement 2005 to 2025	%	10%	
Electricity energy efficiency improvement 2005 to 2025	%	0%	
Heat demand per dwelling (space and water heating)	kWh	9,562	8,606
Electricity demand per dwelling	kWh	3,300	3,300
New dwellings post-2005			
Proportion of electric heating	%	—	25
Individual gas boiler efficiency average	%	—	92
Heat demand per dwelling (space and water heating)	kWh	—	3,000
Electricity demand per dwelling	kWh	—	2,700
Totals all dwellings			
Total heat demand	**GWh**	1,957	1,767
Total electricity demand (without heating)	**GWh**	675	741
	Units	**2005**	**2025**
Non-domestic buildings			
Floor area of existing buildings in 2005	m^2	10,135,370	—
Floor area of buildings demolished 2005-2025	m^2	—	506,768
Floor area of exisiting buildings remaining in 2025	m^2	—	9,628,601
Floor area of buildings constructed 2005-2025	m^2	—	1,471,406
TOTAL FLOOR AREA	m^2	10,135,370	11,100,007
Existing buildings			
Proportion of electric heating	%	20	20
Gas boiler efficiency average	%	80	86
Heat energy efficiency improvement 2005-2025	%	10%	
Electrical energy efficiency improvement 2005-2025	%	0%	
Heat demand (space and water heating)	GWh	1,223	1,045
Electricity demand	GWh	1,145	1,088
New buildings post 2005			
Proportion of electric heating	%	—	10
Gas boiler efficiency average	%	—	92
Heat demand (space and water heating)	GWh	—	80
Electricity demand	GWh	—	116
Totals non-domestic buildings			
Total heat demand	**GWh**	1,223	1,125
Total electricity demand (without heating)	**GWh**	1,145	1,204
Totals all buildings			
Total heat demand	**GWh**	3,180	2,992
Total electricity demand (without heating)	**GWh**	1,820	1,945

2.4 THE FOUR ENERGY SUPPLY SCENARIOS

As already mentioned, the above predictions of the growth in heat and electricity demand are used as inputs into the model and balanced against supply according to four possible different energy supply scenarios:

Centralised low nuclear scenario – The current schedule of nuclear reactor closure is assumed with no extensions to plant life and no new reactors being built. Lost nuclear generation is replaced by centralised gas-fired generation. By 2025 only Sizewell B (1.2GW) is scheduled to remain in operation.

Centralised high nuclear scenario – New nuclear plant is installed at the rate of one 1.6GW station in 2015 and two further 1.6GW stations at five-year intervals to 2025.

Low DE scenario – Existing nuclear power stations (apart from Sizewell B) are allowed to run down as in the centralised low nuclear scenario. A mix of technically proven DE sources (mostly gas-engine CHP generation and a single biomass CHP plant supplying CH networks and some building integrated renewables) and conventional energy generation is added to the energy supply. 23% of the total heat demand, as shown in Map 2 above, is met using DE sources.

High DE scenario – As above but with a higher proportion of DE sources, closer to the technical limits of gas and biomass-fired CHP capacity, the use of domestic 'micro'-CHP, and a higher percentage of building-integrated renewables.

All scenarios assume that large-scale renewables will contribute 20% of the UK's centralised generation by 2025 and that centralised coal-fired power stations will provide 20%, in accordance with the results of the DTI's 2006 Energy Review 'The Energy Challenge' (DTI 2006b). All the technologies in the low DE scenario have been assessed economically using the Net Present Value method and found to have a positive NPV at a test discount rate of 3.5%, which is the Government's accepted level. This indicates that all may operate on the basis of a net profit over the lifetime of the plant when assessed using public sector financial criteria.

Table 2.2: Proportion of electricity supplied to Edinburgh from various sources

(electricity)	CO$_2$ emissions factor g/kWh	2005 %	2025 – low nuclear	2025 – high nuclear
Nuclear	0	19.64	2	11
Renewables	0	2.35	20	20
Hydro	0	1.29	*	*
Coal	972	33.62	20	20
Gas	465	39.14	58	49
Oil	899	1.23	0	0
Other	534	2.73	*	*
Average CO$_2$ factor (g/kWh)		534	464.1	422.25

*Included within the renewables figure above

A fuller analysis of the future power station mix can be found in Appendix B.

Installing solar panels on a school in Spain. A DE strategy has the potential to create jobs as well as encouraging technological development. © Greenpeace/Shirley

2.5 CO$_2$ EMISSIONS, ELECTRICITY AND HEAT BALANCE CALCULATION METHODOLOGY

All the scenarios described are assumed to have the level of energy demand and efficiency savings set out in 2.4 above.

For the two centralised energy scenarios (low nuclear and high nuclear), the assumptions on gas boiler efficiency and the proportion of electric heating enable the overall demands for electricity and gas for Edinburgh to be established. CO$_2$ emission factors from table 2.2 are then applied to the electricity imported to Edinburgh and the emission factor of 190g/kWh is applied to the gas imported to Edinburgh. This enables the total CO$_2$ emissions for Edinburgh in 2005 and in 2025 to be calculated for the two centralised scenarios.

The CO$_2$ emissions for the DE scenarios are calculated by taking the centralised low nuclear total emissions figure and subtracting the reduction in CO$_2$ emissions arising from each DE technology. Detailed assumptions for each technology are given in Appendix C.

In addition to the CO$_2$ emissions, the model calculates:

- the consumption of primary energy (i.e. the ultimate fuel or energy source)
- the contribution from the technologies employed to satisfy the heat demand (the heat balance)
- the contribution from the technologies employed to satisfy electricity demand (the electricity balance).

2.6 SOURCES OF DATA

This study draws on a wide range of different data sources. The Scottish Census 2001 database for dwelling numbers and types has been used to calculate overall domestic energy demands within Edinburgh. The Scottish Census 2001 Univariate Table highlights worker location by sector across the city. By applying worker density factors by sector (English Partnerships, 2001), it is possible to infer total floor area, and therefore energy demands, by sector for each Census Output Area. In calculating energy demands, which represents the last stage in the process, the report draws on information from the Building Research Establishment study *The UK Potential for Community Heating with CHP* (BRE, 2003). One other key document is Edinburgh's Major Development Projects 2006 (CEC, 2006), which provides the forecast city development assumptions for the model.

3. DECENTRALISED ENERGY TECHNOLOGIES AND THEIR EDINBURGH POTENTIAL

Tables 3.1 and 3.2 below summarise the projected market penetration of the various DE technologies that are assumed to be employed for the low DE and high DE scenarios. These technologies include:

- Gas-engine CHP supplying CH networks
- Biomass CHP supplying CH networks
- Building-based CHP (considered for the non-domestic sector only)
- Biomass boilers
- Building-integrated low- and zero-emission technologies, including:
  Domestic CHP
  Renewable heat – solar thermal
  Renewable electricity – micro-wind turbines
  and photovoltaics.

A fuller discussion of these technologies and their Edinburgh potential appears in Appendix C. This includes a description of each technology, an assessment of the likely opportunities for employment of the technology in Edinburgh, and an estimate of each technology's market share under both the low and high DE scenarios.

King's Buildings Energy Centre providing CHP to the University of Edinburgh. Efficient use of heat is key to DE systems. While engineering precision is required to achieve greater efficiencies, the critical decision is to locate and design power plants for heat production and distribution. © Greenpeace/Davison

Table 3.1: Low decentralised energy projections by energy contribution to building type, 2025

DISTRIBUTED GENERATION TYPE	EXISTING DOMESTIC				NEW DOMESTIC				EXISTING NON-DOMESTIC				NEW NON-DOMESTIC			
	Electrical output		Thermal output		Electrical output		Thermal output		Electrical output		Thermal output		Electrical output		Thermal output	
	MW	GWh/yr	MW	GWh/yr	MW	GWh/yr	MW	GWh/yr	MW	GWh/yr	MW	GWh/yr	MW	GWh/yr	MW	GWh/yr
Gas-engine CHP via CH networks	50	250	52	247	10	50	11	49	17	43	18	42	8	20	9	20
Large-scale biomass CHP via CH networks	—	—	—	—	10	70	15	53								
Building based CHP	—	—	—	—	—	—	—	—	18	36	30	60	2	5	4	8
Biomass boilers	n/a	n/a	—	—	n/a	n/a	5	10	n/a	n/a	—	—	n/a	n/a	8	14
Domestic CHP	—	—	—	—	—	—	—	—								
Solar thermal	n/a	n/a	22	12	n/a	n/a	6	4								
Building-integrated and small wind turbines	3	5	n/a	n/a	4	8	n/a	n/a	—	—	n/a	n/a	3	6	n/a	n/a
Photovoltaics panels	1	1	n/a	n/a	2	2	n/a	n/a	—	—	n/a	n/a	6	6	n/a	n/a
TOTALS	54	256	74	259	26	130	37	116	35	79	48	102	19	37	21	42

Table 3.2: High decentralised energy projections by energy contribution to building type, 2025

DISTRIBUTED GENERATION TYPE	EXISTING DOMESTIC				NEW DOMESTIC				EXISTING NON-DOMESTIC				NEW NON-DOMESTIC			
	Electrical output		Thermal output		Electrical output		Thermal output		Electrical output		Thermal output		Electrical output		Thermal output	
	MW	GWh/yr	MW	GWh/yr	MW	GWh/yr	MW	GWh/yr	MW	GWh/yr	MW	GWh/yr	MW	GWh/yr	MW	GWh/yr
Gas-engine CHP via CH networks	75	375	81	371	10	50	11	49	37	93	40	91	8	20	9	20
Large-scale biomass CHP via CH networks	—	—	—	—	20	140	30	106								
Building based CHP	—	—	—	—	—	—	—	—	27	53	45	90	2	5	4	8
Biomass boilers	n/a	n/a	—	—	n/a	n/a	9	20	n/a	n/a	—	—	n/a	n/a	16	28
Domestic CHP	9	18	41	82	—	—	—	—								
Solar thermal	n/a	n/a	43	25	n/a	n/a	13	7								
Building-integrated and small wind turbines	5	11	n/a	n/a	8	16	n/a	n/a	—	—	n/a	n/a	6	12	n/a	n/a
Photovoltaics panels	3	3	n/a	n/a	4	4	n/a	n/a	—	—	n/a	n/a	12	12	n/a	n/a
TOTALS	92	407	165	478	42	210	63	182	64	146	85	181	28	49	29	56

4. DISCUSSION OF RESULTS

4.1 CO_2 EMISSIONS

The reductions in CO_2 emissions for all buildings are shown in Figures 4.1 and 4.2 in absolute and percentage terms for each scenario.

Results

- As a result of improvements in energy efficiency, higher-efficiency boilers and the changes in the grid mix of power stations, the centralised low nuclear scenario results in a 17.9% reduction in CO_2 emissions compared to 2005 levels.
- The centralised high nuclear scenario results in a further 4.7 percentage-point reduction in CO_2 emissions on 2005 levels compared to the centralised low nuclear scenario.
- Implementation of the low DE scenario provides a further 6 percentage-point reduction in CO_2 emissions on 2005 levels compared to the centralised low nuclear scenario.
- Implementation of the high DE scenario results in a reduction of over 28.7% on 2005 levels, compared to the target of 27% – over 10.8 percentage points more than the centralised low nuclear scenario and over 6.1 percentage points more than the centralised high nuclear scenario. It is the only scenario proposed capable of achieving the 2025 target.
- Of the options proposed, only a DE scenario offers a realistic chance of placing Edinburgh on a pathway to achieving the 2050 target.
- Heating properties (and particularly heating domestic properties) is crucial in tackling CO_2 emissions yet this is largely unaffected by the centralised scenarios which can only deal with electricity supply in to the city and not the provision of heat (or future cooling).
- The greatest CO_2 savings are made by adopting CHP technologies. Even based on gas they still significantly improve efficiencies and thus reduce CO_2 emissions. CHP is not an option in a centralised scenario.

