ECONOMIC ANALYSIS OF GLASGOW'S GREEN DEAL

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Pengwern Associates

Table of Contents

List of Figures

List of Tables

Abbreviations

BCR	benefit cost ratio
BEIS	Department for Business Energy and Industrial Strategy
BEV	battery electric vehicle
CCC	Climate Change Committee
CCGT	combined cycle gas turbine
CDR	carbon dioxide removal
CGE	computable general equilibrium
EPC	Energy Performance Certificate
EU	European Union
FTE	full time equivalent
GBP	Great Britain Pounds
GCR	Glasgow City Region
GDP	gross domestic product
GHG	greenhouse gas
GVA	gross value added
ICE	internal combustion engine
IEA	International Energy Agency
IPPR	Institute for Public Policy Research
MMT	modern monetary theory
MW	mega Watt
NAO	National Audit Office
OECD	Organisation for Economic Cooperation and Development
PPP	purchasing power parity
PV	photovoltaic
TCFD	Task Force on Climate-Related Financial Disclosures
TUC	Trades Union Congress
UK	United Kingdom
US	United States

Executive Summary

This report highlights the significant economic benefits that could be delivered by Glasgow's Green Deal and the Glasgow City Region's (GCR's) wider commitment to reach net zero and increase its climate resilience. It considers each of the eight areas of focus of the Green Deal and explores the evidence base on the extent to which interventions connected to each could be expected to deliver net economic benefits, and the extent to which they may also be able to support or generate employment and economic activity.

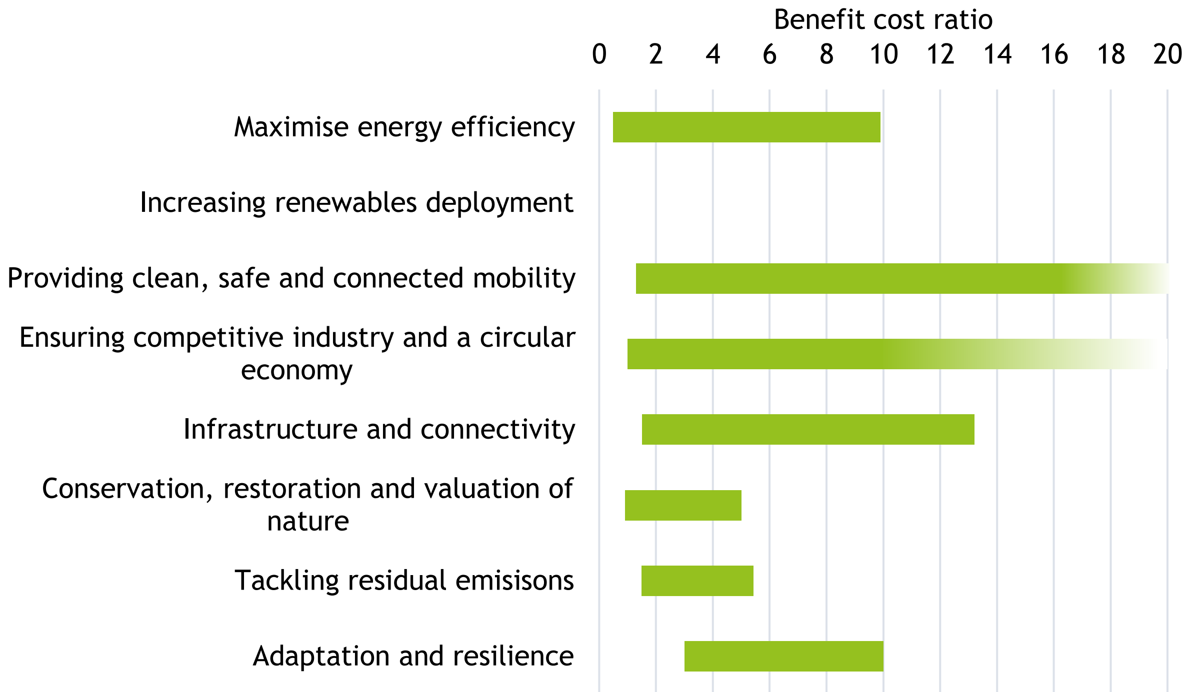
There is good evidence that interventions across all eight areas of focus will generate economic benefits greater than their costs. Figure 1 summarises the evidence collated on the benefit cost ratio (BCR) across the eight areas. The BCR measures the extent to which the (discounted) social benefits of selected intervention exceed their (discounted) social costs i.e. a BCR of two would mean that mean that the benefits are twice as high as the costs. The figure shows that, across all focus areas, the vast majority of evidence suggests that interventions will deliver benefits that are greater than their costs. Indeed, there is good evidence that the benefits could be three or four times greater than their costs, and that, sometimes, benefits may be ten times higher than costs. This evidence base draws on an assessment of a wide range of interventions which are implicitly assumed to be undertaken in isolation from other investments; some analysis, and intuition, indicates that packaging investments may generate greater benefits again.

