The Economics of Low Carbon Cities

A Mini-Stern Review for the City of Bristol

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The University of Bristol

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This report was commissioned during Bristol's year as European Green Capital - catalysed by the growing ambition of the city to accelerate its progress towards becoming a low carbon city, and driven by the commitment of our researchers to delivering impactful and timely research. For more information on other low carbon energy or future cities research at the Cabot Institute, please visit our website at www.bristol.ac.uk/cabot

The Economics of a Low Carbon Bristol

Today

6.4% of city-scale GVA - £870 million - leaves the local economy every year through payment of the energy bill.

6.4% of GVA leaks out of the economy

Tomorrow

Investing 0.4% of GVA p.a. leads to...

Leads to...

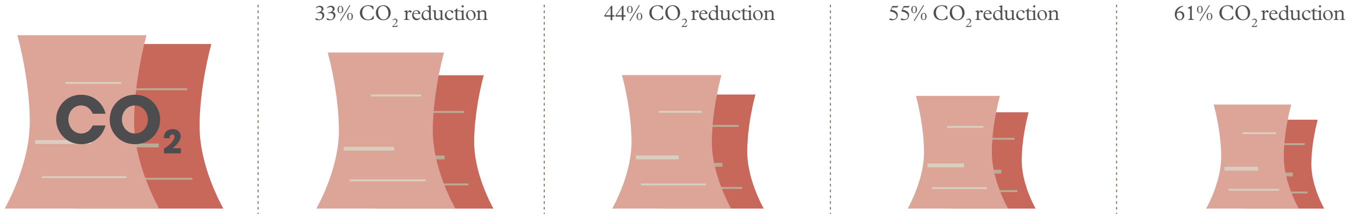
0.4% of GVA or £58 million could be profitably invested, every year for ten years, to exploit economically attractive energy efficiency and low carbon opportunities.

- **Energy**
  reductions in the energy bill averaging 0.7% of GVA p.a. or savings of £220m in 2025
- **Employment**
  2,000 jobs in the low carbon goods and services sector
- **Wider economic benefits**
  More energy security, improved resource efficiency, increased competitiveness
- **Wider social benefits**
  reductions in fuel poverty, improvements in health

Typial Potential to reduce CO_2 emissions

2005 | 2025 →

2005	2025			
	33% CO_2 reduction	44% CO_2 reduction	55% CO_2 reduction	61% CO_2 reduction



	After responding to energy price increases.	Plus supply of lower carbon electricity	Plus exploitation of the profitable options	Plus exploitation of the no net cost options

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Glossary

CCC	Committee on Climate Change (UK government)
CSE	Centre for Sustainable Energy
DECC	Department of Energy and Climate Change (UK government)
DfT	Department for Transport (UK government)
EPC	Energy performance certificate: a graded energy efficiency rating used for domestic and non-domestic buildings in the UK
GHG	Greenhouse gas emissions, including carbon dioxide and other gases (methane, etc.)
GVA	Gross value added measures the contribution to the economy of each individual producer, industry or sector, and is the measure of the value of goods and services produced in each of these areas after subtraction of any intermediate consumption
IEA	International Energy Agency
IPF	Investment Property Forum
LED	Light-emitting diode: A high efficiency form of lighting
LEP	Local Enterprise Partnerships: A UK government initiative designed to foster cooperation between local authorities and businesses to help drive economic growth and job creation within a number of UK regions
NPV	The Net Present Value of an investment, which offers an estimate of the present value of an investment by discounting future costs and savings to present day values using a given discount rate. This discount rates represents the rate of interest an investor would expect upon an investment if the financial capital were available to them today
PV	Photovoltaic solar panels, which (as opposed to solar thermal) convert solar energy directly into electricity
T5	A high efficiency form of fluorescent lighting

The Economics of Low Carbon Cities: A Mini Stern Review for the City of Bristol

Executive Summary

What is the most effective and efficient way to decarbonise a city? There are hundreds of low carbon options available and, although they present a significant opportunity to reduce energy bills and carbon footprints, there is often a lack of reliable information on their performance. The higher levels of risk and uncertainty that emerge as a result of this lack of reliable information can be a major barrier to action, making it hard to develop a political, a business or a social case for investment in low carbon options.

In an attempt to address this problem, this report reviews the cost and carbon effectiveness of a wide range of the low carbon options that could be applied at the local level in households, industry, commerce and transport. It then explores the scope for their deployment, the associated investment needs, financial returns and carbon savings, and the implications for the economy and employment.

It does this for the City of Bristol, an area with a population of 450,000 people, an economy worth £14 billion a year and an energy bill of £870 million a year. Whilst highlighting the very significant and commercially viable opportunities for the decarbonisation of the city– and the potential economic benefits associated with these – the report also recognises the scale of the challenge, the need for investment and the requirement for investment vehicles and delivery mechanisms that can exploit the potential for significant change.

Our Approach

Our approach has been to develop a robust model for assessing the costs and benefits of different levels of decarbonisation at the city scale. We use data from a wide range of sources on the potential energy, cost and carbon savings from hundreds of low carbon measures. We take into account changes in the economy and the wider energy infrastructure, but we focus primarily on the potential for the wider deployment of energy efficiency measures and small- scale renewables. We also assess the potential for their deployment and the rates at which they could be deployed at the local level. Our mitigation estimates are based upon production-based emissions accounting, which considers the carbon emitted within the city's borders and that emitted indirectly due to electricity use. Thus, we do not account for the carbon effectively embodied in imported goods or services.

We use best-available projections to estimate savings emerging from different measures (energy, cost and carbon), future energy prices, and the rate of decarbonisation of the UK electricity grid. For assessing business-led mitigation scenarios we use typical interest rates (8%), while when considering more ambitious scenarios we estimate the maximum potentials for the rates and scales at which different technological and behavioural options could realistically be adopted.

The City of Bristol has a population of 450,000, an economy worth £14 billion a year and an energy bill of£870 million a year.

The Potential for Carbon Reduction – Investments and Returns

We find that by 2025 – compared to 2005 levels – the City of Bristol could reduce its carbon emissions above and beyond business-as-usual[1] trends (including in the decarbonisation of electricity supply) by:

- — 11.6% through cost effective investments that would pay for themselves (on commercial terms) over their lifetime. This would require an investment of £580 million, generating average annual savings of £175 million, paying back the investment in 4 years before generating further savings for the lifetime of the measures.
- —17.5% through cost neutral investments that could be paid at no net cost to the city's economy if the benefits from cost effective measures were captured and re-invested in further low carbon measures. This would require an investment of £2.2billion, generating average annual savings of £240 million, paying back the investment in 10 years before generating further savings for the lifetime of the measures.
- — 18.3% with the exploitation of all of the realistic potential of the different measures. This would require an investment of £4.1 billion, generating annual savings of £250 million, paying back the investment within the lifetime of the measures.

It is important to note though that these figures do not take into account the levels of carbon that are embedded in all of the goods and services consumed in Bristol. Research has shown that when these are taken into account for the UK as a whole, carbon emissions are substantially higher and are rising rather than falling.

Impacts on Future Energy Bills

These figures are particularly significant in the context of projected energy price increases. We calculate that the City's energy bill is currently £870 million per year and estimate that, under business-as-usual trends, this will remain at approximately the same level in 2025, as reductions in energy use are offset by rising energy prices.

- —With investment in all of the cost effective measures, the 2025 annual energy bill could be cut by £220 million (26% of the projected cost).
- —With investment in all of the cost neutral measures, it could be cut by £300 million (35% of the projected cost).
- —With investment to exploit all of the realistic potential, it could be cut by £320 million (38% of the projected cost).

The City of Bristol could therefore significantly enhance its energy security through investments in energy efficiency and low carbon options.

The current City of Bristol energy bill is £870 million per year, this means that 6.4% of everything that is earnt in the city is spent on energy

1 Business as usual here, and throughout the report, refers to emissions trajectories under central energy prices and expected grid decarbonisation, but without an increase in the current rate of deployment of energy efficiency or low carbon measures within the city.

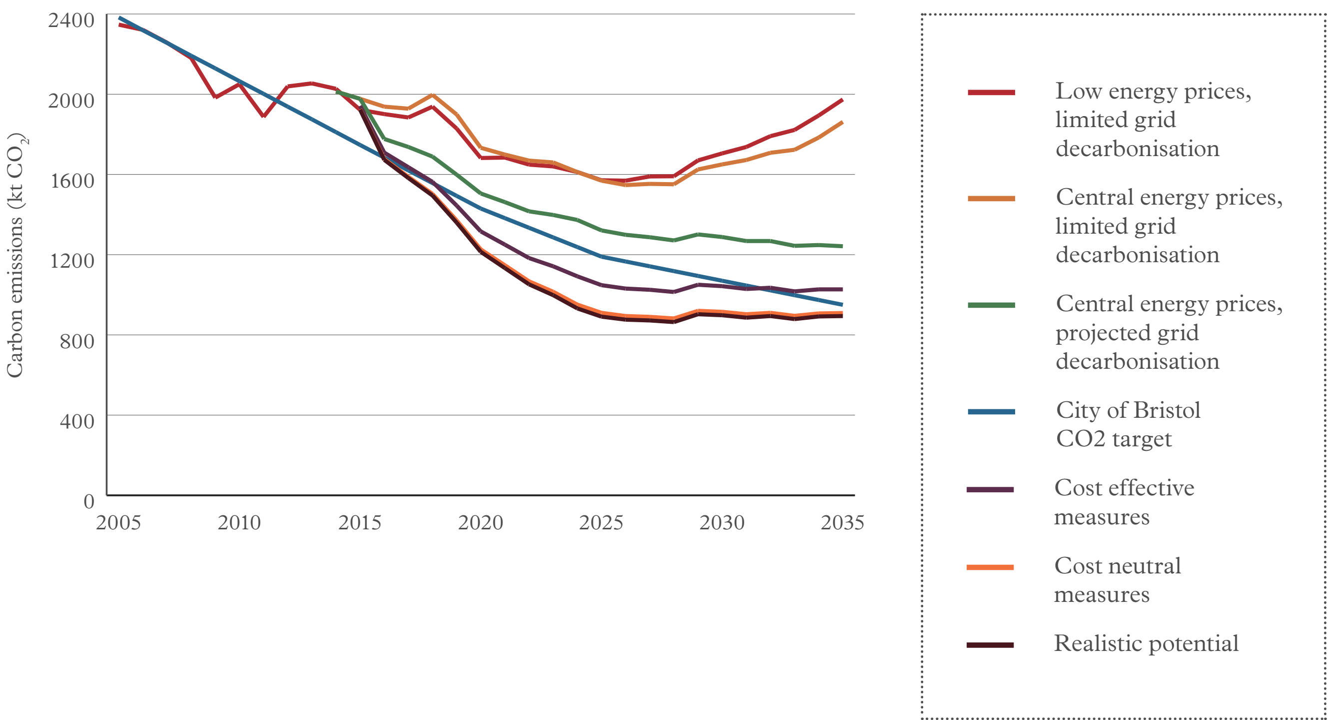
The Wider Context – Other Influences on the City of Bristols Carbon Emissions

To put these energy savings and carbon reduction figures into a wider context, we find that:

- With low energy prices, slow decarbonisation of UK electricity and a continuation of current trends in energy use and efficiency within the city, background trends would lead to a 33% decrease in Bristol's carbon emissions between 2005 and 2025. Without extra effort in the city, this would lead to the city missing its 2020 emissions reduction target of 40%.
- Business-as-usual trends, with higher energy prices and the currently expected rates of decarbonisation of the national electricity system, would lead to Bristol's carbon emissions falling by 44% between 2005 and 2025. This would mean that the city came closer to meeting its 2020 emissions reduction target, but extra effort would also be needed to meet the 2020 target.
- Together, higher energy prices, the currently expected rates of decarbonisation of the national electricity system and the exploitation of all of the cost effective low carbon options within the city would generate a 55% drop in Bristol's carbon emissions between 2005 and 2025.
- The total effect of all of the above plus the exploitation of the remaining cost neutral options would be a 61% drop in Bristol's emissions between 2005 and 2025.
- The total effect of all of the above plus the exploitation of all of the remaining realistic potential would be a 62% drop in Bristol's carbon emissions between 2005 and 2025.

The impacts of these price effects, grid decarbonisation and cost effective, cost neutral and realistic potential are shown in the Figure below.

Figure 1. Baselines and Analysis of Price Effects, Grid Decarbonisation and Cost Effective, Cost Neutral and Realistic Potential



Wider Impacts on Employment and Economic Growth

We also calculate that the levels of investment required to realise these reductions in energy bills and carbon footprints could have wider economic benefits within the City of Bristol:

- Over the next ten years, the levels of investment needed to exploit all cost effective measures with employment generating capacity would lead to the generation of over 2,000 jobs[2].
- Over the next ten years, the levels of investment needed to exploit the all of the cost neutral measures with employment generating capacity would lead to a further 8,000 jobs.
- In total, therefore, we predict that the levels of investment needed to exploit all of the cost effective and cost neutral measures with employment generating capacity would lead to the generation of 10,000 jobs over the next ten years.