Assumptions behind the results

CO_2 emissions fall in all four scenarios for two reasons. Firstly, individual gas boiler efficiencies will improve as a result of Scottish Building Regulations Part 6 requiring the use of condensing boilers in domestic properties (by 2025 it is assumed that all existing boilers will have been replaced) and occupants of non-domestic buildings will invest further in high-efficiency condensing boilers as a result of a combination of energy and sustainability considerations and a continuing rise in gas prices. Secondly, the trend of fuel switching from coal to gas in centralised energy generation and the anticipated parallel increase in centralised renewable energy will continue.

Analysis of results

Overall, the DE scenarios achieve CO_2 emission savings mainly by using gas and biomass-fired CHP systems which are more efficient than combined-cycle gas turbine (CCGT) power stations. The centralised high nuclear scenario achieves emission savings compared to the low nuclear scenario as a result of generating a proportion of its energy from nuclear power stations instead of CCGT. However, as Figures 4.1 and 4.2 demonstrate, despite the increased contribution in the centralised scenarios from zero-emission centralised renewable electricity, the two DE scenarios result in the highest CO_2 reductions with only the high DE scenario enabling Edinburgh to exceed the interim CO_2 reduction target and keep it on track for a reduction of 60% by 2050. This is primarily due to the greater efficiency of CHP compared not just to CCGT but to any centralised generation source.

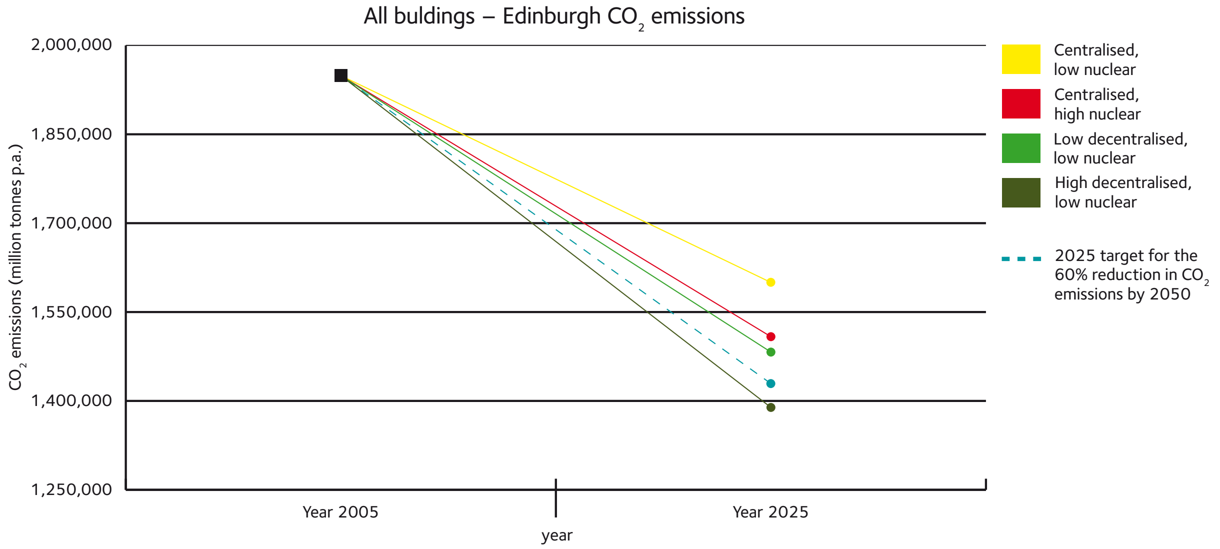


Figure 4.1: CO_2 emissions estimated from 2005 to 2025 – all buildings.
Only the high decentralised energy pathway can put Edinburgh on a trajectory to meet the UK CO_2 emission reduction target of 60% by 2050.

A further consideration is the degree to which adopting each of the energy scenarios offers the potential to make further cuts in CO_2 emissions in order to meet the Government's long-term target of 60% reductions by 2050.

A move towards a decentralised energy future not only offers the means by which Edinburgh can make significant progress towards meeting the 2025 CO_2 reduction target, it also promises to put Edinburgh in a good position to meet the 2050 target. This is a consequence of the 'future-proofing' aspects that result from the installation of infrastructure, allowing the exploitation of renewable energy sources within the boundaries of Edinburgh and the distribution of heat to dwellings and other buildings using a variety of generation technologies or new fuel types as their performance improves or they become readily available. Such future options are not as readily accessible under the centralised scenarios.

A further point to note when referring to Figure 4.2 is the relatively low impact of the role of the 'energy efficiency and more efficient boilers' component in the DE scenarios compared to the centralised scenarios. The emission savings arising within this sector result partly from improvements in the energy efficiency of buildings, which are assumed to be the same across all scenarios, and partly from the increased efficiency of individual boilers. However, within the DE scenarios, it is implicit that the number of buildings generating heat from individual boilers decreases as more of them are connected to CH grids and buildings CHP. Therefore increasing individual boiler efficiency only has a proportionately smaller role in the DE scenarios. Also apparent in Figure 4.2 is the diminishing impact of a lower carbon grid mix within the DE scenarios. This is a result of an increased amount of electricity being generated within Edinburgh as DE technologies are exploited, with a net reduction in electricity imported and a proportionately smaller contribution of centralised generation to overall emissions. The proportions of the mix are assumed to be the same for both DE scenarios and the centralised low nuclear scenario.

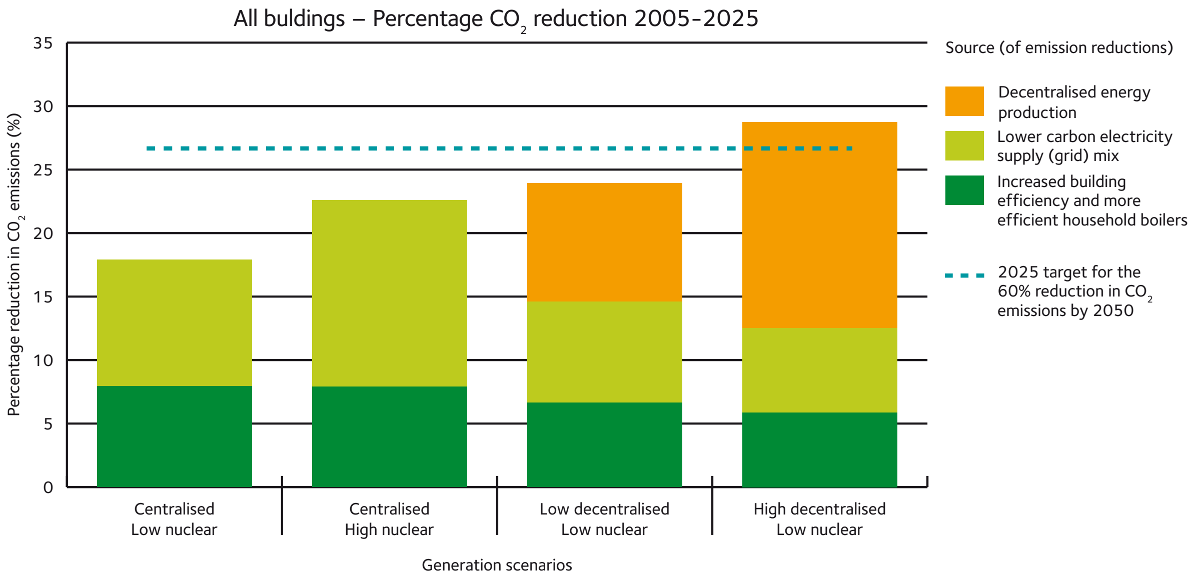


Figure 4.2: Percentage reductions in CO_2 emissions from 2005 level by 2025 – all buildings.
Only the high decentralised energy pathway enables sufficient CO_2 savings to put the Scottish capital on a trajectory to meet the UK CO_2 emission reduction target of 60% by 2050.

The difference between the domestic and non-domestic sectors

Figures 4.3 and 4.4 compare the reduction in CO_2 emissions from buildings in the domestic and non-domestic sectors. The bar charts reveal a marked difference in terms of performance against the overall target. The primary reason for this difference is the proportionally much greater demand for heat than electricity in the domestic sector compared to the non-domestic sector. Non-domestic buildings are typically occupied only in the daytime (thus requiring relatively little heating), often have higher electrical demand (due to the electrical equipment normally found in offices), and are increasingly fitted with electrically powered air conditioning. This combination of factors results in a high electricity demand and a low heat demand.

The bar charts show that the key sector in reducing overall building-related emissions is the domestic sector, and illustrate the fact that in this sector the key requirement that needs to be addressed is the provision of heat. Taking this into account, it is worth reiterating both how effective CH and CHP could be in addressing domestic heat demand, and that changes in the supply of electricity from centralised power stations cannot make a significant impact on the emissions associated with this energy demand – only DE technologies can tackle emissions from heat demand.

Flowers growing in greenhouses heated by waste heat from a CHP power station near Rotterdam in the Netherlands. As a nation, the Netherlands produces 50% of its electricity from CHP. Cities like Rotterdam are outlining plans to increase the use of their surplus industrial heat to achieve maximum efficiencies and maximum competitiveness. © Greenpeace/Reynaers

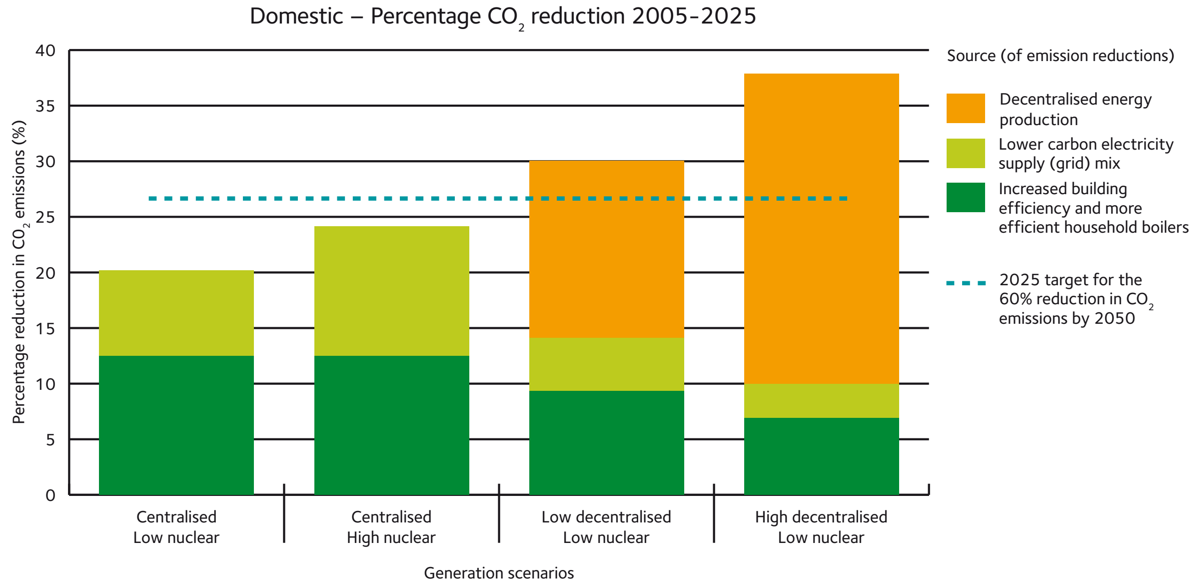


Figure 4.3: Percentage reductions in CO_2 emissions from 2005 level by 2025 – domestic sector. Looking at the sources of emissions reductions shows that tackling the domestic sector's high heat demand is crucial to achieving CO_2 reductions – the centralised generation scenarios fail to address this area.