The large BCRs are indicative of the wide range of different economic benefits associated of interventions in these areas. These high benefit cost ratios partly reflect the value that society has chosen to place on reducing greenhouse gases so as to help avoid the worst impacts of climate change around the world. However, they also reflect that the Green Deal can bring a wide range of other - more immediate and tangible - benefits, many of which will or can be concentrated on the most deprived people and places in Glasgow:

- Energy efficiency improvements can reduce fuel poverty and the poor health outcomes - including influenza, bronchial conditions and childhood asthma - associated with badly insulated properties, which is a disproportionately large problem in Glasgow, especially among its deprived populations.
- Greater penetration of renewable energy can help reduce electricity costs reducing fuel poverty.
- Transport interventions can reduce congestion, making it easier and cheaper for people to access employment opportunities, while active travel measures such as pedestrian walkways and cycle lanes will lead to better mental and physical health for Glasgow's residents. Glasgow also recognises the important role that improved active transport can play a key role in tackling poverty, improving health and reducing inequalities (Glasgow City Council, 2022a).
- Enhancing resource efficiency and moving to a circular economy can help firms enhance their productivity, supporting jobs growth, while helping households realise more from their spending It will also lower the costs of waste treatment, and reduce pollution, improving the natural environment

- Among other benefits, infrastructure and connectivity enhancements can make it cheaper for people to heat their homes and for firms and residents to take advantage of the digital economy.
- Conservation, restoration and valuation of nature both helps reduce (net) emissions and reduce climate vulnerability, as well as providing an improved local environment that people enjoy living, working and playing in (well-being benefits), and which can help to reduce health inequalities.
- Afforestation to address residual emissions provides similar types of benefits to nature conservation and restoration, but can also provide an opportunity for Glasgow to develop a flourishing business in sustainably developed timber products.
- Adaptation and resilience measures bring a range of cross cutting benefits, and can help tackle existing inequalities.

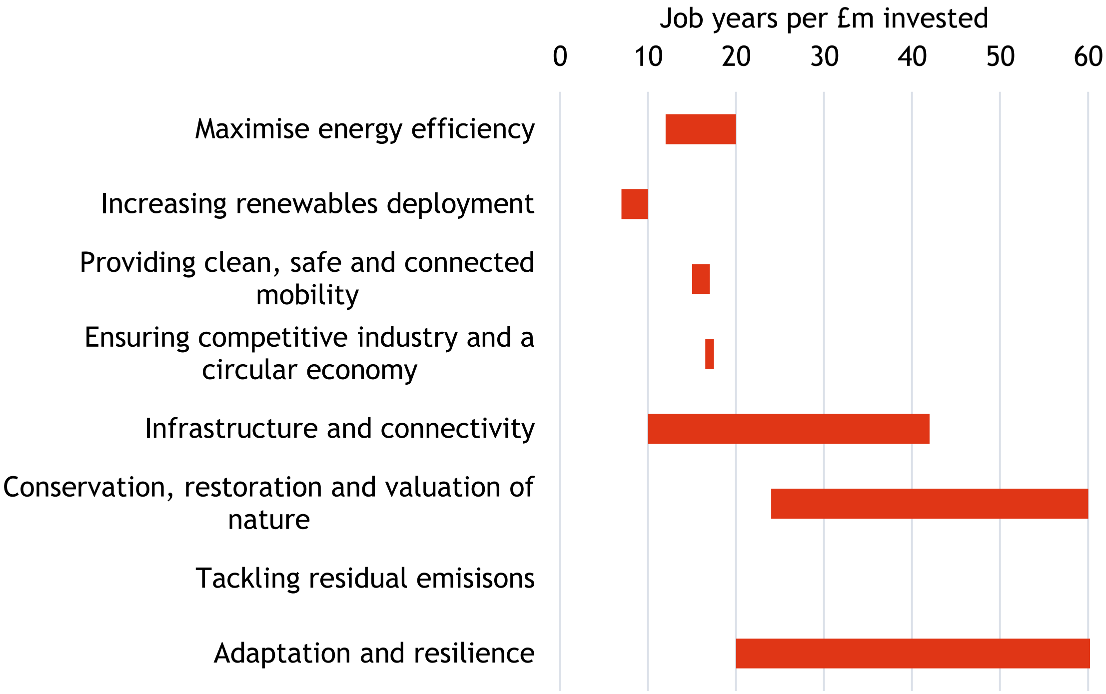
Figure 1 **All eight areas of focus are associated with BCRs typically significantly above one**



Notes: faded bars represent where there is evidence that some interventions will offer BCRs (much) higher than on the scale used for the chart. In addition, note that (1) evidence on the impacts of renewables investment are not typically expressed in terms of a BCR, but there is good evidence to show that these investment both reduce GHGs and electricity generation costs, implying a high BCR; (2) there is relatively small evidence based on BCRs for the circular economy and (3) evidence on tackling residual emissions focuses on afforestation.

There is also strong evidence that the interventions in these focus areas can help support employment. Summarising evidence on the employment implications of interventions in these focus areas might deliver is more difficult than summarising BCRs both because analysts use different measures of employment and because of differences of opinion on the extent to which additional publicly-supported activity affects labour markets into the medium term. Nonetheless, Figure 2 seeks to summarise the available evidence while Table 1 identifies potential implications for the Glasgow City Region (GCR). It shows that many interventions associated with Green Deal are labour intensive and hence provide the opportunity to help reduce regional unemployment. The actual impact on local and regional unemployment is context specific. It will depend on the extent to which the supply chains associated with these focus areas are localised; the functioning of the local labour market; and the extent to which there is a skills match between the jobs associated with the Green Deal and the skills of those in the local labour force. The interplay of these factors may mean that in developing individual business cases, analysis may yield lower jobs estimates than presented here.