Low Carbon Investment: Supply and Demand

The analysis highlights that within Bristol there is considerable potential to reduce energy use and carbon footprints through cost effective and cost neutral investments on commercial terms. However, the fact that these opportunities exist on this scale is obviously not enough to ensure that they are actually exploited. Incentives – no matter how strong they are – have to be matched with appropriate capacities if progress is to be made. These relate both to the capacity to supply appropriate levels of investment and to the capacity to stimulate and sustain demand for such investments.

To stimulate the supply of the very significant levels of investment that are needed, we need to think about innovative financing mechanisms, based on new forms of finance, delivery, cost recovery and benefit sharing and new ways of managing risk. And we need to develop new delivery vehicles that can stimulate and sustain demand for investment in low carbon options by overcoming the many potential barriers to change.

2 Including those directly and indirectly created as well as those induced by economic multiplier effects

Conclusions and Recommendations

From a climate and carbon perspective, the analysis in this report suggests that background trends – particularly in the decarbonisation of electricity – will do a lot to help the City of Bristol to meet its target of a 40% reduction in emissions by 2020, compared to 2005 levels. However, these background trends are not guaranteed. This report has shown that Bristol has significant opportunity to do much more. There are substantial opportunities for the city to reduce its carbon emissions through cost-effective or cost-neutral investments. The analysis shows that many of these opportunities could also be economically attractive and socially beneficial.

Pursuing a low carbon Bristol on this scale and at this rate should be possible. The technological and behavioural options assessed in this report are readily available, the energy and financial savings associated with these are clear (even based on conservative assessments) and, for a significant proportion of the available measures, the investment criteria are commercially realistic.

The economic returns on investment could be very significant indeed. Many of the measures would pay for themselves in a relatively short period of time, they would generate significant levels of employment, and if done well there may be a wider range of social benefits, particularly relating to reductions in fuel poverty and enhanced mobility. The political, social and economic case for large investments in the low carbon economy is very strong.

However, the transition depends on political and social will as well as financial capital. The levels of ambition, investment and activity needed to exploit the available potential are very significant indeed. Substantial levels of investment are required, along with major new initiatives with widespread and sustained influence in the domestic, commercial, transport and industrial sectors. Of course there are significant questions relating to how such investments could best be realized and about the ways in which large-scale programmes could best be designed and delivered.

Whilst this report provides some vital insights, we should of course recognise that economics is not the only discipline that has something useful to say on the transition to a low carbon economy/society. A wider analysis should also consider the social and political acceptability of the different options, as well as issues relating to the social equity and broader sustainability of the different pathways towards a low carbon economy and society.

And, as the discussion in the report makes clear, the significance of consumption-based emissions highlight the need to consider the wider impacts of Bristol's role in climate change. Previous research indicates that, for an average Bristol resident, consumption-based emissions may be twice as large as their production-based emissions. Furthermore, past trends in the UK suggest that consumption-based emissions are rising faster than production-based emissions are falling. Tackling carbon emissions is a major challenge.

We also need to think about `future proofing' investments to consider their compatibility with the more demanding targets for carbon reduction and with the different levels of climate change that are likely to come after beyond 2025.

Introduction

What is the most effective and efficient way to decarbonise the City of Bristol? There are hundreds of low carbon options available and, although they present a significant opportunity to reduce energy bills and carbon footprints, there is often a lack of reliable information on their performance. The higher levels of risk and uncertainty that emerge as a result can be a major barrier to action, making it hard to develop a political, a business or a social case for investment in low carbon options.

In an attempt to address this problem, this reviews the cost and carbon effectiveness of a wide range of the low carbon options that could be applied at the local level in households, industry, commerce and transport. It then explores the scope for their deployment in the City of Bristol. On this basis, we identify least cost pathways towards different levels of decarbonisation within Bristol, and we examine the investment needs and payback periods associated with different levels of decarbonisation. We also consider the wider economic implications of such transitions – with a particular emphasis on the opportunities for job creation in the low carbon and environmental goods and services sector.

Whilst highlighting the very significant and commercially viable opportunities for the decarbonisation of Bristol – and the potential economic benefits associated with these – we also recognise the scale of the challenge. There is a clear need for investment, for policy innovations and for new delivery mechanisms, as well as a need to secure the active support of different social groups.

There are some pressing reasons why we need to better understand how to decarbonise a city or a city region. Cities could be particularly exposed to the impacts of climate change (UN HABITAT, 2009) and as a result we might hope that cities would play a leading role in helping to avoid climate change. There is certainly evidence that many cities are doing just this – and a number of local authorities, such as the City of Bristol, have set ambitious targets for carbon reduction. But climate change is a collective action problem on a global scale, and in some instances the case for action on environmental grounds alone is not strong enough to provoke the necessary action.

Fortunately, there are other drivers that might motivate cities to address issues of climate change, some of which appeal to more local and immediate benefits, such as minimising the leakage of capital from local economies, enhancing transport mobility, and addressing fuel poverty. Furthermore, incentives to invest in energy efficiency and energy security are going up: energy prices are still forecast to increase and possibly to become more volatile in years to come. Policy pressures are intensifying: the UK national government has adopted ambitious carbon targets that will tighten further over time. And economic development opportunities are becoming more prominent: the low carbon and environmental goods and services sector has been estimated to be worth £3.2 trillion a year, to employ 28 million people worldwide and to be growing steadily through the recession (BIS, 2010).

These trends could have major social and economic implications for all – through their impacts on growth, competitiveness, employment, social welfare, fuel poverty and so on – but their effects are likely to be felt more acutely in cities. Globally, more than half of all economic output is generated in cities, and more than half of all people live in cities, but in urbanised countries these figures increase to around 80% (UN HABITAT, 2004; UNWUP, 2009). Further, it has been estimated that between 40 and 70% of all anthropogenic greenhouse gas (GHG) emissions are produced in cities, and that at least 70% of emissions can be attributed to the consumption that takes place within cities (UN HABITAT, 2011). Cities seem to be as exposed to attempts to reduce energy use and carbon footprints as they are vulnerable to the effects of climate change itself.

This considers how the City of Bristol could most efficiently and effectively exploit the wide range of technological and behavioural opportunities to reduce its energy bill and carbon footprint. It considers how much it would cost to reach different levels of decarbonisation through the least cost route. Evidence is presented on the economics of decarbonising the domestic, commercial, industrial and transport sectors as well as the city as a whole.

Approach to the Analysis

For this report, information on the performance of a wide range of different low carbon options has been collated from a variety of sources that supply current, best-available estimates of their costs and energy savings. These sources include the International Energy Agency (IEA), Centre for Sustainable Energy (CSE), Investment Property Forum (IPF) and the UK Committee on Climate Change (CCC)

Based upon their extensive reviews and modelling studies, each of these data providers supply lists of measures with their associated capital costs (including running and maintenance where possible) and energy savings per unit, with an appropriate unit of analysis chosen for each sector.

Given our interest in measures that can be adopted at the local level, we focus only on demand side measures and small-scale renewables, whilst taking account of changes in national energy infrastructure and the forecast decarbonisation of electricity supply. Thereafter, we need to generate data on a range of variables, as set out in Table 1.

To collect or generate data on each of these variables, the methodology follows a number of stages:

1. Identifying the applicable low carbon measures

The various data sources we draw upon include lists of the energy efficiency measures and small-scale renewables that could be adopted in the domestic, commercial, industrial and transport sectors. In the domestic and commercial sectors, we base our analysis on the full lists of measures provided. However, for the transport sector we have reviewed local transport plans and consulted with local experts to determine what measures are appropriate for Bristol, and for the industrial sector we consider only the industrial subsectors that have significant activity in Bristol and thus only those measures which are applicable to these.

A full list of the measures included in the analysis is presented in Table 2. We do not claim that this list of measures is complete – indeed expanding it to include a wider range of (particularly behavioural) measures should be seen as a key priority – but it is the most detailed and extensive list that we have found that is underpinned by comprehensive data sets.

Table 1. List of Variables

Baseline trends	Carbon savings per measure
Range of applicable low carbon measures	Scope for deployment in the City of Bristol
Capital cost of each measure	Rate of deployment in the city of Bristol
Operational costs of each measure	Total costs and carbon savings
Energy savings per measure	Cost and carbon savings for different levels of investment, decarbonisation
Financial savings per measure	

Table 2. Lists of the Low Carbon Measures Considered

Domestic	Air source heat pumps; Cavity wall insulation; Low energy lighting; Draught proofing; External wall insulation; Ground source heat pumps; Hot water tank insulation; Hot water tank thermostat; Internal wall insulation; Loft insulation; Mains gas condensing combi boilers; Oil condensing combi boilers; Old double to triple glazing; Room thermostats; Single to triple glazing; Solar PV; Solar thermal; Solid floor insulation; Suspended floor insulation (DIY); Suspended floor insulation (professional); A++ rated cold appliances; A+ rated wet appliances; Integrated digital TVs; Reduced standby consumption; A rated ovens; Induction hobs; Reduce household heating by 1°C; Turn unnecessary lighting off; Reduce heating for washing machines; Thermostatic radiator valves
Commercial	T5 lighting; LED lighting; Daylight sensing lighting; Movement sensing (PIR) lighting; 95% efficiency boilers; Heating controls; 0.95 Power factor correction; Variable speed pumps; Air tightness; Replace single with double glazing; Solar PV 10kWp; Solar PV 50kWp; Solar PV 100kWp; Wind turbine 20kW; Solar thermal 50m2; Air source heat pumps; Heat recovery; Cooling (Chiller CoP5.4); DC drive fan coils; Chilled beams – active; Chilled beams – passive; Cooling (SFP 2.0/I/s); External shading; T5 lighting - new luminaries; T5 lighting – conversions; Fabric improvements; Warm air blowers
Industrial*	Boilers and Steam Piping (16 sub-sector specific measures); Furnaces (8); Refrigeration (10); Pumps (10); Fans (10); Compressed Air Systems (18);
Transport	Rapid Transit Network; Park and Ride (Bus); Park and Ride (Bus + Dedicated service); Express Bus/Coach Network; Bus Priority and Quality Enhancements; Smartcard/smart ticketing; Smarter Choices (Travel Planning); Walking and cycling; New railway Stations/Lines; Local rail services operating at enhanced frequency; Micro-hybrid; Mild Hybrid; Full hybrid; Plug-in hybrid

* The industrial measures that we consider are numerous and specific to different sectors, but generally involve either efficiency or maintenance improvements, thus here they are grouped into six primary categories

2. Evaluating the cost and carbon performance of each applicable measure

Drawing on the different datasets outlined above, we extract data on the costs of adopting one unit of each measure and the energy (and hence the financial and carbon) savings that can be expected over the lifetime of that measure. This unit of analysis varies for each sector. In the domestic, commercial, and industrial sectors we consider costs per house, unit floor space, and unit of energy saved, respectively. In the transport sector, public transport measures are assessed by considering full-project appraisals, while private transport measures (i.e. ultra-low emissions cars) are assessed at the level of individual vehicles. The costs we consider include both the capital costs and running and maintenance costs where possible. Incentives designed to encourage take up of small scale renewable or energy efficiency measures, such as Feed-inTariffs, are not incorporated in the input data we have sourced.

Future energy costs are based on Department of Energy and Climate Change (DECC) energy price forecasts through to 2035 (DECC, 2014). Future carbon savings are based on projected changes in the carbon intensity of electricity in the period to 2035. Carbon savings from demand reductions are based on the variation in energy demand estimated by DECC under the various CCC energy price forecasts (low, central and high future energy prices.)

3. Understanding the potential for the deployment of different measures within Bristol

We then relate this list of measures to the scope for their deployment at the city scale. Ideally, this process would use observed data to take into account the size, composition and energy efficiency of the domestic, industrial, commercial and transport sectors in each particular locality.

For the domestic sector, such data is available and, by utilising the UK's National Housing Model, CSE have produced a very detailed and highly realistic picture of the scope for saving energy and fitting small- scale renewables in households at the local level. This data – describing the number of houses for which each measure is applicable – forms the input for our domestic scenarios.

For the commercial sector, three datasets are used to estimate deployment potentials: (i) distributions of Energy Performance Certificate (EPC) by score for Bristol's non-domestic buildings; (ii) floor space estimates for various non-domestic building types (offices, warehouses, retail, etc.); and (iii) typical EPC scores (from the IPF) for standard buildings and those that have undergone market refurbishment, again split by non-domestic building type. We therefore estimate – for each building type – the amount of floor space in Bristol at or below the energy EPC rating of a standard market refurbishment and assume that this floor space is eligible for further low-carbon measures.

For industry, local level data is available on both the scale and the sectoral composition of the economy measured by GVA[3]. However, no local or firm level data is available on current levels of energy efficiency or up take of low carbon options. Our data therefore reflects the size and sectoral composition of industry within Bristol, taking into account 30 key industrial sectors, but more data is needed on the level of uptake of energy efficient and low carbon options in the city. In the absence of this, we assume national-level energy intensities for each sector of local industry, and estimate deployment based upon the cost-effectiveness of the various measures[4].

3 This GVA data is provided by the West of England Local Economic Partnership, and is output from the Area Economy Model produced by the RED Group at the University of Plymouth.