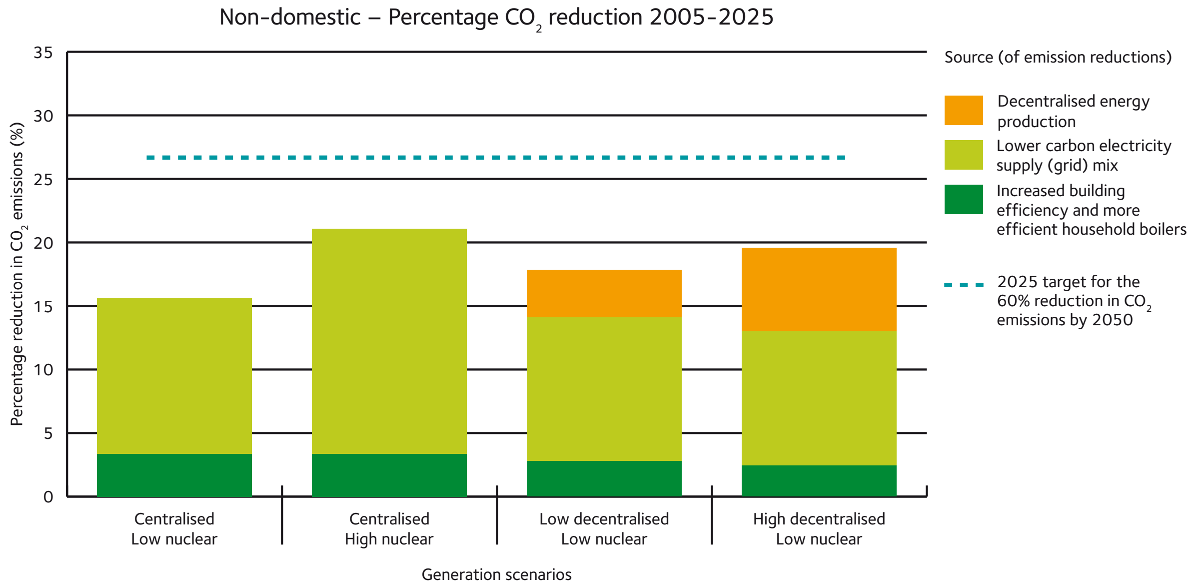


Figure 4.4: Percentage reductions in CO_2 emissions from 2005 level by 2025 – non-domestic sector. The greater reliance on electricity for buildings in the non-domestic sector means that CO2 savings are less easy to achieve. None of the scenarios meets the 2025 emissions.

The difference between existing and new-build dwellings

The contributions from each of the DE technologies to the overall CO$_2$ emission savings in the DE scenarios are shown in Figures 4.5-4.8 for both existing and new buildings. The pie charts show that gas-engine CHP with CH will be the most important single contributor for existing buildings, whereas for new buildings the opportunities to save CO$_2$ are much more diverse. This is partly because in the non-domestic sector we have included no capacity for retrofitting new renewable energy into existing buildings. Gas engine CHP has a relatively low impact in new buildings because a) they number significantly less than the existing buildings and b) the per building heat requirement is less, resulting in a lower heat density and less capacity to support CHP.

It is also because biomass CHP is included as an option for new dwellings, specifically for the area around Leith Docks which is already undergoing redevelopment and is the area in which the most significant redevelopment will take place between now and 2025. Biomass CHP provides the most effective means of carbon dioxide emissions reduction for new build developments in this district of the city due to a) the high build density of the development which predicates the use of community heating, b) the scale of the development which makes biomass CHP technology viable, c) the availability of local wood fuel resources and d) the existing rail and dock infrastructure facilitating fuel delivery to the point of use. It also assumes a prioritisation of energy and environmental objectives by local and Scottish Government.

98% of the energy needs of this building in Malmö, Sweden are covered by renewable energy.
© Greenpeace/Reynaers

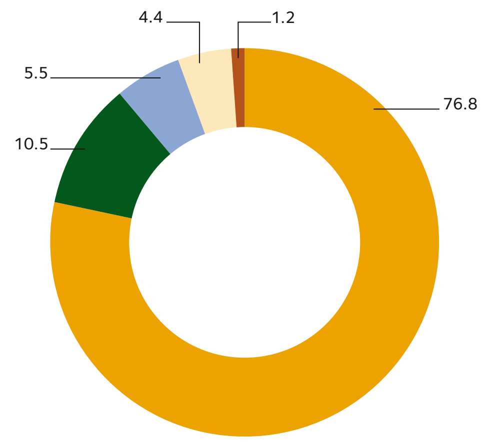


Figure 4.5 – Reductions in CO$_2$ (%) emissions in existing buildings from 2005 level by 2025 by energy source – Low decentralised energy.
Efficient use of gas through widespread use of gas engine CHP (and associated community heating networks) dominates the CO$_2$ savings from existing properties. Buildings CHP becomes significant with building-integrated low and zero carbon technologies making a contribution.

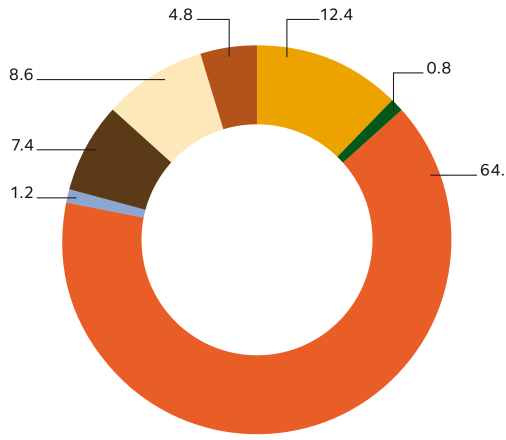


Figure 4.6 – Reductions in CO$_2$ (%) emissions in new buildings from 2005 level by 2025 by energy source – Low decentralised energy.
Biomass CHP accounts for the majority of the CO$_2$ savings in new buildings; building-integrated renewables account for almost a quarter.

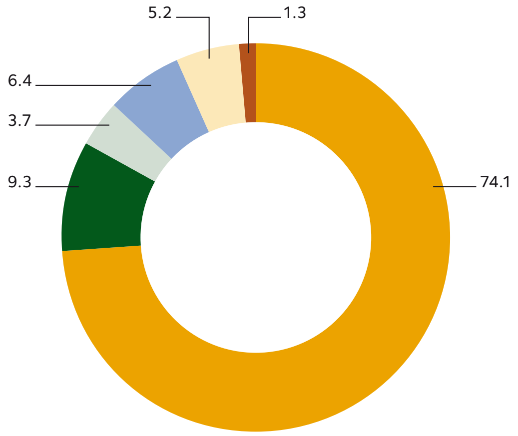


Figure 4.7 – Reductions in CO$_2$ (%) emissions in existing buildings from 2005 level by 2025 by energy source – High decentralised energy.
Gas-engine CHP remains the principle way to save CO$_2$ in existing buildings but building-integrated low and zero carbon technologies begin to make a marked contribution.

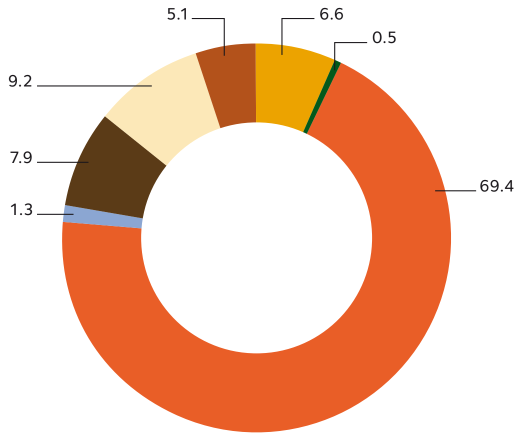


Figure 4.8 – Reductions in CO$_2$ (%) emissions in new buildings from 2005 level by 2025 by energy source – High decentralised energy.
Biomass CHP accounts for the majority of the CO$_2$ savings in new buildings; building-integrated renewables account for almost a quarter: the contribution from gas is reduced even further than under the low DE scenario.

4.2 PRIMARY ENERGY ANALYSIS

Results

- A high DE scenario for Edinburgh cuts primary energy demand by around 25% in comparison to either centralised scenario
- Both DE scenarios contribute to a reduction in overall primary energy demand so the city's dependence on gas is reduced in absolute terms. A reduction of over 5% in gas consumption occurs under the low DE scenario, in comparison to the centralised high nuclear scenario, but a 15% reduction is achieved under the high DE scenario.
- Both decentralised scenarios result in only a small amount of electricity generated by nuclear power being imported into the city. In the High DE scenario this amounts to around 33Gwh p.a., less than 1.4% of Edinburgh's electricity demand.
- DE provides a more diverse fuel mix (and flexibility in the future) and, with this, a greater resilience to fuel price fluctuations.

Analysis of results

The primary energy requirements for Edinburgh as calculated by the model are shown for all scenarios in Figure 4.9 in absolute terms and in Figure 4.10 in percentage terms. Primary energy means the input energy consumed as fuel whether in boilers or in power stations. Nuclear power stations are assumed to have a primary fuel input based on an efficiency of 35% (DTI 2005).

Imported electricity within all 2025 scenarios is assumed to have basically the same mix of primary energy sources regardless of its overall volume. Under the DE scenarios, less centralised electricity is used in Edinburgh and hence the total consumption of primary energy associated with centralised electricity also falls. If the DE approach were extended across the UK, however, the renewable energy contribution could be higher in percentage terms. Figure 4.9 shows that the high DE scenario uses over one-quarter less primary energy in meeting the heat and electricity demands of Edinburgh than the centralised low nuclear scenario. This level of primary energy saving assumes, as has been the case throughout the report, that there are no additional savings through demand-side energy efficiency measures as a result of pursuing a DE pathway – in practice the saving might therefore be expected to be even greater.

Such a large reduction in primary energy should in turn greatly reduce Edinburgh's dependence on imported energy. Indeed, it can be seen from Figure 4.9 that the total gas consumption for the low DE scenario is significantly lower than the current level and that for the centralised low nuclear scenario. Gas demand is slightly lower than that for the high nuclear scenario. The high DE scenario reduces gas use by around 10% compared to the high nuclear scenario. The primary reason for this reduced gas consumption is once again the high efficiency of CHP systems, which reduce the use of gas in boilers and allow much more usable energy to be generated per unit of gas burned. This means that although in percentage terms both DE scenarios are more reliant on gas, they offer a reduced dependence on gas in absolute terms compared both to current consumption levels and to either of the centralised scenarios envisaged.

The extent to which this reduced consumption promises to reduce Edinburgh's vulnerability to gas price fluctuations will moreover increase in the long term as the DE fuel mix diversifies away from a reliance on gas towards a variety of different renewable sources for both electricity and heating. It is also worth noting that even within the centralised scenarios, gas will still be the dominant fuel, providing over 60% of the total primary energy – mainly because it remains the main fuel for space and water heating, by means of condensing boilers. The fuel mix in the heat sector for the centralised scenarios will be less diverse than under the DE scenarios and without the scope for flexibility in changing to new fuel sources provided by the DE scenarios. In addition, whereas rises in fossil fuel prices including gas will tend to result in higher heating and electricity prices under the centralised scenarios, a larger proportion of the cost of heat from CH systems is related to the capital investment in the networks and it is thus less influenced by fuel price changes.

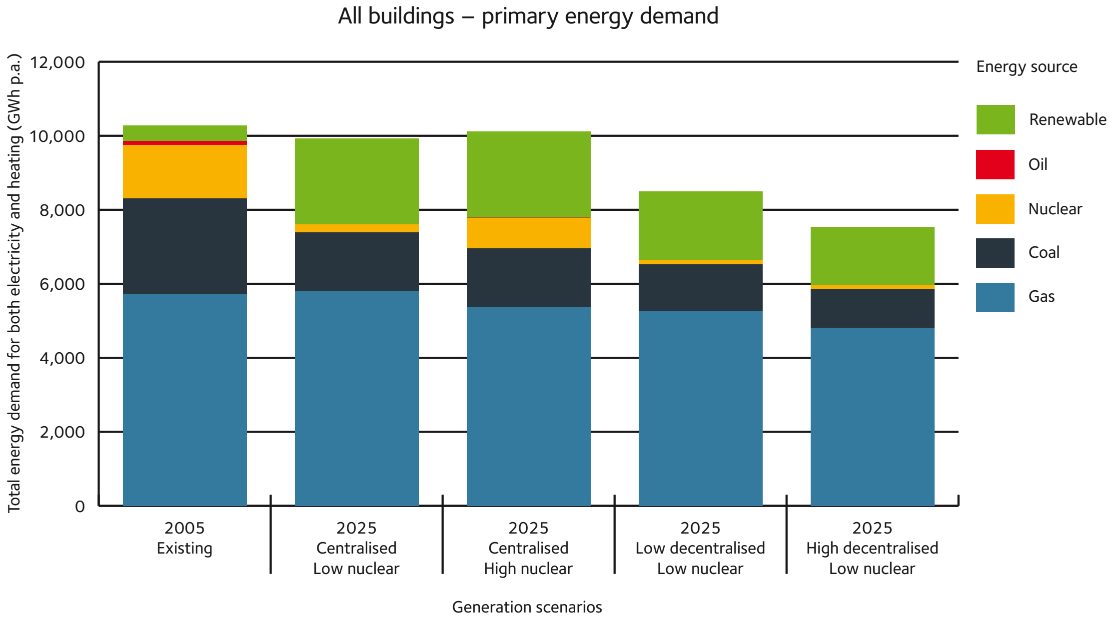


Figure 4.9: Primary energy requirements.
By 2025, primary energy demand will have fallen, under all scenarios, as a result of increased energy efficiency in buildings and boilers. Adoption of a DE pathway enables demand to be actively reduced where primary energy is used for both heat and power production together. The quantity of gas consumed falls under the DE scenarios, as compared to both the centralised scenarios.