Figure 2 Most of the areas of focus support more than 10 job-years for every £m invested



Notes: Energy efficiency job estimates typically include direct and indirect jobs, adjust for displacement effects but are gross estimates. Renewable job estimates account for direct, indirect and induced effects and adjust for displacement effects but are gross estimates. Mobility job estimates are direct, indirect and induced but do not adjust for displacement effects and are gross estimates. Circular economy estimate comes from plastic recycling plant with point estimate of 17; this estimate includes direct and indirect jobs, excludes displacement and is a gross job estimate. The wide range for infrastructure and connectivity partly reflects the range of different activities but also reflects varying treatment on inclusion of indirect and induced jobs. Most studies for this area do not take account of the possibility of displacement. For nature, there is variation in whether studies include induced employment; most studies tend to not account for displacement. Tackling residual emissions in the main analysis are expressed per hectare so not included in the chart. Adaptation and resilience investment relate to job intensity associated with flood protection, and include indirect and induced effects. Box 2 below provides more discussion on the different terms used in this report regarding job impacts.

Table 1 Evidence of employment impacts associated with Green Deal areas of focus

	Potential implications for Glasgow
Maximise energy efficiency	Potential to support 12,000 - 20,000 jobs for each year of the

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	Housing Retrofit program, although some of these jobs may be outside the GCR. Further potential to be explored in rolling out a deep retrofit of Glasgow City Council estate, but not included here as at too early a stage of scoping to estimate the investment and employment potential.
Increasing renewable deployment	Potential for fostering deployment of residential and commercial rooftop solar to be determined. Initial estimates of investment potential on GCC estate could support around 300 to 430 jobs over the lifetime of the investments. There is no information available on investment and employment potential from households and businesses deploying rooftop solar.
Providing clean, safe and connected mobility	Investment in Clyde Metro could support around 250,000 gross job years, although this includes all activities involved in the metro including upstream manufacturing, much of which is unlikely to take place in the Glasgow City region. The investment and employment generation of active travel and vehicle electrification has not been estimated
Ensuring competitive industry and a circular economy	Construction of new material recycling facility could generate or support around 340 job-years, direct and indirect jobs, although some jobs may be outside the GCR. Simple downscaling of nationwide study suggests potential to support additional 6,000 direct and indirect jobs in GCR from shift to circular business models, after adjusting for displacement impacts.
Infrastructure and connectivity	Heat network expansion might support around 120 jobs per year, or just under 600 job-years, although some jobs may be outside the GCR.
Conservation, restoration and valuation of nature	Green infrastructure plans in Glasgow Green Deal could support 300-750 jobs in each year of spend, although some jobs may be outside the GCR.
Tackling residual emissions	250 temporary jobs could be supported in each year of planting plus 540 job years supported by maintenance activities, although some jobs may be outside the GCR.
Adaptation and resilience	High jobs support potential, e.g. if all of the planned adaptation spend of £1bn was spent on flood protection over the period to 2030 could support 2000 to 6000 direct, indirect and induced jobs per year (assuming a 10 year implementation window).

Unlocking these large potential economic benefits, will involve successfully overcoming several challenges. Numerous examples exist of interventions that initially look economically attractive but which fail to deliver the expected magnitude of net benefits. Some of the common reasons for this include:

- rushed design and implementation that fails to build awareness and/or readiness among target groups and/or which means that longer term strategic goals are neglected;

- overly ambitious projections coupled with failures to develop adequate monitoring plans (with associated targets), making nimble course correction challenging;
- inadequate cooperation across different public sector bodies;
- insufficient skilled personnel within the public sector bodies tasked with implementing schemes;
- difficulties in convincing target groups that policies and incentives will be maintained into the medium-term;
- failure to design financing structures that mean that the personal financial incentives faced by firms and households are not aligned to the economy-wide benefits that are projected.

While it will be impossible to eliminate these sorts of challenges, it is important to take steps to reduce them. The Climate and Sustainability Board, supported by the Green Economy Unit, provides an opportunity to maintains strategic focus and a nodal point to support co-operation across relevant public sector agencies within the City. It also provides a platform to further strengthen engagement with the private sector and to consider financing structures that provide appropriate incentives to the firms and households (discussed in a complementary report). It can also help communicate the wider economic benefits associated with the implementation of the Green Deal, helping to demonstrate credibility and commitment.

At the same time, many of these challenges will need continued policy development and refinement from the Scottish and Westminster governments. This will need to be combined with funding arrangements across all tiers of government that provide for sufficient, but efficient, 'on the ground' implementation. Glasgow City Council will need to both advocate for relevant initiatives and policies and ensure that it has the capacity to determine which regional and national initiatives best align with its interests.

1. Introduction

To enhance the evidence base for, and support the implementation of, the Glasgow Green Deal, Glasgow City Council commissioned Pengwern Associates to provide support in relation to the economics and financing of the Deal. As Box 1 explains, it is one of three outputs development by Pengwern Associates and partners to help support acceleration in the implementation of Glasgow's climate and just transition objectives.

Box 1 This report is one of three complementary reports reviewing the economics and financing options of the Green Deal to support its implementation

Pengwern Associates and partners have supported GCC in relation on three key issues to accelerate implementation of the Glasgow Green Deal:

- The first report, this report, reviews the evidence of the economic costs and benefits of each of the Green Deal's areas of focus.
- The second considers the financing solutions GCC can pursue to support the implementation of the Green Deal. Looking across each of the eight areas of focus, it identifies 7 key options for raising and mobilising capital so as to unlock the benefits the Green Deal offers, despite the funding challenges faced by the Council.
- The third provides a practical recommendation for how GCC can implement green budgeting. This will allow the Council to monitor the extent to which its budgets are supporting the delivery of the Green Deal, providing valuable information to help monitor implementation and to make course corrections as necessary. It also considers the relevance of the Council making disclosures in line with those suggested by the Taskforce for Climate Related Financial Disclosures (TCFD).