4 We assume that no cost-ineffective measures have yet been deployed, cost-effective measures at low (3.5% real) discount rates have already been deployed to 1/3rd of their potential, and cost-effective measures at high (7% real) discount rates have been deployed to 2/3rds of their potential

For transport, the national data set developed by the CCC provides data upon the costs and savings for private road transport measures. For this subset of transport sector measures, we take into account the number of vehicles per capita registered at the local level, population projections for Bristol, the average number of miles travelled, and national estimates from the CCC indicating the penetration of hybrid vehicles required to meet the UKs carbon targets. We then develop a detailed picture of private road transport at the local level and the potential for deploying lower-carbon vehicles. Second, we use data from local transporting planning agencies outlining likely and potential public transport options. Cost benefit data is obtained from planning assessments of, and bids for, specific local projects and is supplemented with data from similar transport options evaluated in the previous mini-Stern for the Birmingham City Region where necessary. A summary of the sources of data for this stage of the analysis is included in Table 3.

4. Understanding background trends, developing baselines and scenarios for deployment

The analysis focuses on the adoption of low carbon measures at rates over and above a central baseline scenario intended to estimate the emissions of the City of Bristol under business-as-usual trends. We focus upon production-based emissions accounting, which considers the carbon emitted within the city's borders and that emitted indirectly due to electricity use.

This baseline scenario is developed, out to 2035, by combining (1) historical data describing Bristol's affluence, energy use and carbon emissions, (2) population and economic growth projections for Bristol, and (3) DECC's (central) national carbon emissions and energy price projections to 2035. Along with these emissions projections, DECC also supply the associated national projections of population, affluence, energy use, and carbon intensity of energy.

Using these data, the baseline is calculated by deriving national growth rates of CO_2 emissions per capita for a number of sectors that overlap with those for which historical emissions data is available for Bristol (i.e. industry and commercial, domestic, transport, and electricity). These national growth rates are then used to extrapolate the baseline emissions scenario for Bristol by applying them to the city's most recent (2013) per capita emissions data for each sector and then multiplying by the city's population forecast to obtain total emissions out to 2035.

It should be noted, however, that these calculations only consider specific, local characteristics of Bristol – and hence the likely impact of these on future emissions – in a limited way. They could potentially be made more accurate by considering the high economic growth rates Bristol aspires to (3.4% p.a by 2020), which are significantly larger than national projections (2.4%), and this is likely to impact upon the city's emissions.

As well as this central scenario, we also consider two less favourable scenarios:

Lower future prices – energy price increases (themselves reflecting carbon price increases) generally lead to reductions in demand. We draw upon DECCs estimates of energy use and emissions under low energy price forecasts to estimate an alternative, and higher-carbon, scenario for Bristol (see section 5 for a further discussion of these projections).

Slower decarbonisation of supply – the UK has been, and plans to continue, investing in the replacement of its infrastructure with less carbon intensive alternatives. DECC forecasts carbon intensities for future supply through to 2035 including a central projection and a no policy scenario. We consider the consequences of this latter – higher carbon – national pathway for the emissions for Bristol.

We therefore identify a baseline that reflects the impact of these background trends (but not future initiatives) in the period to 2035.

To consider the potential for the adoption of extra low carbon measures above this baseline, we then assume take up rates of low carbon measures that are based on a realistic proportion of the technical potential of each measure being exploited by 2025.

Table 3. Data Sources

Domestic:	Data from the National Housing Model applied to the Bristol housing stock to obtain current energy usage split by fuel type, potential savings from various measures and the number of households of each type eligible for each measure
Transport:	CCC data on low-emissions vehicles costs and benefits, DfT data on vehicle stock and vehicle usage, and UK Govt. estimates of the penetration of hybrid vehicles required to meet carbon targets. Data for public transport measures from local planning agencies supplemented with data from similar project evaluations elsewhere in the UK.
Commercial:	Office of National Statistics data on commercial floor space used in conjunction with EPC ratings for Bristol's non-domestic buildings and the EPC ratings of standard market refurbishments.
Industry:	SIC data on the sectoral make-up of the Bristol economy from the Regional Econometric Model is utilized, provided by the West of England LEP.

5. Identifying investment needs, financial returns and carbon savings for different decarbonisation scenarios

Having worked out the extent to which each measure could be deployed within the City of Bristol, we calculate aggregated investment needs, payback periods and carbon savings under different conditions. We consider three different investment scenarios, as summarised in table 4:

Cost-effective – in which only measures that are cost-effective on commercial terms are deployed. For this we adopt a commercially realistic interest rate of 8%, which, assuming an inflation rate of 3%, becomes a 5%real interest rate.

Cost-neutral – a scenario deploying all measures that could be afforded if the benefits from the cost effective measures were captured and reinvested in further low carbon options. Therefore, in this scenario there is no net cost.

Realistic potential – a scenario in which all measures are deployed to their estimated, maximum realistic potential, irrespective of the cost.

Energy price forecasts – In order to determine the returns resulting from each energy-savings assumptions must be made regarding future energy prices. DECC produce energy price forecasts – including price forecasts at 'central', 'low' and 'high' levels. Our analysis is based upon the central scenario, but we consider the sensitivity of our results to the alternate forecasts.

Of course, interest rates, energy prices and inflation rates can go up and down and this will affect financial returns. To account for this, we also conduct some sensitivity tests based on a more and less favourable scenarios, as described below.

Table 4. The Different Scenarios

Scenario	Discount/ interest rate	Inflation rate	Energy price
Cost-effective	8%	3%	Central
Cost-neutral	3%	3%	Central
DECC	n/a	n/a	Central

6. Developing league tables of the most cost and carbon effective measures deployable in Bristol

Having completed calculations of the costs and benefits of each option on the basis above, for the central business case we then prioritise options according to the extent that they pay for themselves over their lifetime (i.e. by their Net Present Value). This enables the identification of league tables of the most cost effective measures for the domestic, industrial, commercial and transport sectors and for the city region as a whole. These are presented as league tables of the most cost and carbon effective measures for the domestic, commercial, industrial and transport sectors (see Appendices A and B).

We then identify the different levels of decarbonisation that could be achieved with the three different levels of investment associated with the three scenarios described above.

7. Calculating employment and wider effects on GVA

The final stage of the analysis focuses on the effects that investments in decarbonising the City of Bristol would have on employment and the wider Bristol economy. To do this, we take the forecast levels of investment required to deploy the measures in each of the three scenarios. We draw upon the literature review of the Energy Research Centre (2014) which indicates typical numbers of jobs created for every million invested in energy efficiency in the domestic, commercial, and industrial and transport[5] sectors. These estimates of job creation per unit of investment are inclusive of direct, indirect, and induced employment effects. They indicate the creation of full time equivalent (FTE) jobs, where each job created is assumed to be full time and lasting for the lifetime of the particular plant/measure installed[6]. We assume even levels of investment per year over the period from 2015 to 2025, and assumptions about the amount of the investment retained within Bristol are made based upon assessments undertaken for the previous mini-stern review for the Leeds City Region.

5 For the transport sector, we assume that the purchasing of private, low emissions vehicles will not create jobs in the Bristol area

6 For this study, plant/measure lifetimes range from approximately 8 to 60 years, e.g., from lighting measures to public transport measures, respectively

The Key Findings

At the energy prices and interest rates encountered by households and businesses, how much would it cost to cut energy bills and carbon footprints and how quickly would investments be repaid? How many jobs could we create in the process of cutting energy bills and lowering carbon footprints? And to what extent is it possible to insulate the local economy from future energy price hikes?

The potential for carbon reduction – investments and returns

We find that by 2025 – compared to 2005 levels – the City of Bristol could reduce its carbon emissions above and beyond business-as-usual trends (including in the decarbonisation of electricity supply) by:

- 11.6% through cost effective investments that would pay for themselves (on commercial terms) over their lifetime. This would require an investment of £580 million, generating average annual savings of £175 million, paying back the investment in 4 years before generating further savings for the lifetime of the measures[7].
- 17.5% through cost neutral investments that could be paid at no net cost to the city's economy if the benefits from cost effective measures were captured and re-invested in further low carbon measures. This would require an investment of £2.2billion, generating average annual savings of £240 million, paying back the investment in 10 years before generating further savings for the lifetime of the measures.
- 18.3% with the exploitation of all of the realistic potential of the different measures. This would require an investment of £4.1 billion, generating annual savings of £250 million, paying back the investment within the lifetime of the measures.

Impacts on future energy bills

These figures are particularly significant in the context of projected energy price increases. We calculate that the City's energy bill is currently £0.87 billion per year and estimate that, under business-as-usual trends, this will remain at approximately the same level in 2025, as reductions in energy use are offset by rising energy prices.

- With investment in all of the cost effective measures, the 2025 annual energy bill could be cut by £220 million (26% of the projected cost).
- With investment in all of the cost neutral measures, it could be cut by £300 million (35% of the projected cost).
- With investment to exploit all of the realistic potential, it could be cut by £320 million (38% of the projected cost).

The City of Bristol could therefore significantly improve its energy security and reduce its vulnerability to energy price volatility through investments in energy efficiency and low carbon options.

7 Savings figures here – and the consequent payback periods – assume all measures are deployed in the initial year

Table 5. Main Results

Bristol sector	Capital costs (2015-2025)	Cost savings (2015-2025)	Carbon savings (2015-2025)	Jobs created	Payback	Bristol carbon cut in 2025 (above trend, 2005 base)
	£bn	£bn	$Kt.CO_2$	total*	yrs	%
Cost-effective measures						
Domestic	£0.27	£0.65	1,145	963		
Commercial	£0.07	£0.25	447	534		
Industry	£0.10	£0.08	168	571		
Transport	£0.14	£0.12	167	0		
Total	**£0.58**	**£1.11**	**1,926**	**2,068**	**< 4**	**11.6%**
Cost-neutral measures						
Domestic	£1.36	£0.98	1,822	4,951		
Commercial	£0.44	£0.30	589	3,510		
Industry	£0.28	£0.12	295	1,561		
Transport	£0.14	£0.12	167	0		
Total	£2.23	£1.52	2,873	10,021	< 8	17.5%
Realistic technical potential						
Domestic	£1.36	£0.98	1,822	4,951		
Commercial	£0.44	£0.30	589	3,510		
Industry	£0.67	£0.15	388	3,704		
Transport	£1.62	£0.15	202	16,915		
Total	£4.10	£1.57	3,001	29,080	< 20	18.3%

* Includes direct, indirect and induced jobs

Note: these figures are calculated assuming investment in measures is spread evenly over 10 years

The wider context – other influences on Bristol carbon emissions

It is critically important to note that these figures relate to the impacts of investments that are over and above a continuation of background trends, the ongoing impacts of current policies, the impacts of future increases in energy prices and the impact of a continuing decarbonisation of national energy supply. The combined impacts of all of these factors are reflected in Figure 1. We find that:

- With low energy prices and slow decarbonisation of UK electricity, background trends would lead to a 33% decrease in Bristol's carbon emissions between 2005 and 2025. Without extra effort in the city this would lead to the city missing its 2020 emissions reduction target of 40%.
- Business-as-usual trends, with higher energy prices and the currently expected rates of decarbonisation of the national electricity system, would lead to Bristol's carbon emissions falling by 44% between 2005 and 2025. This would mean that the city came closer to meeting its 2025 emissions reduction target, but extra effort would also be needed.
- Together, higher energy prices, the currently expected rates of decarbonisation of the national electricity system and the exploitation of all of the cost effective low carbon options within the city would generate a 55% drop in Bristol's carbon emissions between 2005 and 2025. In this scenario, the 2020 target would also be met.
- The total effect of all of the above plus the exploitation of the remaining cost neutral options would be a 61% drop in Bristol's emissions between 2005 and 2025.
- The total effect of all of the above plus the exploitation of all of the remaining realistic potential would be a 62% drop in Bristol's carbon emissions between 2005 and 2025.