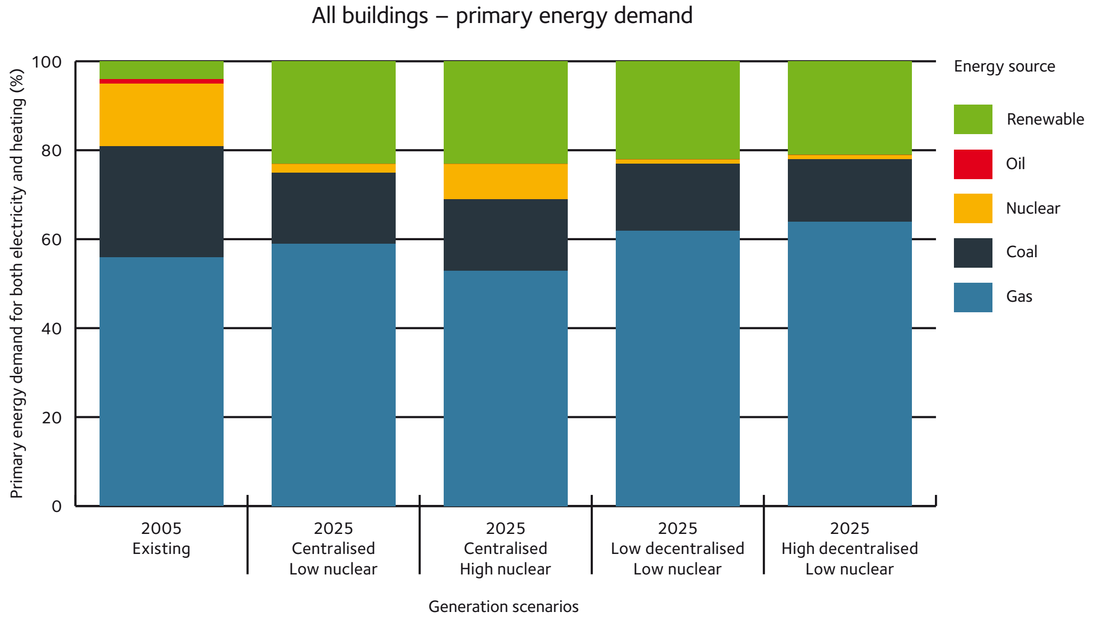


Figure 4.10: Primary energy requirements as percentages.
Use of gas is proportionately higher under the two DE scenarios, but the absolute quantity consumed (as shown in Figure 4.9 above) is reduced.

4.3 HEAT BALANCE

Results

- The centralised scenarios have little impact on the heat market - it is a system unsuited to tackling Edinburgh's major energy demand.
- The high DE scenario can deliver 31.4% of the city's total heat demand.
- The low DE scenario provides 14% of the total heat demand.
- Even assuming that 16% of homes remain electrically heated, the remaining 50%+ of homes envisaged under the high DE scenario as still heated by individual gas boilers in 2025 leave considerable further scope for DE to achieve even greater cuts in CO_2 emissions after 2025 – in an area which centralised scenarios cannot touch.

Analysis of results

The heat balance calculation shows how the heat demand for Edinburgh would be supplied under the various scenarios. The totals shown in Figures 4.11 and 4.12 represent heat delivered. The share of electric heating is assumed to remain at 16% for all scenarios because of the potential difficulties and/or cost of converting electrically heated dwellings to either CH or gas-fired individual boiler systems. In practice, a CH network developer would be likely to prioritise the conversion of electrically heated dwellings, as this is where the greatest CO_2 emission and cost savings would be obtained. However, this variable has been kept constant in each scenario in order to remain consistent with our conservative approach, even though this once again underplays the potential contribution that a DE approach could make to CO_2 emission savings.

For both centralised scenarios the heating supply is dominated by gas-fired boilers. For the low DE scenario, the various DE technologies supply 14.8% of the total heat demand. The majority of this supply is through gas and biomass-fired CHP and CH, but with some contribution from renewable energy. The areas covered by the levels of CH envisaged in both the high and low DE scenarios are shown on Maps 2 and 3 above. For the high DE scenario, the contribution from DE is 31.4% – nearly one-third of the overall heat demand.

Even discounting the 16% share of electric heating, it is clear from Figures 4.11 and 4.12 that there is potential for further expansion of DE heating capacity into the share of the heat market that is envisaged still to be occupied by individual boilers. As this expansion would be in areas of lower-density heat demand where CHP and CH are not considered viable, the DE solutions required would include micro-CHP and solar thermal systems. Both DE scenarios offer a realistic way of ultimately meeting the heat demand of Edinburgh through provision of a number of different types of CHP and solar thermal systems. The variations in the centralised electricity fuel mix do not translate significantly into the heat market and the more immediate requirement is to develop a more efficient way to utilise our limited gas supplies – which CHP and CH can deliver.

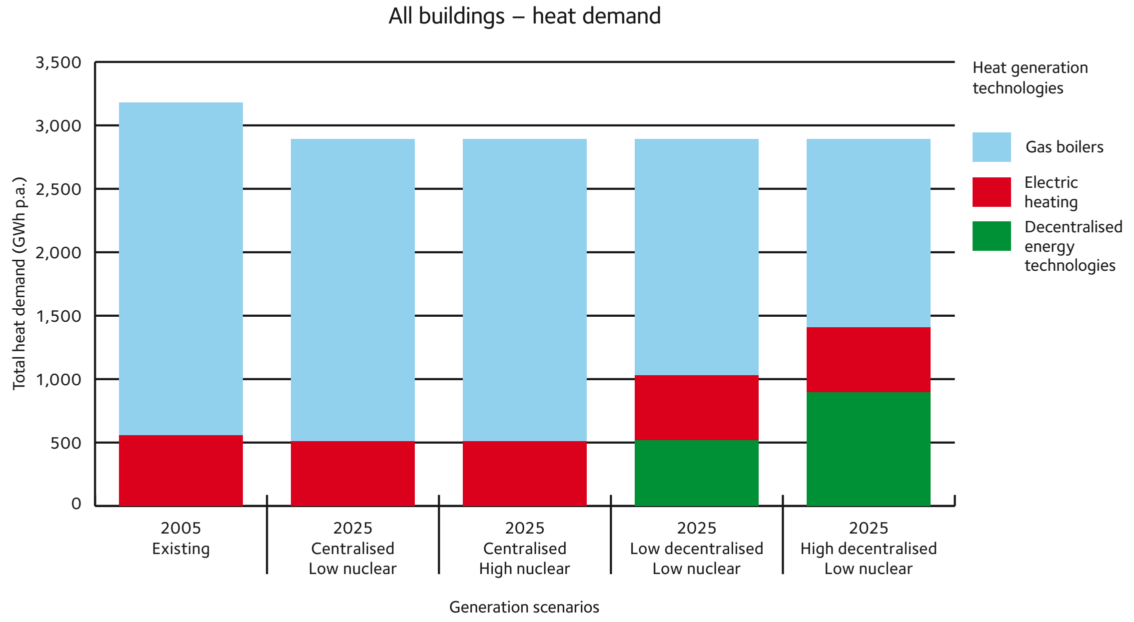


Figure 4.11: Heat balance.
Overall demand for gas for heating remains similar under each scenario. However, there is a double-counting of gas demand under the DE scenarios as gas use is divided between use in individual gas boilers producing only heat and gas that is used in DE technologies, such as CHP, that produce both heat and electricity. Much of the gas use shown in this graph for decentralised heat production is also shown in Figure 4.13 for electricity.

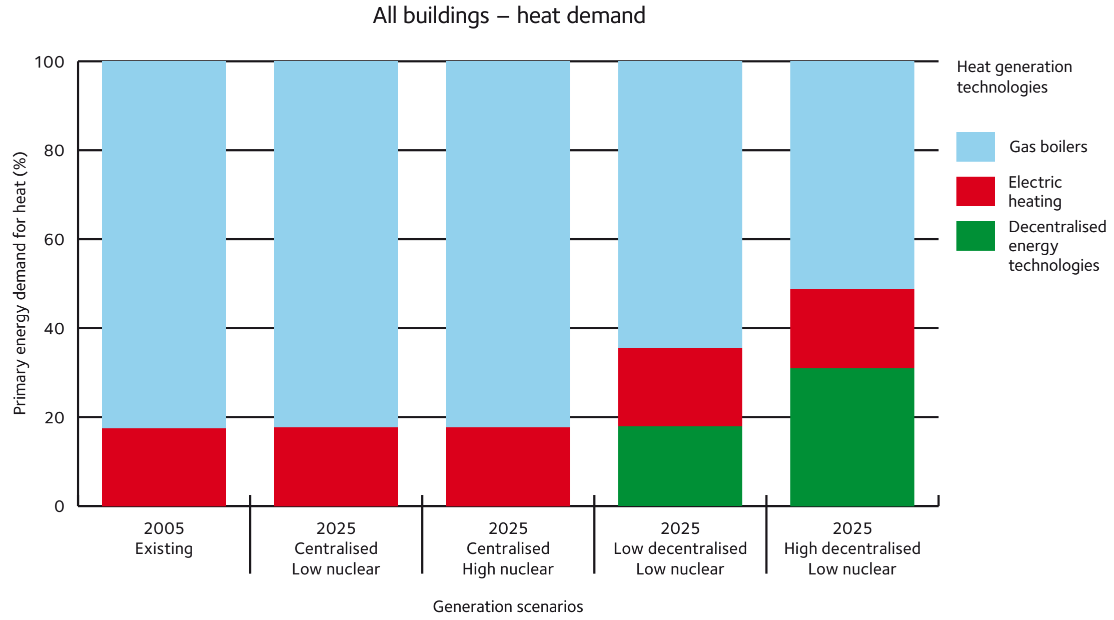


Figure 4.12: Heat balance as percentages.
Provision of heat can be diversified under the DE scenarios with the gas used in decentralised systems also yielding electricity (as indicated in Figure 4.11).

4.4 ELECTRICITY BALANCE

Results

- The high DE scenario can provide nearly one-third of Edinburgh's electricity demand from within the city.
- The combination of DE technologies gives a more reliable, secure and flexible generating mix.
- The proportion contributed by nuclear power in the DE scenarios is greatly reduced when compared with the high nuclear scenario.

Analysis of results

The electricity balance calculation estimates how Edinburgh's electricity demand will be supplied under the various scenarios. The totals shown in Figures 4.13 and 4.14 represent electricity delivered. Total electricity demand is projected to increase by 2025 principally as a result of the expansion of Edinburgh and the assumption that gains in energy efficiency are offset by increased use of appliances.

It can be seen that in the low DE scenario, over 20% of Edinburgh's electricity is generated within the city, with just over one half of the imported centralised electricity provided by gas-fired power stations. In the high DE scenario, 33% of total electricity demand is generated within Edinburgh. The proportion contributed by nuclear power in the DE scenarios is much reduced as a result compared to the high nuclear scenario. Some of the electricity generated in Edinburgh under both DE scenarios (4% in the low DE scenario and 8% in the high DE scenario) is from renewable energy sources (biomass, wind and solar).