The analysis is presented using a common structure centred around each of the eight 'areas of focus' identified in the Glasgow Green Deal. It first presents evidence on the scale of the investment that is or might be expected in the Glasgow City Region as part of the Green Deal. It then presents a summary of some of the key evidence regarding the economic benefits they may deliver. In each case, the economic evidence is presented in two parts:

- First, it focuses on information regarding the benefits (and the relationship of these benefits to the costs) that would be captured in a conventional cost benefit analysis following, for example, the techniques and procedures outlined in the HM Treasury's Green Book (HM Treasury, 2022). Where possible, this analysis draws on evidence specific to the delivery of projects in an urban context. It also identifies cases where these benefits are likely to provide benefits to the most deprived populations and hence help reduce inequalities and/or deprivation.
- Second, it explores the benefits that projects within these areas of focus might bring in terms of economic activity and employment, if these projects were included in a fiscal stimulus package focused on increasing overall spending within the economy. Where evidence is available, the nature of these jobs and the skills profile they would require have been documented. Box 2 explains the different concepts that might be identified in relation to job creation while the annex explores this issue in more detail.

This analysis is not intended to replace the detailed appraisal of specific projects that will be needed as part of the implementation of the Green Deal. Rather it is intended to provide an initial understanding of the potential scale of the benefits that successful delivery of the Green Deal, and associated climate action, could bring.

Box 2 Key terms related to the employment benefits associated with Green Deal investments

A wide range of different terms are used by analysts when describing the job creation/support potential associated with additional spending in the economy. Additional spending can be associated with direct investment in, and operation of, a particular investment or asset. Investment in an asset typically only supports jobs for as long as the construction phase endures, the increase in employment is often measured in job-years where 1 job-year represents the employment of 1 person for 1 year. The operational phase of an investment is normally assumed to support permanent employment, with some studies taking account of the part time nature of some jobs and so expressing these impacts in terms of full time equivalents (FTE).

In some instances, the direct spending and jobs are associated with additional jobs and spending elsewhere in the economy. This is often referred to as the 'multiplier' effect of the initial spending/employment support. Two types of multiplier can be distinguished:

- Indirect jobs and spending: this relates to the additional economic activity and employment that takes place in the supply chain, upstream of the specific investment, in order to supply the intermediate goods and services needed for the investment.
- Induced jobs and spending: this relates to the additional economic activity and employment that arises because of the increased incomes generated by the investment e.g. as workers spend their additional wages and salaries.

However, adjustments to the numbers generated by these calculations may often be needed for at least three reasons.

First, increases in 'green' jobs may be associated with the displacement of 'brown' jobs. For instance, if overall electricity demand is relatively stable then additional renewable power generation is likely to lead to reduce employment in fossil fuel generation. Similarly, the increased adoption of circular business models will likely lead to less employment in the extractive sector.

Second, especially in sub-national analysis, account is sometimes made for leakage i.e. the possibility that some of the jobs created may arise outside of the area of interest. For example, many of the manufacturing jobs associated with solar photovoltaic generation will arise outside of Glasgow and, indeed, the United Kingdom (UK).

Third, broader macroeconomic considerations may temper the jobs impact of a particular intervention. Some of the employment growth may come at the expense of employment elsewhere in the economy. This effect, different from the displacement effect above, arises because the intervention causes purchasing power to shift away from other products or because the employment needed for the intervention means the beneficiary sector outcompetes other sectors for the limited pool of suitably qualified labour. These restrictions are likely to be greater the closer the economy is to full capacity, but will be less significant in an economic downturn. To reflect this economists tend to distinguish between the gross and net jobs associated with an intervention.

The impact of making these adjustments can result in 'adjusted' estimates being notably smaller than headline estimates.

2. Maximise energy efficiency

2.1. Investment need/opportunity

Across Scotland, emissions from homes and non-domestic buildings combined will have to fall by 68% between 2020 and 2030 (Scottish Government, 2021). Comparing this to the reductions made across the buildings sector (UK-wide) of just 8% between 2009 and 2019 demonstrates both the scale of the opportunity but also the challenge in unlocking these potential gains (Dowling et al., 2022).

Fuel poverty remains a real problem for many households in Glasgow – and this is only likely to worsen given the current context of rising energy bills. According to the Scottish House Condition Survey 2017-19, 26% of Glasgow households live in fuel poverty and 12% live in extreme fuel poverty[1]. The proportion of fuel poor has, until recently, improved; in 2012, 32% of Glasgow households were in fuel poverty. However, the proportion of households in extreme fuel poverty is actually rising, up from just 5% in 2012 (Glasgow City Council, 2016). Moreover, fuel poverty is expected to be severely worsened by the recent rise in electricity and gas retail prices not yet reflected in data.

Poor energy efficiency and fuel poverty result in cold homes, with links to poor health. The result is excess winter deaths, estimated at 2,179 in the Glasgow area in 2013-14 (Glasgow City Council, 2016), and an extra strain on the health service to deal with people falling sick due to cold conditions at home.