Beyond 2025

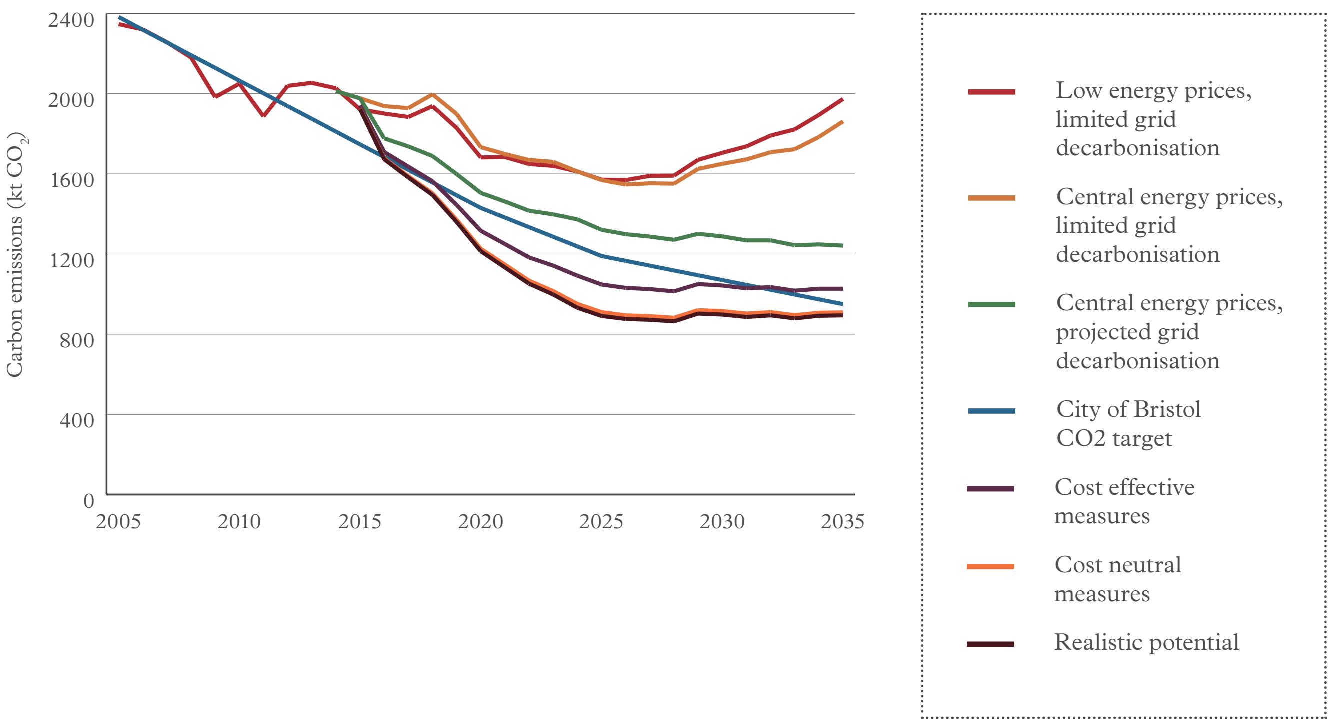
It is also apparent from figure 1 that Bristol's emissions in 2035 would vary even more dramatically under these potential scenarios, when compared to 2025. In particular, if there is limited decarbonisation of electricity supply in the UK, the three trends of on-going economic growth, growing population and greater levels of consumption would lead to a rise in Bristol's emissions back towards 2005 levels. Even with the decarbonisation of electricity, central energy prices, and significant deployment of mitigation measures, Bristol's emissions reductions may plateau beyond 2030 at around 35 to 45% of 2005 levels.

Consumption based emissions: Thinking globally

A further critical issue is that this analysis does not address the issue of consumption-based emissions. Our mitigation estimates are based upon production-based emissions that arise from the carbon that is directly emitted within the city's borders and that is emitted indirectly due to electricity use. These figures do not account for the carbon embodied in imported goods. However, past trends in the UK suggest that consumption-based emissions (i.e. those embodied in goods consumed) have been substantially higher and have been increasing more rapidly than production-based emissions have been falling (Barrett et al., 2013). This means that the UK's carbon footprint is greater than described and has been rising rather than falling.

For Bristol itself, it has been estimated that consumption based emissions were approximately 12 tonnes of CO_2 per capita in 2009 (Minx et al., 2013), this is double the per capita emissions that arise directly within the city. This highlights the need to consider and to find new ways to influence consumption levels and patterns within the city.

Figure 1. Baselines and Analysis of Price Effects, Grid Decarbonisation and Cost Effective, Cost Neutral and Realistic Potential



Sensitivity analysis

There are a various parameters and assumptions that influence the results presented in this report and that could impact significantly upon the investment costs required for the scenarios we explore and the energy, carbon, and cost savings that are realised. These include, for example:

- Projections of energy prices and rates of grid decarbonisation;
- The extent to which technological learning may reduce future investment costs;
- Current levels of efficiency of commercial buildings and industrial plants in Bristol (and the consequences for deployment potential);
- The expected increase in the efficiency of the UK vehicle stock under business-as-usual trends (which influences the carbon savings of any mode shift away from private vehicles).

Here, we restrict our sensitivity analysis to perturbations of two of the most significant variables: energy prices and grid decarbonisation.

Figure 2a shows that the emissions trajectories under each of the three mitigation scenarios could vary significantly under different energy price and grid decarbonisation forecasts.

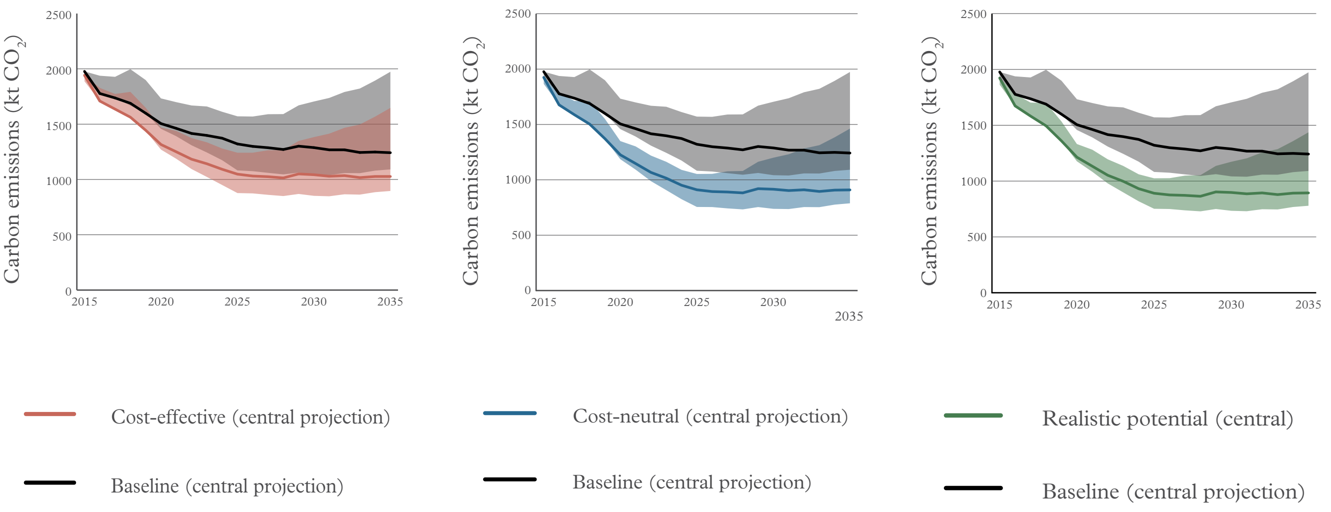
In fact, these uncertainties in future energy prices and decarbonisation leads to large overlap between the baseline scenarios and the three mitigation scenarios.

For example, in the extreme case of low energy prices and limited decarbonisation, even with a deployment of measures to their full, realistic potential, City of Bristol emissions are estimated to be larger in 2035 than the business-as-usual scenario with central prices and decarbonisation (figure 2a, far right).

In terms of cost-effectiveness of carbon abatement, Figure 2b show this also varies significantly between scenarios. The average cost-saving from avoiding one tonne of CO_2 in the cost-effective scenario ranges from £280 to £640, under conditions from low prices and limited decarbonisation to high prices and rapid decarbonisation, respectively. In the realistic potential scenario, abatement incurs costs rather than achieving savings, and this cost of abatement varies from £60 to £190, under the same conditions as above.

Overall, the sensitivity results indicate that the assumptions made in our modelling are significant. But the main conclusions of the work – that there is substantial potential for deploying low-carbon measures in Bristol and that much of this potential would be economically viable – remains robust.

Figure 2a. Sensitivity of the results to changes in future energy prices and rates of grid decarbonisation. Solid lines are the central predictions for the baseline and the three scenarios. Shaded regions are the variations in the projected trajectories when moving from low energy prices and limited grid decarbonisation to high energy prices and rapid grid decarbonisation



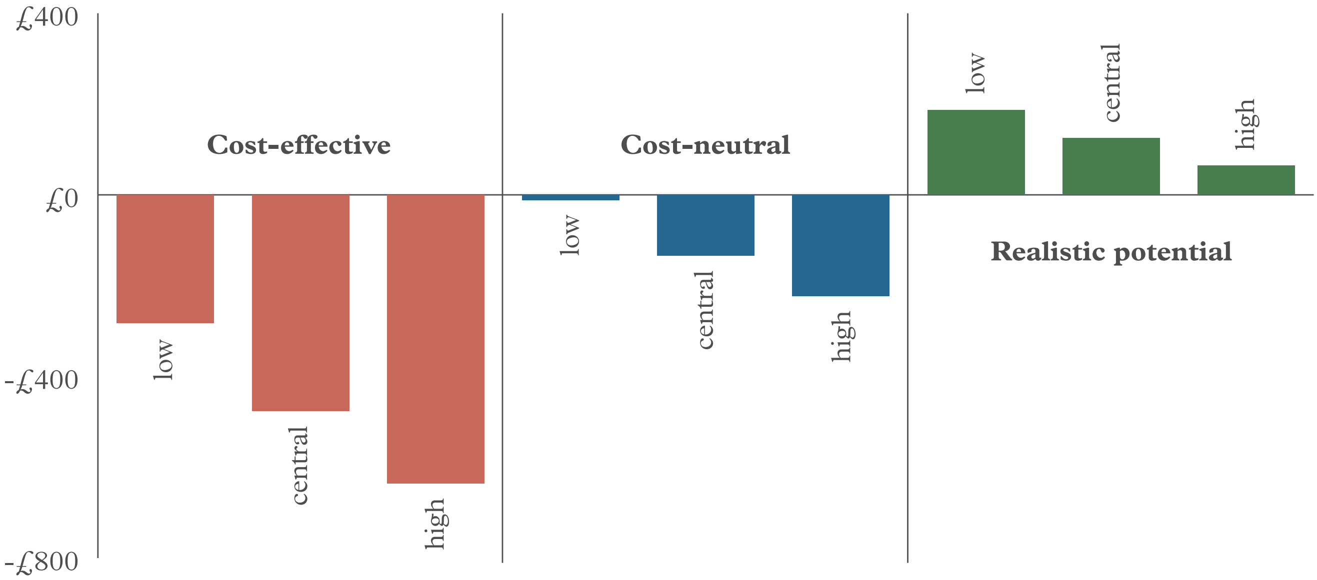
8 These calculations of net present value are based on the economic value of low carbon measures deployed between 2015 and 2025. They assume a 30-year lifespan for the LRT and a 15-year lifespan for vehicles.

Wider impacts on employment and economic growth

In terms of the wider economic implications of the different levels of investment, we estimate that implementation of the cost effective and cost neutral measures in the domestic, non-domestic, industrial and transport sectors will result in the creation of just over 1,000 additional jobs/annum in Bristol over the 10 year period (£10,021 in total).

These totals include the direct impacts of the required levels of investment in employment and GVA and indirect and induced effects based on supply chain and income (or consumption) multipliers. A summary of the estimates by sector is provided in Table 5.

Figure 2b. Sensitivity of the results to changes in future energy prices and rates of grid decarbonisation. 'Low' refers to results with low energy prices and low (limited) decarbonisation, 'high' to high energy prices and high (rapid) decarbonisation, and central to central energy prices and central decarbonisation



Sector Focus

The Domestic Sector

Main Findings
The Domestic Sector

Cost effective opportunities

- There are £270 million worth of cost-effective, energy efficient and low carbon investment opportunities available in the domestic sector in the City of Bristol.
- Exploiting these would generate annual savings of over £100 million a year.
- These investments would pay for themselves in under 3 years, whilst generating annual savings for the lifetime of the measures.
- If exploited, these investments would reduce City of Bristol carbon emissions by 6.9% by 2025, compared to 2005.Cost neutral opportunities

The savings generated by the cost effective measures, if captured and reinvested, would more than pay for the exploitation of the full realistic potential for all of the measures identified for the domestic sector. In other words, exploiting the realistic potential would generate significant financial returns overall.

- The investment needed to exploit these opportunities in the domestic sector in Bristol would be £1.36 billion.
- Exploiting these would generate annual savings of over £150 million a year.
- These investments would therefore pay for themselves in under 9 years, whilst generating annual savings for the lifetime of the measures.
- These investments would reduce Bristol's carbon emissions by 11.1% by 2025, compared to 2005.

Discussion

There are numerous opportunities for reducing the energy use and carbon footprints of households within the City of Bristol. This could be done through investments in the fabric of the built environment (i.e. through loft and wall insulation, double glazing), through investments in more energy efficient appliances (computers, TVs, fridges, freezers etc) or through changes in behaviour (turning off appliances, turning down thermostats etc). The league tables of the most cost and carbon effective measures are included in Tables 6 and 7.

The analysis shows that efficient appliances – such as A++ rated cold appliances – and behavioural changes – such as turning off unnecessary lighting –are generally the most cost effective measures. However, the aggregated carbon savings potential of such measures across the City of Bristol are exceeded by the potential of many others options. These more carbon-effective measures typically involve types of insulation – external, internal and cavity wall – and solar energy technologies – both PV and thermal. A notable exception, however, is reducing household thermostats by 1 degree, which offers the largest, aggregate carbon savings across the city.

In terms of the wider employment and economic effects, domestic measures represent nearly 50% of the total jobs that could be created within Bristol through investments in cost effective and cost neutral low carbon measures.