The implications of the generation of over 33% of Edinburgh's electricity demand locally under the high DE scenario are as follows:

- a much larger number of smaller generators will result in a more reliable, flexible and secure generating mix, which will reduce the total generating capacity needed to supply Edinburgh and enable a greater proportion of intermittent renewable energy to be accommodated on the distribution network, as can be seen in Denmark.
- the reduction in Edinburgh's peak demand for centralised energy will cut the need for investment in additional national grid capacity to meet Edinburgh's growing demand, and may also reduce the cost of maintaining and reinforcing the current system.
- some buildings may enjoy greater security of supply as a result of decentralised generation, depending how this is introduced.
- generating electricity from both gas-fired CHP and building-integrated renewables will require modifications to the distribution system within Edinburgh, to ensure energy balancing within the city and to enable surplus energy to be exported onto the national grid. Upgrades to the distribution network will be able to absorb further local renewable generating capacity as micro-renewable technologies mature.

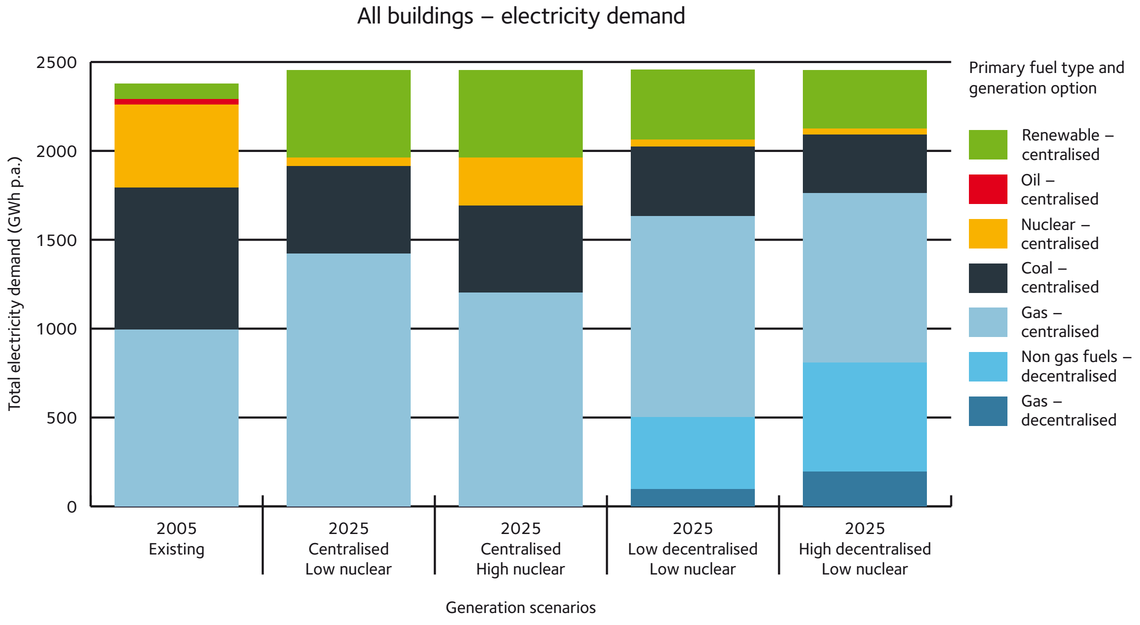


Figure 4.13: Electricity balance.
Edinburgh can produce an increasing amount of its own electricity under the DE options. While an increased dependence on gas is indicated, this same gas is also yielding heat (as explained in Figure 4.11).

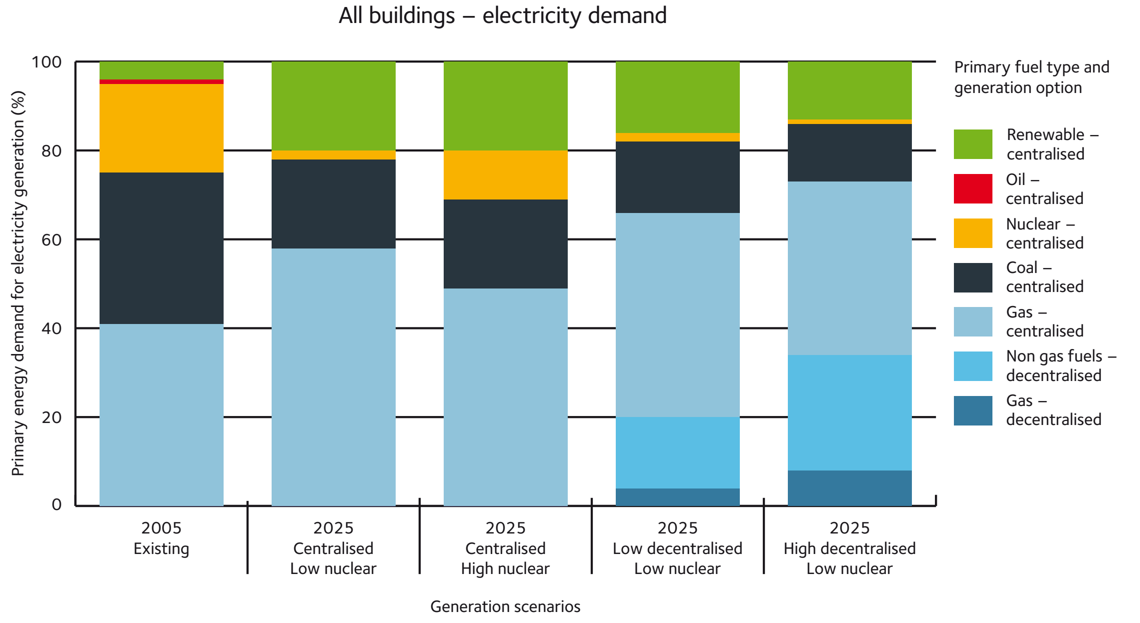


Figure 4.14: Electricity balance as percentages.
Under both DE scenarios, gas remains the dominant fuel for electricity production, but the electricity produced via gas-fired DE is effectively the by-product of heat generation.

5. CONCLUSIONS

The model which forms the basis of this report has been developed to estimate the contribution decentralised energy systems could make by 2025 to supplying Edinburgh's energy needs, enhancing energy security, ensuring adequate heating in every home and reducing CO_2 emissions from buildings. The model has been used to consider two scenarios for the development of DE: a low DE scenario assuming a modest degree of political support which is based on existing technologies and assumptions broadly consistent with current regulations and economic conditions and a high DE scenario using more advanced technologies and in which the regulations and economic background are assumed be more favourable to DE. These have been compared with two scenarios reliant on conventional centralised generation – a low nuclear scenario involving no new nuclear power stations to replace retired plant, and a high nuclear scenario in which a number of new stations are built.

Both DE scenarios:

- reduce CO_2 emissions by 2025 without new nuclear power stations being built.
- reduce CO_2 emissions further than either of the centralised scenarios.
- use less primary energy than either of the centralised scenarios.
- meet Edinburgh's projected heat and electricity demand without assuming any exceptional demand-side energy efficiency gains.
- reduce overall gas consumption despite the use of gas for CHP and the assumption of gas replacing nuclear in centralised generation.

The majority of the CO_2 savings would arise from a major investment in gas-fired CHP and CH systems, although a range of other technologies could also be used, particularly in the new-build sector, offering further scope for exploitation of previously untapped renewable resources and providing greater security through diversity. The installation of CH networks capable of distributing heat from different fuel sources and CHP plants would offer flexibility in meeting heat demand in subsequent decades.

The low DE scenario:

- reduces CO_2 emissions by nearly 24% by 2025.
- uses 16% less primary energy than the high nuclear scenario.
- uses 5% less gas overall than the high nuclear scenario
- supplies nearly 18% of Edinburgh's heat market through DE.
- generates over 20% of Edinburgh's total electricity consumption through DE.
- comes closer to meeting the target necessary to reduce CO_2 emissions by 60% by 2050 than either of the centralised scenarios.

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The high DE scenario:

- **is the only scenario to exceed the 2025 CO_2 emissions reductiontarget.**
- reduces CO_2 emissions by 28.7% by 2025.
- uses 25% less primary energy than the high nuclear scenario.
- uses 15% less gas overall than the high nuclear scenario
- uses a greater proportion of renewable energy than the other scenarios
- supplies 31% of Edinburgh's heat market through DE.
- generates 33% of Edinburgh's total electricity consumption through DE.
- assumes less than 1.4% of Edinburgh's electricity demand is supplied by nuclear power.

Significant progress towards the primary goals set out in the Energy White Paper of CO_2 emission reductions and increased security of supply could thus be made by adopting the DE approach. It has been shown that DE can achieve, and in fact exceed, CO_2 emission reductions in line with the target of a 60% reduction by 2050, whereas with the centralised scenarios (including the high nuclear scenario) this target cannot be met. It has also been shown that the high efficiency of DE will result in a lower consumption of natural gas and that there will be a wider variety of energy sources, many of which are based on local supplies, thus enhancing energy security. These findings suggest that the most effective way for Edinburgh to reduce its CO_2 emissions and increase its energy security is by adopting a DE pathway.

APPENDIX A – ASSUMPTIONS ABOUT ENERGY DEMAND IN EDINBURGH

1. THE DOMESTIC SECTOR

Existing dwellings

The total number of existing dwellings in Edinburgh is a little over 204,000 according to data taken from the 2001 Census. The average annual heat demand per Edinburgh dwelling is estimated in the same study as 9,562kWh. The calculation of heat demand in dwellings is inaccurate in that a substantial minority of households incorrectly identified their properties as semi-detached rather than flats and untangling this has been problematic. The solution – using local knowledge of where these 'four-in-a-block properties were and reclassifying them – results in a likely underestimate of domestic heat demands, however this is consistent with a conservative approach to estimating energy demand.

The proportion of electrically heated dwellings across Scotland is about 20% (SHCS, 2002). However, it is clear from the same survey that this is partly a result of significant areas not being connected to the gas network (particularly in rural areas). The proportion of electric heating in Edinburgh is estiamted at between 16-18%. The conservative figure is adopted here and therefore it has been assumed that 16% of the existing dwellings in Edinburgh are electrically heated and the remaining 84% heated by individual gas boilers. The average efficiency of existing domestic gas boilers is taken to be 70% (BRE, 2005). More recent systems will have a higher efficiency and older systems a lower efficiency.

Indications from City of Edinburgh Council sources are that the number of properties heated by gas-fired boilers and connected to CH systems is negligible in relation to the scale of this study. There are a few systems supplied by CHP or run on renewables but the numbers are too small to be statistically significant.

Annual electricity demand for an average dwelling in the UK is 3,300kWh for lights and appliances (ie excluding electricity for space and water heating). This is the figure that is used by the supply companies in comparing annual costs (BRE, 2005). Although Edinburgh probably has a higher proportion of larger dwellings than the national average and disposable incomes that are also higher on average – a combination that may give rise to higher electricity use – we have cautiously assumed that the average demand for Edinburgh is 3,300kWh a year in accordance with the national average.

By 2025 we would expect existing dwellings to show some reduction in space heating demand as a result of energy efficiency improvements such as cavity wall insulation, increased loft insulation and more flexible and responsive temperature controls. The potential for this is limited, however, by the age and type of the buildings, as a large proportion of residential properties in Edinburgh date from the 19th or early 20th century and do not have cavity wall construction, making cavity wall insulation impossible. A 10% reduction in average heat demand from existing dwellings by 2025 has therefore been estimated, resulting in an average heat demand per dwelling of 8,606kWh a year.

Individual gas boiler efficiencies will rise as a result of the incoming 2007 Scottish Building Regulations for which the Consultation is currently ongoing. This will require the use of a condensing boiler whenever a boiler is replaced – it is assumed that the proposals within the consultation will be accepted and that boiler efficiencies in Scotland will become the same as those currently required in England and Wales. By 2025 it is assumed that most boilers in existence now will have been replaced with a condensing model, so that the average efficiency should rise to at least 86% (SEDBUK B rating).

The proportion of dwellings heated electrically has been assumed to remain the same at 16%, as either gas supply installation will not be feasible for structural reasons or specific reasons for retaining electric heating (such as low installation costs) will exist.