Glasgow's Green Deal places energy efficiency at its centre, as homes, businesses and industry make the largest contribution to emissions.

- **The 'Glasgow City Region Housing Retrofit' aims to raise all homes to an Energy Performance Certificate (EPC) rating of C or higher.** To be delivered over 10-years, it is expected to cost around £10 billion including deployment of insulation and renewable energy technologies in homes. This includes a plan of action for the 428,000 properties currently falling below this standard, and further measures for all 886,156 properties across the region. It is expected to deliver 10.7 million tonnes of CO_2 emissions reductions per year.

- **The Glasgow Green Deal also prioritises energy efficiency in industrial and business processes in to non-domestic and public buildings.** It will also support SMEs in recognition of their significant contribution to the City economy and lower capacity to bear the costs of energy efficiency investments.

2.2. Conventional benefits

As Figure 3 from the International Energy Agency (IEA) sets out, energy efficiency improvements can deliver a wide range of potential benefits (IEA, 2014). These range from

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[1] Defined as spending more than 10% of income on household fuel, extreme fuel poverty over 20%

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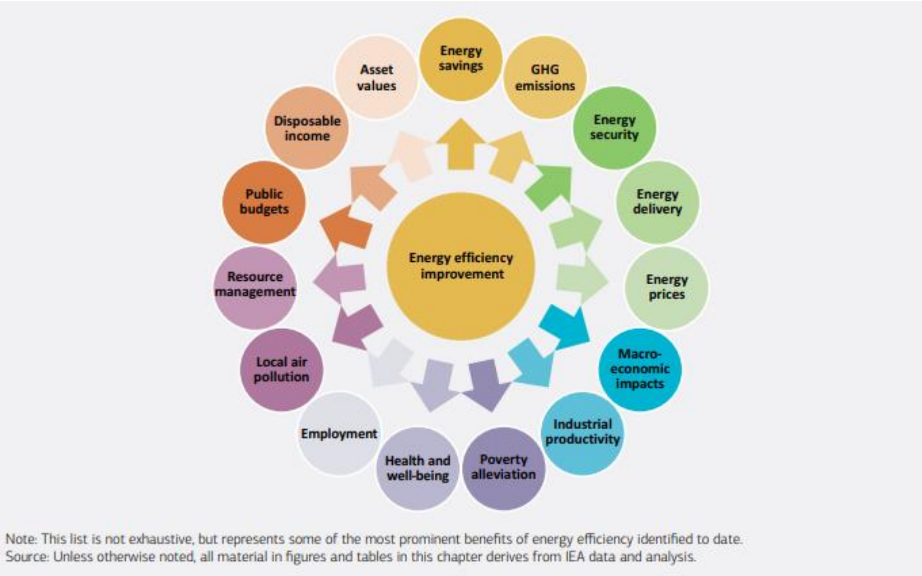
the delivery of energy savings which reduce bills for customers, lower GHG emissions, enhanced energy security, and improved air quality.

Figure 3 The multiple benefits of energy efficiency improvements



Source: (IEA, 2014)

Benefit-cost ratios (BCRs) for energy efficiency measures are often in the region of 4:1 (4)[2]. Typically, health benefits represent up to 75% of overall benefits, with improved mental health through reduction in chronic stress and depression accounting for half of the total health benefits (IEA, 2014). Excess deaths related to cold homes increase sharply once outdoor temperatures fall below 6 degrees Celsius (NICE, 2015). However, research suggests that delivery of health outcomes from energy efficiency improvements is complex – for example, reduced household ventilation may be associated with increases in asthmatic conditions – and that they are most likely to be achieved when delivered through a 'whole of house' approach, while also supporting lifestyle changes among household occupants (Sharpe et al., 2019).

A review of energy efficiency programs in the United States (US) found BCRs ranging from 0.54 to 9.91 (National Action Plan for Energy Efficiency, 2008)**.** The lower BCRs related to studies which only focused on the benefits to energy consumers. On the one hand, this represents only a partial assessment of the total benefits delivered by energy efficiency improvements. On the other hand, this points to a challenge that it can often be difficult to encourage consumers, especially households, to implement energy efficiency measures.

Potential energy savings could benefit fuel poor households the most. As described above, reducing fuel poverty is a major challenge for the City region, and domestic energy efficiency interventions could play a major role in reducing energy bills for the vulnerable households. The improvement in health outcomes associated with energy efficiency improvements could also help reduce health inequalities, given that these challenges disproportionately affect

[2] For the remainder of the report, BCRs are reported in terms of the benefits i.e, a ratio of 4:1 will be reported as 4.

poorer households in the city.

The challenge of low take up has been a common problem for UK-wide schemes to promote energy efficiency. For example:

- **The *'English Green Homes Grant Voucher Scheme'*,** was abandoned in 2021 just six months into a planned 18-month implementation period. The National Audit Office (NAO) found that it had reached 47,500 compared to an initial expectation of supporting 600,000 homes to be more energy efficient, and of the 82,500 jobs it was expected to support only 5,600 had been realised. The report blamed these failings on a rushed design phase which constrained procurement options and reduced engagement with the installer market which made it hard for a many potential suppliers to mobilise to meet demand (National Audit Office, 2021).
- **The *'Green Deal'***, which offered finance to households to make energy efficiency improvements, was only taken up by 14,000 homes and was *'unlikely to have provided any material additional energy and carbon saving over and above what would have been delivered by other policies'* (National Audit Office, 2016).