- In the cost-effective scenario, total capital expenditure for the selected measures over the 10 years is £270 million and this would create nearly 1,000 jobs[9]
- In the realistic potential scenario, total capital expenditure for the selected measures over the 10 years is £1.36 billion and this would create nearly 5,000 jobs

9 Including those directly and indirectly created as well as those induced by economic multiplier effects

Table 6: League Table of the Most Cost Effective Measures for the Domestic Sector

		£/T.CO_2
1	Reduced Standby Consumption	-1025.7
2	A++ rated cold appliances	-£969
3	A rated ovens	-£956
4	Turn unneccesary lighting off	-£752
5	Reduce heating for washing machines	-£752
6	Induction hobs	-£675
7	Hot water tank insulation	-£496
8	A+ rated wet appliances	-£447
9	Cavity wall insulation	-£366
10	Low energy lighting	-£365
11	Loft insulation	-£335
12	Draught proofing	-£331
13	Hot water tank thermostat	-£317
14	Ground source heat pump	-£299
15	Reduce household heating by 1 C	-£298
16	Air source heat pump	-£272
17	Room thermostat	-£150
18	Suspended floor insulation professional	-£108
19	Suspended floor insulation DIY	£72
20	Solid floor insulation	£99
21	Mains gas, condensing combi	£162
22	Oil condensing combi	£168
23	Solar PV	£505
24	Thermostatic radiator valves	£525
25	Internal wall insulation	£532
26	External wall insulation	£877
27	Solar thermal	£1,200
28	Single to triple	£1,661
29	Old double to triple glazing	£2,079

Table 7: League Table of the Most Carbon Effective Measures for the Domestic Sector

		KT.CO_2
1	Reduce household heating by 1 C	238.5
2	External wall insulation	208.5
3	Low energy lighting	199.9
4	Solar PV	184.9
5	Internal wall insulation	182.8
6	Cavity wall insulation	165.6
7	Mains gas, condensing combi	159.7
8	Loft insulation	90.1
9	Solar thermal	89.5
19	Room thermostat	88.0
11	A++ rated cold appliances	75.8
12	Single to triple	75.6
13	Hot water tank insulation	66.3
14	Air source heat pump	55.9
15	Thermostatic radiator valves	54.1
16	A+ rated wet appliances	40.2
17	Solid floor insulation	35.1
18	Hot water tank thermostat	27.7
19	Reduce heating for washing machines	26.2
20	A rated ovens	24.5
21	Induction hobs	24.5
22	Reduced standby consumption	23.7
23	Draught proofing	20.5
24	Old double to triple glazing	12.1
25	Suspended floor insulation DIY	10.9
26	Suspended floor insulation DIY	9.1
27	Ground source heat pump	7.6
28	Turn unneccesary lighting off	3.7
29	Oil condensing combi	2.2

Sector Focus

The Commercial Sector

Main Findings
The Commercial Sector

Cost effective opportunities

- There are £70 million of cost-effective, energy efficient and low carbon investment opportunities available in commercial buildings in the public and private sectors within Bristol.
- Exploiting these would generate annual savings of £40 million a year.
- These investments would pay for themselves in 2 years, whilst generating annual savings for the lifetime of the measures.
- If exploited, these investments would reduce Bristol's carbon emissions by 2.7% by 2025, compared to 2005.

Realistic potential

- The costs of deploying all of the measures we consider in the realistic potential scenario would be exceeded by the savings.
- There are £440 million such opportunities available in the commercial buildings sector in Bristol.
- Exploiting these would generate annual savings of nearly £50 million a year.
- These investments would pay for themselves in under 10 years, whilst generating annual savings for the lifetime of the measures.
- These investments would reduce Bristol's carbon emissions by 3.6% by 2025, compared to 2005.

Discussion

Again, there are numerous energy efficient and low carbon options available in the commercial buildings sector, including various different types of energy saving equipment (light detectors, heating controls, etc.) A range of small scale-renewables could also be adopted and there are various ways in which buildings could be better insulated. The league tables of the most cost and carbon effective measures are included below.

The analysis shows that the most cost effective measures involve upgrades to air conditioning systems, the adoption of more efficient lighting and movement sensing, and the correction of power factors for electricity usage. These cooling upgrades also come out as some of the most carbon-effective measures when savings are aggregated across Bristol. Here they are joined by air source heat pumps, insulation measures – such as fabric improvements, air tightness, and double glazing – and solar PV.

With respect to the wider impacts, commercial measures (i.e. in public and private sector buildings) represent about 25-35% of the total jobs that could be generated investments in low carbon measures.

- In the cost-effective scenario, total capital expenditure for the selected measures over the 10 years is £70 million and this would create over 500 jobs.
- In the realistic potential scenario, total capital expenditure for the selected measures over the 10 years is £440 million and this would create over 3,500 jobs.

Table 8: League Table of the Most Cost Effective Measures for the Commercial Sector

		£/T.CO_2
1	Efficient cooling	-£551
2	0.95 Power factor correction	-£479
3	Daylight sensing	-£464
4	Efficient cooling (Chiller CoP5.4)	-£456
5	Variable speed pumps	-£429
6	T5 Lighting	-£386
7	DC drive van coils	-£368
8	Heat recovery	-£132
9	95% efficiency boilers	-£46
10	Air tightness	£1
11	Heating controls	-£176
12	Fabric improvements	-£446
13	Warm air blowers	-£630
14	Air source heat pump	-£754
15	External shading	-£1,014
16	T5 Lighting - conversions	-£1,150
17	Chilled beams - passive	-£1,171
18	Replace single with double glazing	-£1,323
19	LED lighting	£1,347
20	Solar PV 100 kWp	£1,478
21	T5 lighting - new luminaries	£1,515
22	Solar PV 50kWp	£1,527
23	Solar PV 10kWp	£1,676
24	Chilled beams - active	£2,259
25	Solar thermal 50m²	£2,386
26	Wind turbine 20kW	£2,929
27	Movement sensing (PIR)	£17,281

Table 9: League Table of the Most Carbon Effective Measures for the Commercial Sector

		KT.CO_2
1	Efficient cooling (SFP 2.0/1/s)	387.8
2	Air source heat pump	75.8
3	Efficient cooling (Chiller CoP5.4)	70.6
4	Fabric improvements	53.2
5	Air tightness	40.6
6	DC drive fan coils	34.4
7	Solar PV 100kWp	31.5
8	Heat recovery	30.6
9	Replace single with double glazing	21.2
10	Solar PV 50kWp	15.7
11	95% efficiency boilers	12.3
12	Wind turbine 20kW	11.4
13	0.95 Power factor correction	9.8
14	Variabe speed pumps	9.3
15	Heating controls	8.9
16	Chilled beams - passive	8.3
17	External shading	7.7
18	Warm air blowers	7.5
19	Daylight sensing	4.9
20	Chilled beams - active	4.5
21	Solar thermal 50m²	4.2
22	LED lighting	4.0
23	T5 lighting - new luminaries	3.6
24	T5 lighting - conversions	3.6
25	Solar PV 10kWp	3.1
26	T5 lighting	1.5
27	Movement sensing (PIR)	0.6

Sector Focus

The Industrial Sector

Main Findings
The Industrial Sector

Cost effective opportunities

- There are £100 million of cost effective, energy efficient and low carbon investment opportunities available in industry in the City of Bristol.
- Exploiting these would generate annual savings of over £12 million a year.
- These investments would pay for themselves in less than 9 years, whilst generating annual savings for the lifetime of the measures.
- If exploited, these investments would reduce Bristol's carbon emissions by 1% by 2025, compared to 2005.

Cost neutral opportunities

- There are £280 million of cost neutral, energy efficient and low carbon investment opportunities available in industry in the City of Bristol. Exploiting these would generate annual savings of nearly £20 million a year.
- Collectively, these investments would pay for themselves in under15 years, whilst generating annual savings for the lifetime of the measures.
- They would reduce Bristol's carbon emissions by 1.8% by 2025, compared to 2005.

Discussion

There are over 70 energy efficient and low carbon measures that could be adopted in different sectors of industry and that have been analysed in this research. The league tables of the most cost and carbon effective measures are included below.

With such a large number of often very specific, measures – and the difficulty of accurately determining deployment potentials for each – it is difficult to make particular recommendations as to where mitigation efforts should focus for the industrial sector. However, an important result that can be gathered from the analysis is that the majority of measures (40 of the 73 considered) would be cost-effective, even when savings are only considered out to 2025. If the full lifetime savings were factored into investments decisions – lifetimes that can extend to 25 years for the longest lasting of these measures – then the economics would look more favorable still.

In terms of their wider economic impact, industrial measures represent 15-25% of the total jobs that could be generated through cost effective and cost neutral investments in low carbon measures:

- In the cost-effective scenario, total capital expenditure for the selected measures over the 10 years is £100 million and this would create nearly 600 jobs.
- In the realistic potential scenario, total capital expenditure for the selected measures over the 10 years is £280 million and this would create over 1,500 jobs.

Table 10: League Table of the Most Cost Effective Measures for the Industrial Sector

			£/T.CO_2
1	Pumps	Isolate flow paths to no-essential equipment	-£551
2	Compressed Air Systems	Fix leaks, adjust compressor controls, establish ongoing plan	-£538
3	Fan	Correct damper problems	-£529
4	Compressed Air Systems	Address restrictive end use drops and connections	-£525
5	Compressed Air Systems	Shut-off idle equipment, engineered nozzles	-£512
6	Compressed Air Systems	Eliminate inappropiate compressed air uses	-£499
7	Compressed Air Systems	Predictive maintenance	-£486
8	Fan	Correct damper problems	-£486
9	Compressed Air Systems	More frequent filter replacement	-£473
10	Fan	Fix leaks and damaged seals	-£464
11	Fan	Isolate flow paths non-essential or non-operating equipment	-£464
12	Compressed Air Systems	Replace existing condensate drains with zero loss type	-£447
13	Fan	Repair or replace inefficient belt drives	-£443
14	Compressed Air Systems	Eliminate artificial demand with pressure optimisation/control	-£434
15	Pumps	Use of pressure switches	-£430
16	Compressed Air Systems	Install sequencer	-£382
17	Compressed Air Systems	Correct compressor intake problems	-£369
18	Pumps	Fix leaks, damaged seals and packaging	-£343
19	Fan	Correct poor airflow conditions at fan inlets and outlets	-£335
20	Refrigeration	Electronically controlled pumps	-£335
21	Fan	Predictive maintenance	-£313
22	Pumps	Predictive maintenance	-£309
23	Compressed Air Systems	Install dedicated storage with metered recovery	-£278
24	Compressed Air Systems	Improvement of automatic control	-£252
25	Refrigeration	Reduced cooling load	-£226
26	Compressed Air Systems	Reconfigure branch header piping to reduce critical pressure loss	-£226
27	Compressed Air Systems	Match air treatment to demand side needs	-£200
28	Pumps	Trim or change impeller to match output	-£188
29	Compressed Air Systems	Correct excessive pressure drops in main line distribution piping	-£188
30	Refrigeration	Regular cleaning/maintenance	-£118
31	Compressed Air Systems	Correct excessive supply side pressure drop	-£97
32	Boilers and Steam Piping	Heat exchanger	-£85
33	Pumps	Remove sediment/scale buildup	-£84
34	Furnaces	Maintenance of door and tube seals	-£62
35	Boilers and Steam Piping	Repair leaks	-£52

36	Furnaces	Reduce Wall heat losses	-£39
37	Boilers and Steam Piping	Insulate valves and fittings	-£19
38	Boilers and Steam Piping	Reduced excess air	-£19
39	Boilers and Steam Piping	Improve steam traps and maintain steam traps	-£19
40	Boilers and Steam Piping	Improved process control (including the flue gas monitoring)	-£19
41	Furnaces	Improved process controls (e.g. air-to-fuel ratio)	£6
42	Furnaces	Reducing Radiation heat losses	£96
43	Refrigeration	Systems optimisation	£98
44	Boilers and Steam Piping	Automatic monitoring of steam traps	£115
45	Pumps	Remove scales from heat exchangers and strainers	£124
46	Boilers and Steam Piping	Flash condensate	£148
47	Boilers and Steam Piping	Insulation pipes (Improvement and Maintenance)	£148
48	Boilers and Steam Piping	Feedwater economiser	£148
49	Boilers and Steam Piping	Return condensate	£148
50	Pumps	Install variable speed drive	£176
51	Furnaces	Flue gas heat recovery	£208
52	Compressed Air Systems	Variable speed drive	£210
53	Compressed Air Systems	Size replacement compressor to meet demand	£215
54	Furnaces	Efficient design burners (e.g. low NOx)	£275
55	Fan	Install variable speed drive	£314
56	Refrigeration	Improved process measuring and control	£314
57	Refrigeration	Improved insulation	£422
58	Boilers and Steam Piping	Minimise short cycling (multiple boiler operation; boiler downsizing)	£481
59	Boilers and Steam Piping	Improved blowdown	£481
60	Furncaes	Oxygen enrichment	£500
61	Refrigeration	Speed-controlled compressor and fan	£530
62	Boilers and Steam Piping	Boiler maintenance	£814
63	Boilers and Steam Piping	Vapour recompression	£814
64	Furnaces	Reducing wall heat losses on already insulated areas	£950
65	Fan	Replace oversized fans with more efficient type	£984
66	Boilers and Steam Piping	Vent condenser	£1,147
67	Pumps	More efficient pump	£1,524
68	Fan	More efficient motor	£2,065
69	Refrigeration	Improved compressor/heat exchanger	£2,692
70	Pumps	More efficient motor	£3,150
71	Refrigeration	Multicompressor refrigeration systems	£3,773
72	Refrigeration	Multi-level compression and absorbtion process	£5,934