Non-heating electricity demand per existing dwelling is also assumed to remain the same, as it is likely that improvements in the efficiency of appliances will be offset by a growth in their number and use. There is also the possibility that there will be a growth in air-conditioning in the existing domestic sector if climate change trends continue; however, this has not been taken into account.

Demolitions will have occurred by 2025. The *40% House* report (ECI, 2005) estimates recent national demolition rates at 20,000 dwellings annually, a figure

These solar thermal units at Western Harbour in Malmö, Sweden, are connected together and supply 20% of the community heating network. © Greenpeace/Reynaers predicted to rise to 80,000 per year to 2050. This equates to 680 a year for Edinburgh, giving a total over 20 years of around 13,600 dwellings demolished. This may be an overestimate for Edinburgh, where property values are relatively high and there is high demand for housing due to continuing investment and growth; however, the national rate has been assumed in the absence of more local data. The number of existing properties remaining in 2025 has therefore been assumed to be 191,083.

New dwellings
Edinburgh is expected to undergo significant expansion in the period to 2025. Information provided by City of Edinburgh's Department for Economic Development indicates that nearly 41,000 dwellings are due to be built.

As within the assessment undertaken for the Edinburgh study, the energy assessment represents that of a typical two-bedroom apartment, as new dwellings are likely to be at a high density of development. On the basis of the new Building Regulations coming into force in 2007, we have estimated an average heat demand for space heating and hot water of 3,000kWh a year per dwelling – the same as used in the London study and representing a conservative assumption in respect of heat demand. Over the period 2006 to 2025 it is expected that Building Regulations will be further tightened, and so on average a further reduction in heat demand may be seen for the dwellings built up to 2025; however, this has not been taken into account as it cannot be quantified. The same approach is taken in respect of lifestyle choices and proliferation of appliances – there will be changes but they are unknown at present and problematic to forecast.

Average boiler efficiency has been assumed to be 92%, the SEDBUK A level, which future Building Regulations are likely to make compulsory.

Electric heating is currently estimated to have a share of around 50% of the new-build market, although no firm data is available; but with the updates to the Building Regulations we would expect this to fall – the reduction is assumed to leave an average of 25% for new dwellings built 2005-2025. Under the DE scenarios the percentage of new dwellings with electric heating would be expected to be lower; nevertheless we have taken the conservative approach of retaining the 25% electric heating share under all scenarios, although this favours the centralised energy scenarios.

Average electricity demand for new dwellings has been assumed to fall by 2025 to about 18% less than for existing dwellings, or 2,700kWh a year, as new, more efficient appliances are acquired and low-energy lighting installed as a Building Regulations requirement. As with heating, the smaller average size of new dwellings will also be a factor.

It can be seen that the heat demand for new dwellings is much reduced compared to that for existing dwellings, to the point where it is only 11% higher than the electricity demand.

In respect of new dwellings, it is clear from projections that they are set to be built in specific locations of the city on land earmarked for regeneration, particularly in the areas of Leith Docks, Granton Waterfront and Western Harbour. In anticipation of the high build densities likely for the proposed developments, a prioritisation of energy and environmental objectives by the City Council would support the connection of these dwellings to high capacity cogeneration plant such as a large biomass or large gas-engine CHP with community heating.

2. THE NON-DOMESTIC SECTOR

Existing non-domestic buildings
The buildings database developed for this research is based not on actual floorspace source data, but instead applies employment densities for various types of non-domestic property developments to worker data from the 2001 Scottish Census. This first stage results in a broad representation of geographically specific (to Census Output Area) non-domestic building use across Edinburgh. To derive heat and electricity demand, energy benchmarks were applied to the resulting gross floor areas for each property type / building use within each Census Output Area, giving a heat and electricity demand and density.

The energy benchmarks applied to the buildings data were originally developed for use within *The UK Potential for Community Heating with CHP* and were calculated using a business rates database. This classifies buildings into a number of categories, to each of which we assigned heat and electricity demands. As with the domestic sector, a 10% average improvement in heat energy efficiency in existing properties by 2025 has been estimated on the basis of these categories.

The total existing non-domestic floorspace has been estimated at 10,135,370m^2 with an annual heat demand of 120.6kWh/m^2 and an electricity demand of 113kWh/m^2. Office space predominates in Edinburgh, with the retail floorspace about one tenth of that assumed for offices[11]. The amount of air conditioning installed is a major determinant in the electricity demand of such non-domestic floorspace, but detailed information on the extent of air conditioning is not available, so we have assumed 50% air conditioned and 50% naturally ventilated floorspace in determining the above figures. It is also likely that there will be a growth in air conditioning in the future if climate change trends continue; the impact of this has not been included in the current model.

It is assumed that 20% of existing non-domestic floorspace utilises electric heating and that this level of electric heating will continue through to 2025. Gas boiler efficiencies are assumed to rise from the current figure of 80% to 86% (SEBDUK B).

New non-domestic buildings
City of Edinburgh Council's Department for Economic Development is predicting an increase in gross floorspace of around 1,337,642m^2 in specific locations. We have assumed that another 10% will be built across the rest of the city, bringing the gross new floorspace to 1,471,406m^2. We have assumed the demolition of 5% of existing floor space so the net new floorspace is just under 965,000m^2.

Energy use in new non-domestic buildings will vary considerably with the type of building, the use pattern and whether air conditioning is employed. Average heat demand has been estimated assuming a 25% reduction from 'Good Practice' levels for offices: these represent a significantly higher level of performance than the 'Typical' levels assumed in estimating the demand for existing buildings (both benchmarks are taken from CIBSE Guide F (CIBSE, 2004). On the basis of this calculation, average annual heat demand has been taken as 54.2kWh/m^2. Boiler efficiencies in new non-domestic buildings are assumed to be 92%, as it is likely that future revisions to the new Building Regulations will make such a level of efficiency compulsory.

It is assumed that the proportion of electrically heated floorspace in new buildings will fall to 10% as a result of Scottish Executive Policy measures and revisions to the Scottish Building Regulations.

Electricity demand is taken to be 30% below 'Typical' levels, as the scope for improvement is not as great as for heating, and Building Regulations do not currently cover the use of electrical equipment (such as computers), which is currently producing a rising energy demand trend. The average annual electricity demand has therefore been taken as 79.1kWh/m^2.

As with new dwellings, the ratio between electricity and heat is predicted to change, with heat demand becoming a less significant (but still important) proportion of the total energy demand of new non-domestic buildings.

There is significant effort in the construction industry to design naturally ventilated buildings, encouraged in the drive to lower the energy consumption of buildings. However we have assumed that 50% of new non-domestic floor space will be air-conditioned in the future. The use of DE would potentially enable lower-emission cooling sources such as absorption chillers to be used. However, no account has been taken in the DE scenarios of the further emission savings that might result from implementation of this approach.

APPENDIX B – ASSUMPTIONS ON FUTURE POWER STATION MIX

To determine the overall CO_2 emissions for Edinburgh, the amount of centrally generated electricity 'imported' and the emissions from the power stations that supply it must be calculated. The calculation of total CO_2 emissions assumes that electricity supplied from outside Edinburgh has a CO_2 emissions factor equivalent to the average of the emissions from the total UK national grid. This reflects that electricity is traded UK-wide under the British Electricity Trading and Transmission Arrangements (BETTA) and is not divided up between the different nations. The proportion of electricity supplied to the national grid by each power source is given in the tables 2.2a and 2.2b below, together with the CO_2 emissions factor associated with each. From this data the average CO_2 emissions per unit of electricity delivered by the grid can be calculated.

Table 2.2a: Proportion of electricity supplied to the national grid from different sources, and associated CO_2 emissions factors, 2005

	CO_2 emissions factor	2005	Contribution to emissions factor
	g/kWh	%	g/kWh
Nuclear	0	19.64	0
Renewables	0	2.35	0
Hydro	0	1.29	0
Coal	972	33.62	326.79
Gas	465	39.14	182.00
Oil	899	1.23	11.00
Other	534*	2.73	14.58
Average CO_2 factor (g/kWh)			534

*The calculation is derived from DUKES (2005), which does not provide details of the emissions factor for the generation component termed 'Other'. This has therefore been taken as the average of all sources for the purposes of deriving an average CO_2 emissions factor.

Table 2.2b: Proportion of electricity projected to be supplied to the national grid from different sources, and associated CO_2 emissions factors, 2025

	CO_2 emissions factor	2025: low nuclear	2025 high nuclear
	g/kWh	%	%
Nuclear	0	2	11
Renewables	0	20*	20*
Coal	972	20	20
Gas	465	58	49
Average CO_2 factor (g/kWh)		464.1	422.25

*Hydro proportion included within renewables figure

Notes:

a) Imports and oil use have been ignored as these are small quantities.

b) Although nuclear and renewables have a zero CO_2 emissions factor, it is recognised that as for all energy technologies, there are emissions associated with the construction of generation facilities and, in the case of nuclear, with the fuel processing cycle. These emissions have been ignored.

The proportion of electricity from renewable sources is expected to rise to 20%, and Scotland is already on track to exceed the current 40% target set out in the Scottish Executive Renewable Energy Strategy documents (Scottish Executive, 2003). However, we have retained the assumption of 20% to reflect the UK-wide aspirational 2020 renewable energy target announced in the EWP (DTI 2003).

The proportion of electricity from coal-fired stations is expected to fall in the future due to the introduction in 2008 of the EU Large Combustion Plant Directive (EU LCPD) and the impact of the EU Emissions Trading Scheme (EU ETS). The Energy Review (DTI, 2006b) predicts that around 20% of electricity will be generated from coal in 2020.13 We have assumed that the same proportion will be in place in 2025, partly due to the advantages of maintaining a diversity of fuel sources, although it is recognised that coal-fired electricity may be increasingly uncompetitive as a result of the constraints of the EU LCPD and EU ETS.

The balance of electricity production is assumed to be made up by gas-fired stations of the CCGT type. The electrical efficiency of the existing gas-fired stations is typically 45%, with the next generation typically achieving 50% (IPPC Bureau, 2005). This may rise to 55% over time. We have assumed 50% average efficiency when calculating the fuel displaced by DE generation (see below).

The DE options which generate electricity will displace electricity imported to Edinburgh. In order to calculate the resultant CO_2 emission savings an assumption has to be made as to which centralised power source would be displaced. It is clear that it would not be nuclear or renewables, as these stations have low operating costs and will therefore generate at maximum output whenever available. It has therefore been assumed that it is the gas-fired stations whose output will fall. If instead the coal-fired plant were to be taken as the marginal plant to be displaced by DE, the resultant CO_2 emission savings would be significantly higher. The emission reductions estimated for the DE scenarios are consequently likely to be lower than would occur in practice, and the approach taken is therefore robust.

In the centralised electricity system, energy is lost not only at the point of generation but also from the transporting of electricity through the transmission and distribution networks to where it is needed. Average electricity losses are taken as 3% for the main transmission system and 6% for the distribution system (IEA, 2005). In calculating the impact of decentralised electricity production we have assumed a saving of the full 9% for both DE scenarios. In practice the smaller domestic-scale systems will save a higher proportion of the losses associated with centralised production and the larger district- or community-scale ones will save less.

APPENDIX C – DECENTRALISED ENERGY TECHNOLOGIES AND THEIR EDINBURGH POTENTIAL

The potential for CHP and CH is closely related to the density of heat demand. The methodology adopted for this research closely follows that utilised for a similar study for London: *The Community Heating Development Study for London* (GLA, 2005) developed GIS maps of the potential heat demand density of London, based on the Census 2001 enumeration districts.

The method of calculating domestic energy demands used in the graphical map outputs is identical to the original London study, using Scottish Census 2001 data to determine property type and distribution and applying energy benchmarks to them. The method of deriving total heat densities differs from that of the London study – energy demands of non-domestic buildings were calculated using Scottish Census 2001 Univariate data and applying worker density benchmarks to estimate the building floor areas. Energy benchmarks were then applied to each building type within each Census Output Area to calculate energy demand and heat and electricity density.