Local context matters in delivering energy efficiency; a recent study found that place-specific energy efficiency interventions in Glasgow can deliver significant benefits. The study explored the benefits to the buildings sector from implementing a range of measures, of which four directly relate to energy efficiency: (1) insulation, (2) energy efficiency appliances (households) or heating and lighting (businesses), (3) heating efficiency and (4) behavioural change (for households)[3]. The study found that when these measures were employed in a place specific way, accounting for the proportion of the building stock for which they were most relevant, they could deliver indicative[4] BCRs of 6.5 to 22.5, as Table 2 illustrates. This is significantly higher than when interventions are applied in a place agnostic manner.

Table 2 BCRs from place-specific energy efficiency investments in Glasgow

	Investment (£ millions)	Energy and operational savings (£ millions)	Wider social benefits (£ millions)	Indicative BCR
Domestic				
Energy efficiency measures (appliances)	14	185	130	22.5
Insulation	248	442	1,172	6.5
Heating efficiency	25	66	95	6.4

[3] The study also explored other interventions affecting the building stock not related to energy efficiency, such as micro-generation and low-carbon heat, which are discussed further below.
[4] Throughout, the analysis from this report is classed as 'indicative' it only provides cumulative values, not discounted values. This is likely to lead to an upward bias in the reported BCRs. BCRs from this source are calculated treating the energy and operational savings as a benefit (rather than as deducting these from the investment costs provided).

Behavioural change	0	255	410	n/a *(positive only - zero cost)*
Commercial				
Energy efficiency measures (e.g. sensors, increasing efficiency of technologies)	14	185	130	22.5
Insulation	248	442	1,172	6.5
Heating Efficiency	25	66	95	6.4

2.3. Economic activity and employment benefits

Energy efficiency can provide a significant boost to employment. For example, the UK government expects the transition to low-carbon buildings[5] will sustain 175,000 direct and indirect green jobs by 2030 (BEIS, 2021a). A particular attraction of many of these jobs is that the nature of the activity means that the direct jobs supported are embedded in the local economy.

A number of studies have reviewed the jobs that might be supported for each dollar or pound of investment in energy efficiency with the bulk of the evidence implying between 12 and 20 job-years per £1m of annual investment:

- A wide-ranging evidence review found that each US$1 million invested in energy efficiency and low-carbon buildings supported an average of 14 *job years* of employment, with a range of 0.25 to 35.5 job years (Gouldson et al., 2018). This review focused on studies that took account of the possible displacement of jobs, for example from energy generation, but it is unclear whether the underlying studies looked at direct and/or indirect and/or induced employment. Converting these estimates to Great Britain Pounds (GBP)[6] suggests a mid point of 20.9 and a range of 0.4-53.1 job years per £1m of investment.
- A 2017 study found that that an annual US$1 million investment in energy efficiency supports 7.77 full-time equivalent jobs, implying that an investment of £1m would support 11.61 jobs (Garrett-Peltier, 2017). This includes direct and indirect jobs but given that this study only focuses on short-term employment impacts, it would be best considered as an assessment of job-years. This places it within the range identified above.

[5] This includes activities beyond those conventionally considered as energy efficiency.
[6] Here and elsewhere through this report, the conversion to job intensities per £m is based on PPP exchange rates as reported by the Organisation for Economic Cooperation and Development (OECD) (OECD, 2022). The £:US$ PPP exchange rate in 2021 was £0.669:US$1.

- IEA analysis identified a range of 8-27 job years per €1m of investment (IEA, 2014)[7], which would be largely the same per £m given current purchasing power parity (PPP) exchange rates[8]. The associated discussion in the report suggests that these figures include direct and indirect employment and are likely to account for displacement.

An alternative perspective focuses on the job potential per dwelling upgraded. Using this approach, one study found a labour requirement of 81.5 job years for every 1000 dwellings upgraded in a year with an ongoing need for the 3.1 permanent maintenance jobs per 1000 dwellings upgraded (Chapman et al., 2018). This focuses only on direct jobs and does not appear to account for displacement.

Table 3 summarises the evidence collated.

Table 3 Job creation potential from energy efficiency interventions

Study	Methodology	Job years per £1 million invested
(Gouldson et al., 2018)	Focus on job-years, takes account of displacement. Unclear whether relates to direct, indirect or induced.	20.9 (0.4 – 53.1)
(Garrett-Peltier, 2017)	Best interpreted as job-years, takes account of displacement. Direct + indirect jobs	11.6
(IEA, 2014)	Focus on job-years. Discussion suggests direct and indirect employment and are likely to account for displacement	8-27
(Chapman et al., 2018)	Direct jobs only, no account of displacement	81.5 job-years during retrofit and 3.1 permanent maintenance jobs** ***(per 1,000 dwellings)*

This analysis suggests that the current stated jobs impacts from the energy efficiency improvements associated with the Glasgow Green Deal is conservative. At present, the literature suggests that the £10bn investment over 10 years will deliver 7500 jobs; this is equivalent to 7.5 job-years per £1m of annual investment in each of the 10 years of the programme. This is lower than the data points presented in Table 3, although this may be appropriate given the tendency for headline jobs estimates to be adjusted downwards as more detailed work in undertaken, and especially as the proportion of jobs that would be retained within the Glasgow City Region is difficult to estimate.