Table 11: League Table of the Most Carbon Effective Measures for the Industrial Sector

			KT.CO_2
1	Boilers and Steam Piping	Boiler maintenance	57.9
2	Boilers and Steam Piping	Vapour recompression	57.9
3	Pumps	More efficient pump	39.4
4	Boilers and Steam Piping	Return condensate	38.8
5	Fan	Install variable speed drive	35.2
6	Compressed Air Systems	Size replacement compressor to meet demand	34.1
7	Furnaces	Flue gas heat recovery	30.2
8	Furnaces	Efficient design burners (e.g. low NOx)	29.4
9	Fan	Replace oversized fans with more efficient type	28.9
10	Boilers and Steam Piping	Insulation pipes (Improvement and Maintenance)	27.5
11	Pumps	Install variable speed drive	26.4
12	Compressed Air Systems	Variable speed drive	26.4
13	Boilers and Steam Piping	Improved process control (including flue gas monitoring)	21.3
14	Boilers and Steam Piping	Improved blowdown	20.3
15	Boilers and Steam Piping	Vent condenser	20.3
16	Boilers and Steam Piping	Feedwater economiser	19.4
17	Boilers and Steam Piping	Automatic monitoring of steam traps	16.4
18	Boilers and Steam Piping	Improve steam traps and maintain steam traps	15.3
19	Boilers and Steam Piping	Flash condensate	14.5
20	Boilers and Steam Piping	Minimise short cycling (multiple boiler operation; boiler downsizing	14.5
21	Pumps	Remove scales from heat exchangers and strainers	13.2
22	Pumps	Trim or change impeller to match output	13.0
23	Compressed Air Systems	Fix leaks, adjust compresor controls, establish ongoing plan	13.0
24	Compressed Air Systems	Eliminate inappropiate compressed air uses	11.3
25	Boilers and Steam Piping	Insulate valves and fittings	11.0
26	Furnaces	Oxygen enrichment	9.8
27	Furnaces	Improved process controls (e.g. air-to-fuel ratio)	9.0
28	Pumps	Isolate flow paths to non-essential equipment	8.7
29	Furnaces	Reducing Radiation heat losses	8.2
30	Pumps	More efficient motor	7.9
31	Fan	More efficient motor	7.9
32	Pumps	Predicitve maintenance	7.8
33	Fan	Isolate flow paths to non-essential or non-operating equipment	6.9
34	Compressed Air Systems	Shut-off idle equipment, engineered nozzles	6.9
35	Compressed Air Systems	Install sequencer	6.9

36	Refrigeration	Multi-level compression and absorbtion process	6.6
37	Boilers and Steam Piping	Heat exchanger	6.2
38	Pumps	Remove sediment/scale buildup	6.1
39	Compressed Air Systems	Eliminate artifical demand with pressure optimisation/control	6.1
40	Boilers and Steam Piping	Repair leaks	5.7
41	Compressed Air Systems	Match air treatment to demand side needs	5.2
42	Pumps	use of pressure switches	4.3
43	Fan	Correct poor airflow conditions at fan inlets and outlets	4.3
44	Compressed Air Systems	Predictive maintenance	4.3
45	Refrigeration	Improved insulation	4.2
46	Furnaces	Reducing wall heat losses	4.0
47	Boilers and Steam Piping	Reduced excess air	3.8
48	Compressed Air Systems	Improvement of automatic control	3.6
49	Compressed Air Systems	Address restrictive end use drops and connections	3.5
50	Refrigeration	Improved process measuring and control	2.7
51	Fan	Correct damper problems	2.6
52	Fan	Fix leaks and damaged seals	2.6
53	Compressed Air Systems	Replace existing condensate drains with zero loss type	2.6
54	Compressed Air Systems	Install dedicated storage with metered recovery	2.6
55	Compressed Air Systems	Reconfigure branch header piping to reduce critical pressure loss	2.6
56	Compressed Air Systems	Correct excessive pressure drops in main line distribution piping	2.6
57	Compressed Air Systems	Correct excessive supply side pressure drop	2.6
58	Furnaces	Reducing wall heat losses on already insulated areas	2.4
59	Refrigeration	Speed-controlled compressor and fan	2.3
60	Refrigeration	Systems optimisation	2.3
61	Pumps	Fix leaks, damaged seals and packaging	2.2
62	Fan	Repair or replace inefficient belt drives	2.2
63	Refrigeration	Improved compressor/heat exchanger	1.7
64	Fan	Predicitive maintenance	1.7
65	Compressed Air Systems	More frequent filter replacement	1.7
66	Furnaces	Maintenance of door and tube seals	1.6
67	Fan	Correct damper problems	1.3
68	Refrigeration	Regular cleaning/maintenance	1.2
69	Refrigeration	Electronically controlled pumps	1.0
70	Refrigeration	Multicompressor refrigeration systems	0.9
71	Compressed Air Systems	Correct compressor intake problems	0.9
72	Refrigeration	Reduced cooling load	0.4

Sector Focus

The Transport Sector

Main Findings
The Transport Sector

The transport sector is fundamentally different from the other three sectors we consider for a variety of reasons. These primarily relate to public transport measures:

Cost effective opportunities

- —The deployment of public transport measures is often motivated by benefits other than saving energy and avoiding carbon emissions.
- —The energy and hence the financial savings from public transport measures are often not received by the investor themselves.
- —The embodied emissions in vehicles and infrastructure become highly important when comparing the environmental impacts of public transport with private vehicles.

Consequently, our analysis does not consider the fact that such investment decisions regarding public transport measures will typically be motivated by, for example, reducing road congestion, or paid for via other flows of income such as parking or passenger fees. In addition, we systematically underestimate the energy and carbon savings of public transport, as embodied energy and emissions per passenger are typically much smaller for public transport than for private vehicles.

With this in mind, we therefore present results for the cost-effective and realistic potential scenarios. While the public transport measures we consider appear cost-ineffective via our cost-benefit process, in reality the co-benefits of such projects are likely to justify their implementation.

- —There are £140 million of cost effective, energy efficient and low carbon investment opportunities available in the transport sector in the City of Bristol.
- —Exploiting these would generate annual savings of nearly £10 million a year.
- —These investments would pay for themselves in less than 15 years, whilst generating annual savings for the lifetime of the measures.
- —These investments would reduce Bristol's carbon emissions by 1% by 2025, compared to 2005.

Realistic potential

- —There are £1.62 billion of energy efficient and low carbon investment opportunities available in the transport sector in the City of Bristol in the realistic potential scenario.
- —Exploiting these would generate annual savings of £17 million a year.
- —Although the public transport measures in this scenario would not pay for themselves via the direct cost savings resulting from lower fuel use, the co-benefits (reduced congestion, enhanced mobility, etc) and other forms of income (passenger fees, etc) would be highly likely to justify investments.
- —Collectively, these investments would reduce Bristol's carbon emissions by 1.2% by 2025, compared to 2005, but if embodied emissions in vehicles and infrastructure were taken into account the environmental benefits would be far more significant.

Discussion

The list of low carbon measures available in the transport sector is less extensive than the lists for the other sectors. Clearly there are other measures that could be included. Nonetheless, there are significant opportunities for reducing the energy use and carbon footprints of transport within the City of Bristol. These include investments in walking and cycling infrastructure and smarter choices initiatives and particularly investments in more fuel-efficient and hybrid vehicles. League tables of the most cost and carbon effective measures are included in Tables 12 and 13.

In terms of their employment creating potential, transport measures represent over 50% of the total jobs that could be generated in the realistic potential scenario: a total of over 15,000 jobs over the 10 years of investment.

A report by Ekosgen on employment in sustainable transport (Ekosgen, 2010) shows that a shift from cars to rail, bus and cycle transport would also lead to an increase in jobs due to their higher job densities per km traveled. It concludes that between 1993 and 2010 an increase in rail, bus and cycle use could generate 130,000 jobs nationally, which would more than offset the 43,000 jobs lost in the motor industry through reduced car use. If this is true, then modal shift would have a significant impact on jobs and GVA in Bristol since the job gains are most likely to be local whilst many the job losses are likely to occur outside Bristol due to the location of the car industry.

All of the cost effective measures are associated with the introduction of hybrid and electric vehicles. These changes are unlikely to have a significant impact on jobs in Bristol since we are not aware of any major car, light vehicle or truck manufacturers in the region, and thus we assume that investments into low-emissions vehicles do not have job creating potential.

In reality, there may be some job creation potential in the supply of components for hybrid and electric vehicles (e.g. electric motors and batteries) but we are not aware of any suppliers in Bristol, which could benefit from the opportunities. The establishment of an electric vehicle charging infrastructure in Bristol will lead to some job creation. However, the potential is not likely to be very significant since the current suppliers of these systems are based outside Bristol and hence the opportunities are mainly associated with local installation.

Table 12: League Table of the Most Cost Effective Measures for the Transport Sector

		£/T.CO_2
1	Micro-hybrid	£495
2	Mild Hybrid	£285
3	Plug-in hybrid	£300
4	Full hybrid	£572
5	Walking/Cycling	£1,282
6	Smartcard/smart ticketing	£3,040
7	Express Bus/Coach Network	£8,324
8	Smarter Choices (Travel Planning)	£12,659
9	Park and Ride (Bus)	£13,739
10	Rapid Transit Network	£43,461
11	Bus Priority and Quality Enhancements	£49,586
12	Park and Ride (Bus + Dedicated service)	£84,522
13	Local rail services operating at enhanced frequency	£172,412
14	New railway Stations/Lines	£198,267

Table 13: League Table of the Most Carbon Effective Measures for the Transport Sector

		KT.CO_2
1	Plug-in hybrid	32.7
2	Micro-hybrid	22.6
3	Full hybrid	17.8
4	Mild Hybrid	13.1
5	Walking/Cycling	10.4
6	Smarter Choices (Travel Planning)	9.3
7	Rapid Transit Network	8.3
8	Smartcard/smart ticketing	4.7
9	New railway Stations/Lines	2.2
10	Local rail services operating at enhanced frequency	1.9
11	Express Bus/Coach Network	1.0
12	Bus Priority and Quality Enhancements	0.5
13	Park and Ride (Bus)	0.3
14	Park and Ride (Bus + Dedicated service)	0.3

Low Carbon Investment: Supply and Demand

The analysis has highlighted that within the City of Bristol there is very considerable potential to reduce energy use and carbon footprints through cost effective and cost neutral investments on commercial terms. However, the fact that these opportunities exist on this scale is obviously not enough to ensure that they are actually exploited. Incentives – no matter how strong they are – have to be matched with appropriate capacities if progress is to be made. These relate both to the capacity to supply appropriate levels of investment, and to the capacity to stimulate and sustain demand for such investments.

Supply side factors: unlocking the supply of investment resources

The most obvious capacity that is needed is a capacity to raise, invest and secure returns on the very significant sums that are highlighted as being required within the report. We forecast that to exploit the cost effective opportunities alone, a total investment of £580 million is needed. When spread over ten years, this equates to an investment of less than 0.4% of Bristol GVA per year. Potentially, some of this level of investment could come from organsations such as the Green Investment Bank, but these investment opportunities are forecast to be profitable on commercial terms – particularly for investors with slightly longer time horizons than most UK investors (i.e. pension funds and other large institutional investors). The potential to attract very substantial levels of private sector investment should also therefore be explored.

The potential for investment depends in part on the mechanisms for cost recovery and the arrangements for benefit sharing that could be put in place. Public and private sector expertise on cost recovery has advanced rapidly in the UK in recent years, for example through experiments with different forms of Energy Service Company (ESCO). These mechanisms offer an opportunity to collect returns on investment either through energy companies on a pay as you save basis, or through longer-term energy service contracts. Benefit sharing arrangements are also key as there needs to be a strong enough incentive for both the source and the recipient of the investment to participate. Such arrangements can easily be tailored to reflect the levels of risk and return associated with different low carbon options.

The potential for investment also depends in part on the development of innovative financing mechanisms, such as revolving or self-replenishing funds. Potentially, a much smaller level of initial investment could enable the exploitation of the most cost effective measures first, with the investment fund then replenishing itself before moving on to less cost effective measures. The detailed analysis of the capital and operational costs and benefit streams of the wide range of low carbon options that have been investigated in this report could be used to underpin the more detailed cash-flow analysis that is needed to investigate this issue further. Different cost recovery and benefit sharing arrangements could easily be explored in such an investigation.

The potential for investment also depends on capacities for identifying and managing risk. The energy and hence financial savings forecast in this report are based on a number of detailed evaluations of different energy saving or low carbon measures in different contexts. The results of these evaluations are then interpreted conservatively to generate the data that has underpinned this research. The results have also been subjected to a sensitivity test to see how susceptible they are to changes in key factors such as energy prices or interest rates. But there are still risks of course – and the actual potential of many of the cost effective low carbon measures identified will need to be evaluated in finer detail before investment in particular measures can be recommended.