The results are reproduced graphically as Maps 1, 2 and 3. These show the heat demand density grouped into ranges of total heat demand. The areas of highest heat demand were identified using minimum heat densities beneath which community heating with CHP would not be economically viable. Map 2 assumes minimal policy intervention from either local, Scottish or UK Government, and represents around 23% of Edinburgh's total heat demand. Map 3 assumes a proactive policy approach, with energy efficiency and supply as a key consideration of policy makers in local and national offices and represents 35% of Edinburgh's total heat demand.

The various technologies that would contribute to meeting these policy objectives are considered in turn below.

1. Gas-engine CHP supplying CH Networks

The main alternative to using centralised power generation is that of CHP, which can be located closer to customers thereby saving transmission costs and allowing the provision of efficient, locally generated heat through CH pipe networks. Gas-engine CHP technology supplying CH networks is well established, particularly in Jutland, Denmark and in the Netherlands. In Edinburgh there are currently no good examples that exist – this is primarily a result of council policy to replace community heating schemes with individual gas boilers in the 1970s and 1980s.

Examples of the conversion of existing housing to CHP/CH can be found across Europe, where significant heating networks were installed during the 1970s and 1980s; here in the UK the CHP/CH system at the Dickens Estate in Portsmouth provides a good example.

Description of technology

Over the last 15 years developments in reciprocating engine technology have been significant. A number of European diesel engine suppliers are now offering spark ignition gas engines designed for use as base-load CHP generators. Efficiencies have improved and emissions have reduced. Engines are available in the size range from 1MWe to 8MWe – we have assumed a 2.2MWe engine size as being typical for Edinburgh.

Edinburgh opportunities

There is currently very little gas-engine CHP capacity in Edinburgh that is connected to communty heating networks, which are of primary importance for the widespread usage of CHP. The city's conservation areas and preservation orders may be a significant barrier to the uptake of community heating. However, the precedent of excavation and disruption of infrastructure and building use has been set by the installation of utilities and communication networks. The laying of pipe networks falls within the same category. CH networks have been successfully installed in heritage-rich cities in Europe such as Copenhagen, Amsterdam and Paris.

Expected market share

The primary market for this technology is the existing building stock reached through newly-built CH networks. The city centre provides the focus for potential in 2025, as relatively high building density and zones of mixed use result in the requisite demands that support community heating with CHP. The high domestic densities in the city centre and in outlying local centres also provide the necessary heat demands.

An earlier study, *The UK Potential for Community Heating with CHP* (BRE, 2003), estimated that the potential for CHP for existing buildings in Edinburgh is a total of 134MWe of gas-engine CHP. Under the low DE scenario the potential capacity of 134MWe estimated by the BRE study is considered to be optimistic, and an assumption for potential of 85MWe has been adopted. This is based on the minimum required heat density.

Under the high DE scenario, the figure proposed by BRE is broadly consistent with the PB analysis in that the results of the heat density mapping using a lower requirement on heat density suggest that the potential is around 130MWe This is consistent with an active policy framework from local and national Government that prioritise energy and environmental objectives. The projected capacities for each of new domestic (10MWe) and new non-domestic (8MWe) buildings remain the same.

2. Biomass CHP via CH networks

Fuel resource and type

Biomass is a renewable energy source that has been underdeveloped in the UK. Although the resource available from forestry is more limited than in some other European countries, there is still a significant amount of clean wood waste that is sent to landfill. In the future energy crops such as wood, straw or miscanthus grass may be able to contribute. There is a wood fuel resource within Edinburgh itself, but to supplement that, the Lowland and Borders regions of Scotland have an abundant wood resource, which is close enough to Edinburgh to justify fuel transport.

Description of technology

The technology of biomass CHP using steam turbines in the range 10MWe to 50MWe is well established in the Scandinavian countries, Germany, The Netherlands and Austria. However, most UK experience has been with heat-only boilers or electricity-only production. This must change if Edinburgh is to contribute its share to the ambitious national targets set by the Scottish Executive for renewable energy in Scotland.

Edinburgh opportunities

The analysis is based on a large-scale biomass CHP system proposed for the new waterfront developments at Leith Docks, Western Harbour and Grafton Waterfront, which a) has the scale to warrant adoption of viable biomass CHP technology, b) will have the required density to support extensive CH networks, and c) has the infrastructure to support fuel delivery by boat or rail and will contribute significantly to the mitigation of carbon dioxide emissions in Edinburgh.

Expected market share

The fuel resource available in the areas surrounding Edinburgh provide huge scope for the use of biomass - the limits are exerted by demand. The resource locally available from the Lowlands and Borders is estimated at around 3 million tonnes (dry weight) for wood fuel of the requisite size and quality (see Appendix E). Under the low DE scenario we have assumed a 10Mwe scheme with a 15MW heat output supplying new build developments. For the high DE scenario a 20MWe scheme with 30MW of heat output is assumed to supply the new build developments and also connect to some of the existing building stock. The demand of the technologies and capacity can easily be met by the locally available wood fuel resource.

3. Buildings based CHP

In some non-domestic buildings connection to a local CH scheme is likely to be less suitable than having a dedicated CHP system on site. On-site systems will also be suitable for buildings not within the reach of CH networks, particularly where the occupants also wanted to secure their electricity supply in case of grid failure.

Candidate buildings include:

- hospitals
- prisons
- university campuses
- hotels
- leisure centres
- large retail or office complexes where cooling is required.

Description of technology

The technology normally involves smaller gas engines within the range of 100kWe to 1MWe, although packaged small scale gas turbines of around 100KWe are also available. In the future fuel cells may become commercially available for this application. Recent technological developments have led to smaller CHP units down to 5kWe, which would be suitable for quite small buildings.

Edinburgh opportunities

A number of building CHP systems already exist in universities and hospitals: for example, Edinburgh University, Royal Edinburgh Infirmary and the Western General Hospital. There are also good examples operating in the commercial sector including Scottish Water's Seafield Wastewater Treatment works and several of the large hotel chains. The main applications are expected to be in new build non-domestic buildings and in the larger existing buildings. Under the low DE scenario we envisage 18MWe of CHP capacity in existing buildings, comprising 6 major sites of 2MWe and 20 minor sites of 300kWe. Most of these will be located in outer Edinburgh, outside the CH network areas. In the new-build sector we have assumed nearly 2.5MWe of CHP capacity, principally located in commercial developments. Under the high DE scenario the capacity is developed further in existing buildings to nearly 27MWe, with no increase in the new-build sector.

4. Biomass boilers

For details of the fuel resource and type, refer to the description under Biomass CHP

Description of technology

The use of biomass boilers for heating is an established technology, the only constraints being availability of suitable fuel, adequate space for fuel delivery and storage and increased labour costs for maintenance and operation compared to conventional gas boilers. As a result of these issues, biomass boilers are more likely to be used in new-build developments.

Expected market share

Under the low DE scenario we have assumed 5.7% of new dwellings and 10% of new non-domestic floor space utilising biomass boilers. Under the high DE scenario 11% of new dwellings and 20% of new non-domestic floorspace are assumed to utilise biomass boilers.

5. Building-integrated low- and zero emission technologies

There is a wide range of low and zero-emission technologies suited to incorporation into properties. Zero-emission renewable energy sources include solar thermal and PV units and small-scale wind turbines. Low-emission technologies include gas-fired micro-CHP units.

Description of technology

Domestic CHP

The utilisation of larger-scale CHP to supply the residential sector requires CH networks to deliver the heat. This is cost-effective in areas of high development density, but less so in low-density suburban streets with semi-detached or detached dwellings. Significant research has been devoted to developing a domestic scale CHP unit which would take the place of a conventional boiler and generate around 1kW of electricity and enough heat for space and water heating. At present the Stirling engine and the organic Rankine cycle are the most promising technologies for the coming decade, with an electrical efficiency of around 15% and heat efficiency of around 70%, but they are still far from commercial viability. In the longer term fuel-cell CHP, which offers higher efficiency, may become economically viable.

Renewable heat – solar thermal

Solar thermal systems, using panels fixed to a south facing roof, are designed to provide heat only to a domestic hot-water heating system. They work in conjunction with a conventional heating system which provides top-up capacity, especially in winter. This technology is not normally compatible with CHP (because CHP systems usually have surplus heat available in the summer when solar thermal output is at its highest), although there are a few systems in existence in which larger solar thermal arrays provide heat to a CH network.

Renewable electricity – photovoltaic panels and wind turbines

Two technologies are considered under this head: photovoltaic panels (PV) and building-integrated wind turbines (BIWT). The advantages of these technologies include the avoidance of grid losses and the zero-emission energy sources used. The disadvantage of PV is that unshaded surfaces are needed; the disadvantage of BIWT is that the output can be relatively low due to the lower wind velocities in built-up areas.

Expected market share

The fact that the areas of high heat density would be predominantly served by CH networks means that the main opportunities for the micro-generation technologies lie in the outer areas of the city, and outside the majority of the conservation and preservation areas. The degree to which these technologies penetrate the market will depend on local and national Government policy and also the market readiness and cost of these technologies.

Domestic CHP

Under the low DE scenario we have assumed that the current technical barriers will not be overcome by 2025, and therefore there is no capacity included for domestic CHP. Under the high DE scenario we have assumed that from 2010 domestic CHP will gain about a 10% share of the new boiler market, which is estimated to be 1.2 million units p.a. (CT, 2005) for the UK and approximately 7000 units in Edinburgh. This results in nearly 800 units a year in Edinburgh over 15 years (2010 to 2025) which means by 2025 there would be 11,700 units – covering about 5% of the total number of dwellings.

Renewable heat – solar thermal

The main market is considered to be in new dwellings, where the capital cost of the initial installation can be lower than for retrofit and where future planning regulations will require consideration of solar thermal and other renewables. In addition, solar thermal systems will be appropriate for dwellings in outer Edinburgh where CHP and CH are unlikely to be viable. Apart from specialist buildings such as hotels and leisure centres, the non-domestic sector is unlikely to have sufficient summer heat demand to justify solar thermal systems. Under the low DE scenario 3060 dwellings are assumed to have solar thermal systems, representing 7.5% of the new-build total, along with 10,240 existing dwellings, representing 5% of dwellings in the low heat density areas of outer Edinburgh. Under the high DE scenario these numbers are doubled to 6,100 new build dwellings and just under 20,500 in existing dwellings.

Renewable electricity – photovoltaic panels and wind turbines

We expect the main market to be in the new-build non-domestic sector where the high cost of the PV can be offset by avoided costs for high-quality cladding materials and where concerns over noise from wind turbines will not be as relevant. Moreover, electricity demand for this sector is highest during the daytime, which is obviously compatible with PV. Under the low DE scenario we have assumed that:

- 10% of the electricity demand of new non-domestic buildings is met from PV and BIWT
- 10% of new dwellings will have PV or BIWT installed
- 1.3% of existing dwellings will have PV or BIWT installed.

Total installed capacity for the entire new-build sector is assumed to be 7MWe of BIWT and nearly 8MWe of PV. Total installed capacity (at a much lower density) for existing buildings is assumed to be just over 2.5MWe of BIWT and 1.3MWe of PV. Under the high DE scenario we have assumed that:

- 20% of the electricity demand of new non-domestic buildings is met from PV and BIWT
- 20% of new dwellings will have PV or BIWT installed
- 2.6% of existing dwellings will have PV or BIWT installed

Total installed capacity for the entire new-build sector is assumed to be 14MWe of BIWT and 15.5MWe of PV. Total installed capacity for existing buildings is assumed to be just over 5MWe of BIWT and 1.6MWe of PV.

6. Implications of Planning Restrictions and Conservation Areas

The introduction of infrastructure associated with the adoption of DE should be entirely possible while respecting Edinburgh's heritage status and associated planning restrictions. Other prominent historic cities, such as Amsterdam and Copenhagen, have installed large-scale community heating networks without aesthetic damage, and existing planning regulations in Edinburgh have not prevented similar infrastructural changes such as the installation of telecommunications networks.