[7] Elsewhere in the same report it identifies a range of 7-22 job years per €1m invested while would imply a range of 10-33 job years per £1m invested.
[8] OECD report a PPP exchange rate for the EU27 of €0.66:US$1 in 2021 while, as per footnote 6 the UK: US PPP exchange was £0.669:US$1 in 2021

3. Increase renewables deployment

3.1. Investment need/opportunity

The UK will need to deliver 80% of the electricity grid balance from renewables by 2050 (Committee on Climate Change, 2020b)**.** While carbon emissions reductions from electricity supply have fallen rapidly across the UK, by 65% between 2009 and 2019 (Dowling et al., 2022), there is still a large amount of investment needed to continue to decarbonise the power sector.

Across Scotland, renewable electricity generation has expanded rapidly and generated the equivalent of 97% of Scotland's gross electricity consumption in 2020. This represents a step change over the past decade, with renewables output rising from just 24% of gross electricity consumption at the start of the decade to reach 50% by 2014, and 97% in 2020 (Scottish Renewables, 2022). However, heating remains a key challenge, with 86% of Scotland's homes reliant on gas or oil (Energy Systems Catapult, 2021).

The Glasgow Green Deal also includes deployment of large scale renewables and local energy generation. The aim is to support grid decarbonisation, facilitate electrification (and hence decarbonisation) of heat, meet the increased demand from electric transport, and, potentially, manufacture green hydrogen. Examples of planned and potential renewables initiatives include:

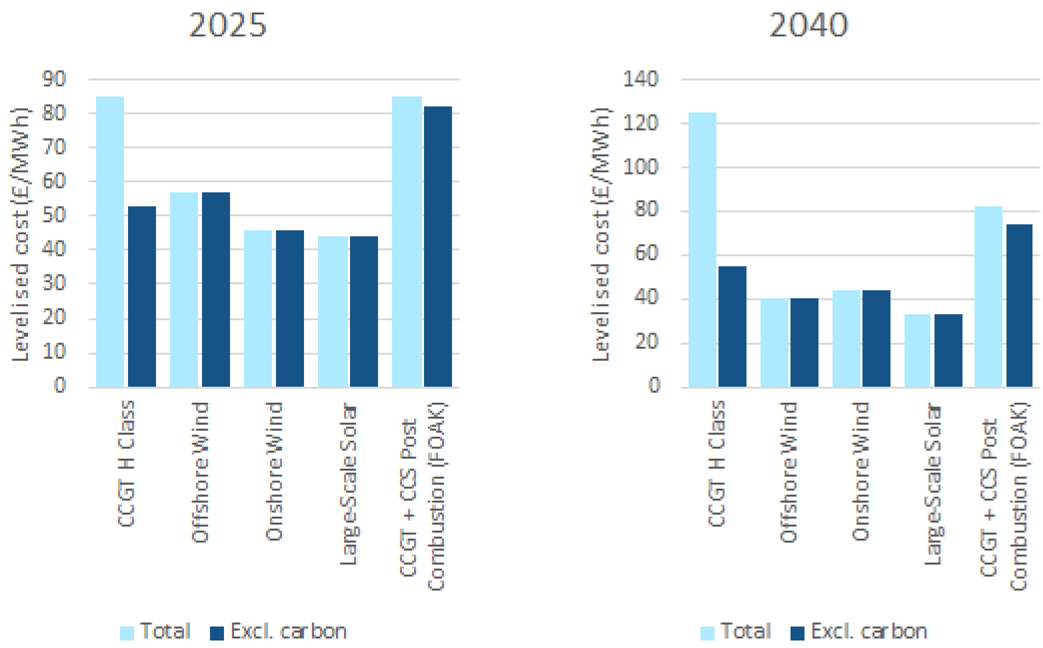
- a partnership of Glasgow City Council, SSE, and the Castlemilk and Carmunock Community Wind Park Trust (CCCWT), has installed a £5m (3MW) wind turbine, which is expected to support the trust and reduce local fuel poverty;
- a roof mounted solar array with battery storage and electric vehicle chargers in Duke Street car park is being installed as part of the EU Horizon 2020 funded RUGGEDISED project;
- over 5km^2 of vacant and derelict land has been mapped for potential use to site local renewable power generation;
- potential deployment of solar PV on GCC owned estate and landfill sites;
- the Scottish Government also aims to aims to accelerate deployment of 2 GW of locally owned renewable energy by 2030 through the Community and Renewable Energy Scheme.

3.2. Conventional benefits

Increased renewables deployment first and foremost significantly reduces GHG emissions. In 2019, renewable electricity generation across Scotland saved 13.5 million tonnes of carbon dioxide equivalent (Scottish Renewables, 2022).Using the UK Green Book ranges to value CO_2 emissions reductions, this represents an annual benefit of between £1.6 billion and £4.9 billion (HM Treasury, 2022).

Renewables electricity generation is already competitive with and at the point of generation often more cost-effective than conventional fossil-fuel technologies. Figure 4shows that, even ignoring any costs associated with CO_2, the costs of generating electricity from large scale wind and solar are already similar to those of conventional combined cycle gas turbine (CCGT) gas plants, as illustrated by the dark blue bars (BEIS, 2020a). By 2040, a clear cost advantage for renewables is expected to emerge – this would imply a high benefit cost ratio as investments in renewable generation will deliver both emissions reductions and cost savings relative to the alternative. The Climate Change Committee estimates that the abatement cost per tonne of CO_2 for renewables is -£6, compared to £50 per tonne for low-carbon conventional power (nuclear or gas with carbon capture and storage), and up to over £125 per tonne for bioenergy with carbon capture and storage (Committee on Climate Change, 2019a).