Demand side factors: unlocking demand for investment resources

As well as raising sufficient investment funds, there is also a need to consider the extent to which different actors in the domestic, commercial, industrial or transport sectors may want to access these funds and participate in any related schemes. A long list of issues could restrict their involvement (see BIS, 2009, 2010; DEFRA, 2010a and 2010b; Carbon Trust, 2010; Federation of Small Businesses, 2010).

Short-termism can be a key barrier to change. Even where there are demonstrable returns on investments in the medium to long term, some actors appear to overlook them because of more pressing priorities in the short term. High levels of risk aversity can also mean that some actors are sceptical about the presence or the relevance of purported opportunities in their particular context. Perceived risks can be higher where there is a lack of honest brokers who are sufficiently trusted and who have the expertise and experience needed to make a compelling case for investment, or a lack of learning networks through which information can flow and capacities can be built.

There can also be significant opportunity costs where the perceived risks of diverting scarce resources (including time and attention) from priority areas and channeling them towards what can be seen as peripheral issues can prevent the exploitation of apparent opportunities. Under these conditions, decision makers tend to over-estimate the costs and under-estimate the benefits. There are often also organisational barriers to investment, and these in turn often relate to split incentives where the costs of investment fall on one party (i.e. a landlord or a finance department) whilst the benefits accrue to another (i.e. a tenant or another department or subsidiary). On occasion there can also be regulatory barriers that prevent change – for example in the regulated utilities companies can be legally prevented from investing in various low carbon options.

Furthermore, there are commonly significant issues to do with embedded or locked-in forms of behaviour. Habits and routines emerge gradually over many years, and they can be incredibly resistant to change, particularly in large, complex organisations. Technological lock-in can also be a major factor as some decisions – such as investments in major infrastructure or capital projects – have long life times and the windows of opportunity within which changes can be made do not arise very regularly. And in smaller organisations the fixed costs (and the hassle costs) of searching for and accessing information on particular options can fall on one person who often lacks the time and the specialist expertise needed to take a good decision. Finally, instead of being available in the form of relatively `big wins', efficiency issues often present themselves as a large number of small and fragmented opportunities. This amplifies the significance of many of the other barriers to change mentioned above.

Unless all of these factors can be overcome, it is quite possible that opportunities to improve energy use and carbon footprints will be overlooked even if investment resources are made available. We need to think then not only about raising investment, but also about stimulating demand through an appropriate delivery vehicle that has the capacity to address all of the barriers to change presented above, whether in the domestic, commercial, industrial or transport sectors.

Conclusions and Recommendations

From a climate and carbon perspective, the analysis in this report suggests that the City of Bristol has to go above and beyond business-as-usual trends if it is to meet its target of reducing carbon emissions by 40% by 2020.

Decarbonising on this scale and at this rate should be possible. The technological and behavioural options are readily available, the energy and financial savings associated with these are clear (even based on conservative assessments), the investment criteria are commercially realistic, and the deployment rates – despite the levels of uncertainty – have been based upon best available data and are therefore realistic.

The economic returns on investment could be very significant indeed:

- Many of the measures would pay for themselves in a relatively short period of time.
- They would generate significant levels of employment and economic growth in the process.
- If done well there may be a wider range of indirect benefits (not least from being a first mover in this field).

Therefore, the political and business case for very large investments in the low carbon economy is strong.

However, the transition depends on political and social capital as well as financial capital. The levels of ambition, investment and activity needed to exploit the available potential are very significant indeed. Enormous levels of investment are required, and major new initiatives are needed with widespread and sustained influence in the domestic, commercial and industrial sectors.

And of course we need to think about some major innovations, particularly in stimulating the supply of and the demand for major investment resources. We need to think about innovative financing mechanisms, based on new forms of cost recovery and benefit sharing and new ways of managing risk. And we need to develop new delivery mechanisms that can stimulate and sustain demand for investment in low carbon options by overcoming the many potential barriers to change.

Of course the list of low carbon measures included in the analysis here may not be complete. Identifying and evaluating other low carbon measures and including them in an analysis that allows their performance to be compared with the wider range of options is critically important if Bristol is to adopt a least cost pathway towards the low carbon economy/society.

And fundamentally, we should recognise that economics is not the only discipline that has something useful to say on the transition to a low carbon economy/ society. A wider analysis should also consider the social and political acceptability of the different options, as well as issues relating to the social equity and broader sustainability of the different pathways towards a low carbon economy and society. We also need to think about `future proofing' investments to consider their compatibility with the more demanding targets for carbon reduction and with the different levels of climate change that are likely to come after 2025.

A final critical point is that our analysis is based upon production-based emissions accounting and hence we do not account for the carbon embodied in the goods and services consumed within the city. Other studies have estimated that Bristol's consumption-based emissions may be twice the production-based emissions, and past trends in the UK suggest that consumption-based emission have been rising at higher rates than production-based emissions have been falling. This highlights that there is no room for complacency about carbon emissions, and that Bristol needs to think about how it can start to tackle its consumption-based carbon footprint as well as its more direct emissions. Here, perhaps Bristol could be a first-mover and set an example for other cities to follow.

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Appendices
Appendix A

League Table of the Most Cost Effective Measures for all Sectors

Cost-effective | Cost-neutral | Realistic potential

			£/T.CO_2	
			2015-2025	2015-2035
1	Domestic	Reduced standby consumption	-£1,026	-£1,863
2	Domestic	A++ rated cold appliances	-£969	-£1,801
3	Domestic	A rated ovens	-£956	-£1,816
4	Domestic	Turn unneccesary lighting off	-£752	-£1,074
5	Domestic	Reduce heating for washing machines	-£752	-£1,074
6	Domestic	Induction hobs	-£675	-£1,629
7	Commercial	Cooling (SFP 2.0/I/s)	-£551	-£782
8	Industrial	Pumps - Isolate flow paths to no-essential equipment	-£551	-£771
9	Industrial	Compressed Air Systems - Fix leaks, etc.	-£538	-£763
10	Industrial	Fan - Correct damper problems	-£529	-£757
11	Industrial	Compressed Air Systems - Address restrictive end use drops	-£525	-£755
12	Industrial	Compressed Air Systems - Shut-off idle equipment, nozzles	-£512	-£747
13	Industrial	Compressed Air Systems - Eliminate inappropriate compressed air	-£499	-£739
14	Domestic	Hot water tank insulation	-£496	-£627
15	Industrial	Compressed Air Systems - Predictive maintenance	-£486	-£731
16	Industrial	Fan - Correct damper problems	-£486	-£731
17	Commercial	0.95 Power factor correction	-£479	-£738
18	Industrial	Compressed Air Systems - More frequent filter replacement	-£473	-£723
19	Commercial	Daylight sensing	-£464	-£868
20	Industrial	Fan - Fix leaks and damaged seals	-£464	-£718
21	Industrial	Fan - Isolate flow paths non-essential or non-operating equipment	-£464	-£718
22	Commercial	Cooling (Chiller CoP5.4)	-£456	-£724
23	Domestic	A+ rated wet appliances	-£447	-£1,471
24	Industrial	Compressed Air Systems - Replace existing condensate drains	-£447	-£707
25	Industrial	Fan - Repair or replace inefficient belt drives	-£443	-£704
26	Industrial	Compressed Air Systems - Eliminate artificial demand	-£434	-£699
27	Industrial	Pumps - Use of pressure switches	-£430	-£696
28	Commercial	Variable speed pumps	-£429	-£707
29	Commercial	T5 lighting	-£386	-£1,338
30	Industrial	Compressed Air Systems - Install sequencer	-£382	-£667
31	Industrial	Compressed Air Systems - Correct compressor intake problems	-£369	-£659
32	Commercial	DC drive fan coils	-£368	-£670
33	Industrial	Cavity wall insulation	-£366	-£484
34	Domestic	Low energy lighting	-£365	-£435
35	Industrial	Pumps - Fix leaks, damaged seals and packaging	-£343	-£643

36	Domestic	Loft insulation	-£335	-£444
37	Industrial	Fan - Correct poor airflow conditions at fan inlets and outlets	-£335	-£638
38	Industrial	Refrigeration - Electronically controlled pumps	-£335	-£638
39	Domestic	Draught proofing	-£331	-£445
40	Domestic	Hot water tank thermostat	-£317	-£387
41	Industrial	Fan - Predictive maintenance	-£313	-£624
42	Industrial	Pumps - Predictive maintenance	-£309	-£622
43	Domestic	Ground source heat pump	-£299	-£862
44	Domestic	Reduce household heating by 1 C	-£298	-£302
45	Industrial	Compressed Air Systems - Install dedicatated storage	-£278	-£603
46	Domestic	Air source heat pump	-£272	-£826
47	Industrial	Compressed Air Systems - Improvement of automatic control	-£252	-£587
48	Industrial	Refrigeration - Reduced cooling load	-£226	-£571
49	Industrial	Compressed Air Systems - Reconfigure branch header piping	-£226	-£571
50	Industrial	Compressed Air Systems - Match air treatment to demand side	-£200	-£555
51	Industrial	Pumps - Trim or change impeller to match output	-£188	-£547
52	Industrial	Compressed Air Systems - Correct excessive pressure drops	-£188	-£547
53	Domestic	Room thermostat	-£150	-£327
54	Commercial	Heat recovery	-£132	-£309
55	Industrial	Refrigeration - Regular clearning / maintenance	-£118	-£504
56	Domestic	Suspended floor insulation professional	-£108	-£345
57	Industrial	Compressed Air - Correct excessive supply side pressure drop	-£97	-£491
58	Industrial	Boilers and Steam Piping - Heat exchanger	-£85	-£142
59	Industrial	Pumps - Remove sediment/scale buildup	-£84	-£483
60	Industrial	Furnaces - Maintenance of door and tube seals	-£62	-£126
61	Industrial	Boilers and Steam Piping - Repair leaks	-£52	-£127
62	Commercial	95% efficiency boilers	-£46	-£140
63	Industrial	Furnaces - Reducing Wall heat losses	-£39	-£115
64	Industrial	Boilers and Steam Piping - Insulate valves and fittings	-£19	-£111
65	Industrial	Boilers and Steam Piping - Reduced excess air	-£19	-£111
66	Industrial	Boilers and Steam Piping - Improve/maintain steam traps	-£19	-£111
67	Industrial	Boilers and Steam Piping - Improved process control	-£19	-£111
68	Commercial	Air tightness	£1	-£83
69	Industrial	Furnaces - Improved process controls (e.g. air-to-fuel ratio)	£6	-£94
70	Domestic	Suspended floor insulation DIY	£72	-£267
71	Industrial	Furnaces - Reducing Radiation heat losses	£96	-£51
72	Industrial	Refrigeration - Systems optimisation	£98	-£371
73	Domestic	Solid floor insulation	£99	-£256
74	Industrial	Boilers and Steam Piping - Automatic monitoring of steam traps	£115	-£48
75	Industrial	Pumps - Remove scales from heat exchangers and strainers	£124	-£355

76	Industrial	Boilers and Steam Piping - Flash condensate	£148	-£32
77	Industrial	Boilers and Steam Piping - Insulation pipes	£148	-£32
78	Industrial	Boilers and Steam Piping - Feedwater economiser	£148	-£32
79	Industrial	Boilers and Steam Piping - Return condensate	£148	-£32
80	Domestic	Mains gas, condensing combi	£162	-£199
81	Domestic	Oil condensing combi	£168	-£104
82	Industrial	Pumps - Install variable speed drive	£176	-£323
83	Commercial	Heating controls	£176	-£35
84	Industrial	Furnaces - Flue gas heat recovery	£208	£2
85	Industrial	Compressed Air Systems - Variable speed drive	£210	-£302
86	Industrial	Compressed Air Systems - Size replacement compressor	£215	-£299
87	Industrial	Furnaces - Efficient design burners (e.g. low NOx)	£275	£34
88	Transport	Mild Hybrid - petrol engine	£285	-£413
89	Transport	Plug-in hybrid - petrol engine	£300	-£317
90	Industrial	Fan - Install variable speed drive	£314	-£238
91	Industrial	Refrigeration - Improved process measuring and control	£314	-£238
92	Industrial	Refrigeration - Improved insulation	£422	-£171
93	Commercial	Fabric improvements	£446	£109
94	Industrial	Boilers and Steam Piping - Minimise short cycling	£481	£126
95	Industrial	Boilers and Steam Piping - Improved blowdown	£481	£126
96	Transport	Micro-hybrid - 2nd gen petrol engine	£495	-£388
97	Industrial	Furnaces - Oxygen enrichment	£500	£141
98	Domestic	Solar PV	£505	-£61
99	Domestic	Thermostatic radiator valves	£525	-£45
100	Industrial	Refrigeration - Speed-controlled compressor and fan	£530	-£104
101	Domestic	Internal wall insulation	£532	-£99
102	Transport	Full hybrid - petrol engine	£572	-£325
103	Commercial	Warm air blowers	£630	£180
104	Commercial	Air source heat pump	£754	£339
105	Industrial	Boilers and Steam Piping - Boiler maintenance	£814	£284
106	Industrial	Boilers and Steam Piping - Vapour recompression	£814	£284
107	Domestic	External wall insulation	£877	£51
108	Industrial	Furnaces - Reducing wall heat losses on already insulated areas	£950	£353
109	Industrial	Fan - Replace oversized fans with more efficient type	£984	£175
110	Commercial	External shading	£1,014	£115
111	Industrial	Boilers and Steam Piping - Vent condenser	£1,147	£441
112	Commercial	T5 lighting - conversions	£1,150	£282
113	Commercial	Chilled beams - passive	£1,171	£276
114	Domestic	Solar thermal	£1,200	£222
115	Transport	Walking / Cycling	£1,282	£191