As a city of significant historic importance, Edinburgh has recognised areas in which regulations apply in respect of a) restricting disruption to existing infrastructure, particularly in respect of temporary alteration of the aesthetic qualities of the built or natural environment and b) permanent structural or aesthetic modifications to the exterior of buildings of a certain vintage or design. The City Council seeks to protect and enhance these areas through the application of statutory and non-statutory policies and guidance when considering development projects.

150 KW capacity photovoltaic facility on the roof of the Bundeskanzleramt (Federal Chancellery), Berlin, Germany .©Paul Langrock/Zenit/Greenpeace

The location of multiple sites with World Heritage status in the centre of Edinburgh also places an obligation and stringent rules of operation on planning departments and engineering organisations to work closely together to ensure their preservation.

The engineering works necessary to enable installation of the pipe networks that comprise community heating will involve some excavation of paved and cobbled road surfaces in Edinburgh and possibly minor modifications to buildings. A strong policy commitment to improve existing energy infrastructure could work within planning regulations to ensure that building energy use and its reduction contribute to achieving carbon emission cuts.

It is also clear that the micro-generation technologies that are improving and becoming more readily available are of vital importance in contributing to the same goal, and therefore that their use should be widely encouraged where appropriate. The degree to which they are appropriate is measured here by a) whether their installation competes with that of CHP and community heating and b) how their installation affects the aesthetic qualities of the building(s) on which they are installed. It should be possible, with careful siting, to incorporate DE technologies in all areas of the city.

APPENDIX D – ASSUMPTIONS FOR CALCULATIONS RELATING TO HEAT, GAS AND ELECTRICITY BALANCE AND RESULTING CO_2 EMISSIONS

The following paragraphs describe the calculations carried out within the model and some of the key assumptions on which they were based.

1. Gas-engine CHP supplying CH networks – CO_2 savings calculation

The CO_2 saving calculation is based on medium-scale gas engine CHP plant displacing individual gas-fired boilers and electricity produced by centralised gas-fired power stations. The CHP efficiency has been obtained from suppliers of gas-engine CHP plant and is: electrical 38%, thermal 42%, overall 79%, The amount of energy generated by the CHP units is governed by the annual running hours. This will depend on the heat demand profiles and the economic balance between investments in CHP capacity and savings in boiler fuel. The use of thermal storage, which enables demand profiles to be smoothed and running hours maximised, has also been assumed. For many schemes there will be a mix of domestic and non-domestic loads, but the calculations have been set up for each sector separately. The annual running time has been taken as 5,000 hours for domestic load and 2,500 hours for non-domestic load, as non-domestic buildings tend to have limited summer heat demand. If all schemes have a mix of domestic and non-domestic load then the average annual running time will be about 4,500 hours, which is consistent with the assumptions in the BRE study The UK Potential for Community Heating with CHP (BRE, 2003).

Gas balance calculation

The gas balance calculation takes account of the gas used by the CHP engine, and the gas consumption displaced from conventional heating boilers and centralised power stations (electricity generation displaced is assumed to be gas-fired CCGT).

Electricity balance calculation

The electricity balance is calculated on the basis of how much centrally generated electricity is displaced.

Heat balance calculation

The heat balance calculation is based on the total heat supplied by gas-engine CHP as a proportion of the total heat demand. Heat losses from the distribution system are taken at 8%, less than for the more extensive CCGT schemes.

2. Biomass CHP - CO_2 savings calculation

The calculation of CO_2 savings for the Low DE scenario are based on output from a 10MWe biomass CHP plant. CO_2 savings for the High DE scenario are based on a 20MWe plant. In each case, it is proposed that they would supply heat to the new developments on or adjacent to the Leith Docks area, with the 20MWe plant also supplying some existing dwellings and commercial premises. The calculations take account of CO_2 emitted in the course of fuel transportation, and assume that the electricity displaced is from CCGT plant.

Gas balance calculation

The gas balance calculation takes account of the gas consumption displaced from individual heating boilers and centralised power stations (electricity generation displaced is assumed to be gas-fired CCGT).

Electricity balance calculation

The electricity balance is calculated on the basis of how much centrally generated electricity is displaced. The electricity generated is based on an annual operating time of 7,000 hours, which reflects the availability level of this type of plant. Account is taken of reductions in nominal electricity output as heat is extracted.

Heat balance calculation

The heat balance calculation is based on the total heat supplied by biomass CHP as a proportion of the total heat demand. A load factor of 45% and heat distribution and losses of 10% are assumed in assessing the annual heat delivered.

3. Building-based CHP - CO_2 savings calculation

The CO_2 savings calculation is based on small-scale gas-engine CHP plant displacing individual gas-fired boilers and electricity produced by centralised gas-fired power stations. The CHP efficiency has been obtained from suppliers of gas-engine CHP plant and is: electrical 29.7%, thermal 50%, overall 79.7%. The annual running time has been taken as 2,000 hours for the non-domestic sector. This is lower than for the gas-engine CHP/CH technology because the use of thermal storage is less likely and because building-based CHP does not benefit from the diversity of demand which occurs with multiple buildings on CH networks. In practice, however, some buildings that are well suited to CHP, such as hotels and leisure centres, will have much longer operating hours and consequently greater savings than those estimated here.

Gas balance calculation
The gas balance calculation takes account of the gas used by the CHP engine, and the gas consumption displaced from conventional heating boilers and centralised power stations (electricity generation displaced is assumed to be gas-fired CCGT).

Electricity balance calculation
The electricity balance is calculated on the basis of how much centrally generated electricity is displaced.

Heat balance calculation
The heat balance calculation is based on the total heat supplied by building-based CHP as a proportion of the total heat demand. There are no heat losses as the CHP units are within buildings.

4. Domestic CHP - CO_2 savings calculation
The CO_2 savings calculation is based on domestic-scale Stirling-engine CHP plant displacing individual gas-fired boilers and electricity produced by centralised gas-fired power stations. The efficiency assumed for domestic CHP units is: electrical 15%, thermal 70%, overall 85%. The average annual running time has been taken as 2,000 hours. This relatively low figure again reflects the absence of demand diversity.

Gas balance calculation
The gas balance calculation takes account of the gas used by the CHP unit, and the gas consumption displaced from conventional heating boilers and centralised power stations (electricity generation displaced is assumed to be gas-fired CCGT).

Electricity balance calculation
The electricity balance is calculated on the basis of how much centrally generated electricity is displaced.

Heat balance calculation
The heat balance calculation is based on the total heat supplied by domestic CHP as a proportion of the total heat demand. There are no heat losses as the CHP units are within dwellings.

5. Biomass boilers - CO_2 savings calculation
The CO_2 savings calculation is based on biomass boilers displacing gas-fired boilers, assuming a load factor of 25% for new domestic buildings and 20% for new nondomestic buildings, and a biomass boiler efficiency of 75%.

Gas balance calculation
The gas balance calculation takes account of the gas consumption displaced from individual heating boilers.

Electricity balance calculation
This is not required as no electricity is generated by this technology.

Heat balance calculation
The heat balance calculation is based on the total heat supplied by biomass boilers as a proportion of the total heat demand. No heat losses are included as the biomass boilers are assumed to be small-scale and local to the building or buildings supplied.

6. Building-integrated renewables – solar thermal CO_2 savings calculation
Each domestic solar thermal system is assumed to supply 60% of the annual heat demand for domestic water heating, which is taken to be 2,000kWh p.a. We have assumed that the alternative heating system will be a gas-fired boiler and the CO_2 saving therefore arises from displaced gas consumption.

Gas balance calculation
The gas balance calculation takes account of the gas consumption displaced from individual heating boilers.

Electricity balance calculation
This is not required as no electricity is generated by this technology.

Heat balance calculation
The heat balance calculation is based on the heat supplied by solar thermal systems as a proportion of the total heat demand.

7. Building-integrated renewables – photovoltaics and micro wind turbines - CO_2 savings calculation
The Renewables Toolkit (GLA, 2004c) gives an annual output figure for PV systems of 854kWh per kW installed capacity, but over the next 20 years technical improvements are likely. We have assumed an annual output of 1MWh per kW installed capacity, which is a 17% improvement on current levels. BIWT is assumed to produce 2MWh annually per kW installed capacity, which is lower than The Renewables Toolkit's estimate of 2,400kWh per kW installed: the latter was based on sites with a 4m/s average wind speed, but some sites may not be so favourable. The CO_2 savings calculation is based on building-integrated renewables displacing electricity generated by centralised gas-fired power stations.

Gas balance calculation
The electricity generated is assumed to displace electricity from centralised gas-fired power stations and therefore reduces the gas demand for Edinburgh.

Electricity balance calculation
The electricity balance is calculated on the basis of how much centrally generated electricity is displaced.

Heat balance calculation
This is not required as no heat is generated by these technologies.

APPENDIX E – LOCAL WOOD FUEL RESOURCE

Forestry Commission and Privately Owned Standing Biomass (Oven Dried Tonnes) estimated average annual production

	Species	Stemwood 7-14 (Oven Dried Tonnes)
Scottish Lowlands	Pines	201,444
	Spruces	1,137,340
	Other Conifers	88,784
Scottish Borders	Pines	148,085
	Spruces	1,237,998
	Other Conifers	106,371
Total (Oven Dried Tonnes)		2,920,022

Figures are given in oven-dry tonnes. Woodfuel will never be delivered at this moisture content. Typical moisture contents will vary from 50-60% (measured on a fresh weight basis) for harvesting brash to 25-30% for conditioned woodchips.

Figures are estimates of the annual sustainable production that can be made available taking account of technical and environmental constraints. They do not take account of economic or market constraints.

Figures do not include production from woodlands <2ha in area. These can be a significant resource in particular locations, e.g. Norfolk, Powys, Scottish Borders, Tayside, Cambridgeshire, and Hereford and Worcester (all more than 5000ha). For more information see Appendix 22 of Final Report B/W3/00787/REP, URN 03/1436

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ABBREVIATIONS

CCGT	combined cycle gas turbine
CH	community heating (also known as district heating)
CHP	combined heat and power
CO$_2$	carbon dioxide (a product of combustion)
DE	decentralised energy
DH	district heating (also known as community heating)
DTI	Department of Trade and Industry
EWP	Energy White Paper
CEC	City of Edinburgh Council
SEDBUK	seasonal efficiency of domestic boilers in the UK

UNITS

°C	degrees Celsius
bar	pressure, bar
hr	hour
kW	power, kilowatts (103 watts)
MW	power, megawatts (106 watts)
GW	power, gigawatts (109 watts)
kWh	energy, kilowatt hours
MWh	energy, megawatt hours
GWh	energy, gigawatt hours
p.a.	per annum
tC	tonnes of carbon
tCO^2	tonnes of carbon dioxide

ENDNOTES

1. DTI (2006b), p114
2. The calculation of CO$_2$ emissions assumes that electricity supplied from outside Edinburgh has a CO$_2$ emissions factor equivalent to the average of the emissions from the total UK national grid, reflecting the fact that electricity is traded UK-wide under the British Electricity Trading and Transmission Arrangements (BETTA)
3. Efficiency is defined for the purposes of this report as the amount of energy extracted from the primary fuel source expressed as a percentage
4. The Lerwick scheme currently uses waste heat from an incinerator plant. Greenpeace opposes the use of energy-from-waste combustion, but it is clear that Lerwick provides a good example of how community heating networks can work as part of an integrated DE solution.
5. Fuel cells are not included in the model discussed due the relatively early stage of their development and our intention to only include existing, proven technologies
6. There may be potential for geothermal energy within Edinburgh, particularly given the proximity to old mine workings within the city, however the quantity of heat that could be delivered has not been investigated in detail
7. BREDEM 12 and supported by data from June 2006 Quarterly Energy Prices (DTI, 2006d).
8. This estimate results from a limited survey sample and should therefore be treated with caution, but represents the low estimate of electric heating penetration for housing in Edinburgh, and is below the survey range for national estimates.
9. (CEC 2006) Calculated on the basis of site specific building forecasts and an additional 10% across the rest of the city.
10. Efficiencies range from 78%-82% using stated carbon intensity factors and variations on use at design capacity.
11. It is clear that the calculation for retail floorspace is significantly lower than reality, because of the difficulty in applying differences in worker density across retail types i.e. town centre shops as opposed to superstore retail outlets.

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November 2006