116	Commercial	Replace single with double glazing	£1,323	£509
117	Commercial	LED lighting	£1,347	£285
118	Commercial	Solar PV 100kWp	£1,478	£468
119	Commercial	T5 lighting - new luminaries	£1,515	£502
120	Industrial	Pumps - More efficient pump	£1,524	£509
121	Commercial	Solar PV 50kWp	£1,527	£498
122	Domestic	Single to triple	£1,661	£416
123	Commercial	Solar PV 10kWp	£1,676	£590
124	Industrial	Fan - More efficient motor	£2,065	£842
125	Domestic	Old double to triple glazing	£2,079	£532
126	Commercial	Chilled beams - active	£2,259	£950
127	Commercial	Solar thermal 50m2	£2,386	£1,013
128	Industrial	Refrigeration - Improved compressor / heat exchanger	£2,692	£1,228
129	Commercial	Wind turbine 20kW	£2,929	£1,363
130	Transport	Smartcard/smart ticketing	£3,040	£1,107
131	Industrial	Pumps - More efficient motor	£3,150	£1,511
132	Industrial	Refrigeration - Multicompressor refrigeration systems	£3,773	£1,895
133	Industrial	Refrigeration - Multi-level compression and soprtion process	£5,934	£3,227
134	Transport	Express Bus/Coach Network	£8,324	£3,135
135	Transport	Smarter Choices (Travel Planning)	£12,659	£5,198
136	Transport	Park and Ride (Bus)	£13,739	£5,417
137	Commercial	Movement sensing (PIR)	£17,281	£8,480
138	Transport	Rapid Transit Network	£43,461	£17,944
139	Transport	Bus Priority and Quality Enhancements	£49,586	£20,526
140	Transport	Park and Ride (Bus + Dedicated service)	£84,522	£35,250
141	Transport	Local rail services operating at enhanced frequency	£172,412	£87,654
142	Transport	New railway Stations/Lines	£198,267	£100,904

Appendix B

League Table of the Most Carbon Effective Measures for all Sectors

Cost-effective | Cost-neutral | Realistic potential

			KT.CO_2	
			2015-2025	2015-2035
1	Commercial	Cooling (SFP 2.0/I/s)	387.8	629.2
2	Domestic	Reduce household heating by 1 C	238.5	605.4
3	Domestic	External wall insulation	208.5	480.5
4	Domestic	Low energy lighting	199.9	475.3
5	Domestic	Solar PV	184.9	442.2
6	Domestic	Internal wall insulation	182.8	421.4
7	Domestic	Cavity wall insulation	165.6	382.1
8	Domestic	Mains gas, condensing combi	159.7	383.4
9	Domestic	Loft insulation	90.1	211.1
10	Domestic	Solar thermal	89.5	212.4
11	Domestic	Room thermostat	88.0	211.6
12	Commercial	Air source heat pump	75.8	185.7
13	Domestic	A++ rated cold appliances	75.8	114.7
14	Domestic	Single to triple	75.6	179.3
15	Commercial	Cooling (Chiller CoP5.4)	70.6	114.6
16	Domestic	Hot water tank insulation	66.3	146.0
17	Industrial	Boilers and Steam Piping - Boiler maintenance	57.9	122.2
18	Industrial	Boilers and Steam Piping - Vapour recompression	57.9	122.2
19	Domestic	Air source heat pump	55.9	105.5
20	Domestic	Thermostatic radiator valves	54.1	130.1
21	Commercial	Fabric improvements	53.2	114.4
22	Commercial	Air tightness	40.6	88.6
23	Domestic	A+ rated wet appliances	40.2	60.4
24	Industrial	Pumps - More efficient pump	39.4	63.8
25	Industrial	Boilers and Steam Piping - Return condensate	38.8	81.9
26	Industrial	Fan - Install variable speed drive	35.2	57.0
27	Domestic	Solid floor insulation	35.1	82.4
28	Commercial	DC drive fan coils	34.4	55.8
29	Industrial	Compressed Air Systems - Size replacement	34.1	55.3
30	Transport	Plug-in hybrid - petrol engine	32.7	121.9
31	Commercial	Solar PV 100kWp	31.5	51.1
32	Commercial	Heat recovery	30.6	58.1
33	Industrial	Furnaces - Flue gas heat recovery	30.2	63.8
34	Industrial	Furnaces - Efficient design burners (e.g. low NOx)	29.4	62.0
35	Industrial	Fan - Replace oversized fans with more efficient type	28.9	46.8

36	Domestic	Hot water tank thermostat	27.7	66.9
37	Industrial	Boilers and Steam Piping - Insulation pipes	27.5	58.0
38	Industrial	Pumps - Install variable speed drive	26.4	42.8
39	Industrial	Compressed Air Systems - Variable speed drive	26.4	42.8
40	Domestic	Reduce heating for washing machines	26.2	49.5
41	Domestic	A rated ovens	24.5	36.7
42	Domestic	Induction hobs	24.5	36.7
43	Domestic	Reduced standby consumption	23.7	35.5
44	Transport	Micro-hybrid - 2nd gen petrol engine	22.6	76.7
45	Industrial	Boilers and Steam Piping - Improved process control	21.3	44.9
46	Commercial	Replace single with double glazing	21.2	44.8
47	Domestic	Draught proofing	20.5	47.9
48	Industrial	Boilers and Steam Piping - Improved blowdown	20.3	42.8
49	Industrial	Boilers and Steam Piping - Vent condenser	20.3	42.8
50	Industrial	Boilers and Steam Piping - Feedwater economiser	19.4	40.9
51	Transport	Full hybrid - petrol engine	17.8	57.4
52	Industrial	Boilers and Steam Piping - Automatic monitoring of steam traps	16.4	34.6
53	Commercial	Solar PV 50kWp	15.7	25.5
54	Industrial	Boilers and Steam Piping - Improve/maintain steam traps	15.3	32.3
55	Industrial	Boilers and Steam Piping - Flash condensate	14.5	30.5
56	Industrial	Boilers and Steam Piping - Minimise short cycling	14.5	30.5
57	Industrial	Pumps - Remove scales from heat exchangers and strainers	13.2	21.4
58	Transport	Mild Hybrid - petrol engine	13.1	42.2
59	Industrial	Pumps - Trim or change impeller to match output	13.0	21.1
60	Industrial	Compressed Air Systems - Fix leaks, etc.	13.0	21.1
61	Commercial	95% efficiency boilers	12.3	25.9
62	Domestic	Old double to triple glazing	12.1	26.2
63	Commercial	Wind turbine 20kW	11.4	18.5
64	Industrial	Compressed Air - Eliminate inappropriate compressed air	11.3	18.3
65	Industrial	Boilers and Steam Piping - Insulate valves and fittings	11.0	23.2
66	Domestic	Suspended floor insulation DIY	10.9	25.5
67	Transport	Walking / Cycling	10.4	23.8
68	Commercial	0.95 Power factor correction	9.8	15.9
69	Industrial	Furnaces - Oxygen enrichment	9.8	20.7
70	Transport	Smarter Choices (Travel Planning)	9.3	21.1
71	Commercial	Variable speed pumps	9.3	15.1
72	Domestic	Suspended floor insulation professional	9.1	21.3
73	Industrial	Furnaces - Improved process controls (e.g. air-to-fuel ratio)	9.0	19.0
74	Commercial	Heating controls	8.9	18.8
75	Industrial	Pumps - Isolate flow paths to no-essential equipment	8.7	14.0

76	Commercial	Chilled beams - passive	8.3	13.4
77	Transport	Rapid Transit Network	8.3	19.6
78	Industrial	Furnaces - Reducing Radiation heat losses	8.2	17.3
79	Industrial	Pumps - More efficient motor	7.9	12.8
80	Industrial	Fan - More efficient motor	7.9	12.8
81	Industrial	Pumps - Predictive maintenance	7.8	12.6
82	Commercial	External shading	7.7	11.5
83	Domestic	Ground source heat pump	7.6	14.2
84	Commercial	Warm air blowers	7.5	15.9
85	Industrial	Fan - Isolate flow paths non-essential or non-operating equipment	6.9	11.2
86	Industrial	Compressed Air Systems - Shut-off idle equipment, nozzles	6.9	11.2
87	Industrial	Compressed Air Systems - Install sequencer	6.9	11.2
88	Industrial	Refrigeration - Multi-level compression and soprtion process	6.6	10.6
89	Industrial	Boilers and Steam Piping - Heat exchanger	6.2	13.0
90	Industrial	Pumps - Remove sediment/scale buildup	6.1	9.8
91	Industrial	Compressed Air Systems - Eliminate artificial demand	6.1	9.8
92	Industrial	Boilers and Steam Piping - Repair leaks	5.7	12.1
93	Industrial	Compressed Air Systems - Match air treatment to demand side	5.2	8.4
94	Commercial	Daylight sensing	4.9	7.4
95	Transport	Smartcard/smart ticketing	4.7	9.5
96	Commercial	Chilled beams - active	4.5	7.2
97	Industrial	Pumps - Use of pressure switches	4.3	7.0
98	Industrial	Fan - Correct poor airflow conditions at fan inlets and outlets	4.3	7.0
99	Industrial	Compressed Air Systems - Predictive maintenance	4.3	7.0
100	Commercial	Solar thermal 50m2	4.2	9.0
101	Industrial	Refrigeration - Improved insulation	4.2	6.7
102	Industrial	Furnaces - Reducing Wall heat losses	4.0	8.5
103	Commercial	LED lighting	4.0	5.5
104	Industrial	Boilers and Steam Piping - Reduced excess air	3.8	8.1
105	Domestic	Turn unneccesary lighting off	3.7	7.0
106	Industrial	Compressed Air Systems - Improvement of automatic control	3.6	5.9
107	Commercial	T5 lighting - new luminaries	3.6	5.9
108	Commercial	T5 lighting - conversions	3.6	5.9
109	Industrial	Compressed Air Systems - Address restrictive end use drops	3.5	5.6
110	Commercial	Solar PV 10kWp	3.1	5.1
111	Industrial	Refrigeration - Improved process measuring and control	2.7	4.3
112	Industrial	Fan - Correct damper problems	2.6	4.2
113	Industrial	Fan - Fix leaks and damaged seals	2.6	4.2
114	Industrial	Compressed Air Systems - Replace existing condensate drains	2.6	4.2
115	Industrial	Compressed Air Systems - Install dedicatated storage	2.6	4.2

116	Industrial	Compressed Air Systems - Reconfigure branch header piping	2.6	4.2
117	Industrial	Compressed Air Systems - Correct pressure drops	2.6	4.2
118	Industrial	Compressed Air Systems - Correct supply side pressure drop	2.6	4.2
119	Industrial	Furnaces - Reducing wall heat losses on already insulated areas	2.4	5.2
120	Industrial	Refrigeration - Speed-controlled compressor and fan	2.3	3.8
121	Industrial	Refrigeration - Systems optimisation	2.3	3.7
122	Domestic	Oil condensing combi	2.2	5.5
123	Industrial	Pumps - Fix leaks, damaged seals and packaging	2.2	3.5
124	Industrial	Fan - Repair or replace inefficient belt drives	2.2	3.5
125	Transport	New railway Stations/Lines	2.2	4.2
126	Transport	Local rail services operating at enhanced frequency	1.9	3.8
127	Industrial	Refrigeration - Improved compressor / heat exchanger	1.7	2.8
128	Industrial	Fan - Predictive maintenance	1.7	2.8
129	Industrial	Compressed Air Systems - More frequent filter replacement	1.7	2.8
130	Industrial	Furnaces - Maintenance of door and tube seals	1.6	3.4
131	Commercial	T5 lighting	1.5	1.8
132	Industrial	Fan - Correct damper problems	1.3	2.1
133	Industrial	Refrigeration - Regular clearning / maintenance	1.2	1.9
134	Industrial	Refrigeration - Electronically controlled pumps	1.0	1.7
135	Transport	Express Bus/Coach Network	1.0	2.4
136	Industrial	Refrigeration - Multicompressor refrigeration systems	0.9	1.4
137	Industrial	Compressed Air Systems - Correct compressor intake problems	0.9	1.4
138	Commercial	Movement sensing (PIR)	0.6	1.2
139	Transport	Bus Priority and Quality Enhancements	0.5	1.2
140	Industrial	Refrigeration - Reduced cooling load	0.4	0.7
141	Transport	Park and Ride (Bus)	0.3	0.8
142	Transport	Park and Ride (Bus + Dedicated service)	0.3	0.8

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