Figure 4 Estimates of the Levelised Cost of Electricity from different generations sources (£/MWh)



Source: BEIS (2020)

However, as the share of intermittent renewable generation increases, there are incremental system costs associated with grid balancing, back-up power generation etc. Most of the evidence suggests that these are relatively modest, with integration costs amounting to around £10-25/MWh for renewable electricity generation penetration of 50%-65%, but potentially increasing further at higher penetration levels. A key determinant of the size of these costs is the extent of flexibility built into the electricity system, for example, the ability to shift electricity demand to periods where there is plentiful generation. (Committee on Climate Change, 2019b). Section 6 discusses the role of smart grids and smart meters as technologies that support this flexibility.

No impact has been found on house prices from at scale deployment of onshore wind in Scotland. Despite concerns that wind farms represent a blight on local landscapes and could reduce the value of property for local communities, researchers analysed over 500,000 property sales between 1990 and 2014 and found no significant effect on the change in price of properties withing 2km or 3km of wind turbines or wind farms (Heblich et al., 2016).

While large scale renewables appear cost-effective - at least up to very high penetration rates - the same is not always true for microgeneration such as rooftop solar PV. For example, of an identified investment need of £42 million investment potential in Glasgow would deliver just £13 million of energy and operational savings, and a further £9 million of wider social benefits through reduced GHG emissions (Dowling et al., 2022) , for a total (indicative) societal BCR of just 0.52. This finding is not unique to Glasgow – across all the non-London cities explored in this study the upfront costs of microgeneration were greater than the cost savings and wider economic benefits. Similarly, a prior literature review identifies the risk of higher energy prices as a result of investment in residential renewables deployment. The study notes that *'Policies for small-scale renewables in residential and commercial buildings can be highly regressive when they lead to higher energy prices'* (Gouldson et al., 2018).

Using renewable electricity to displace conventional gas and oil for domestic heating, offers lower benefits. For example, the Climate Change Committee found that the marginal abatement cost of converting residential homes to low carbon heat (primarily through use of heat pumps or green hydrogen) had abatement costs of up to £311/tCO_2 with a weighted average abatement cost of around £176/tCO_2 (Committee on Climate Change, 2019c).While the project carbon price values for use in appraisal would imply that these investments still have a positive benefit cost ratio, these high financial costs imply that the roll out of these technologies will be challenging. The recent analysis looking at the costs and benefits of low-carbon heat specifically with Glasgow also suggested that the economic case for this investment was relatively weak (Dowling et al., 2022).

Finally, from an equity perspective –consideration needs to be given to the balance of (1) decarbonisation objectives, and (2) household energy costs. Schemes which could result in a rapid rollout of rooftop PV or rapid increase in heat pumps may help decarbonise, but could increase or decrease bills depending on cost efficiency and the way in which the intervention is funded. In cases where there are additional costs that are met through energy bills, there would need to be long term financial support for vulnerable households to offset any risk of energy price increase.

3.3. Economic activity and employment benefits

A 2014 review of employment found that renewable energy can support additional employment. Reviewing studies that take account of displacement as fossil fuel generation declines, and accounting for construction jobs only having a short duration, it found that renewable generation technologies supported an additional 0.5 jobs/GWh. The majority of the studies informing this summary statistic considered direct, indirect and induced jobs. The strongest employment impacts were found for solar, with wind being less employment intensive (Blyth et al., 2014).

Most studies suggest that renewable power creates around 7-10 jobs per £m investment. For example, the study referenced above found an average net job intensity of 10 jobs per £m, considered over the lifetime of the investment (Blyth et al., 2014). Another study found a difference in direct and indirect job creation/support of renewable power and fossil fuel electricity generation of 4.8 jobs per US$m[9], equivalent to 7.2 jobs per £m, although this study

[9] 7.49 direct and indirect jobs for renewable technologies compared with 2.65 direct and indirect

only focuses on the construction phase of the respective technologies, so may be best interpreted as a difference in job-years (Garrett-Peltier, 2017).

Most of the jobs supported by renewables will be during the construction phase, with more modest employment associated with maintenance and operation. For example, one study suggests employment factors for onshore wind of 9 job-years per MW during the construction phase and 0.3 jobs per MW for maintenance. Offshore wind is more labour intensive, supporting 18 job years per MW installed, and 0.7 jobs for maintenance, while hydro projects are the most labour intensive supporting 48.5 job years per MW installed and 1.3 jobs per MW for maintenance (Chapman et al., 2018).

Retraining and skills development has an important role to play in the transition to a renewables based energy system. The Scottish economy was particularly affected by the loss of 150,000 jobs in the UK oil and gas sector between 2014 and 2017. As a result, the national skills agency put in place a 'Transition Training Fund' for oil and gas workers at risk of redundancy, which surpassed its objectives to help re-employ at least 1,000 workers per year, although only around half of these found new jobs outside the oil and gas sector (Skills Development Scotland, 2019).

If the City were to deploy rooftop PV on landfill and the GCC estate, this could support up to 430 jobs. Not all of these would be in the City region, as this includes manufacturing and international supply chains. Most jobs are likely to be in sales, engineering and maintenance of systems, and finance, with manufacturing occurring outside the region.

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jobs for fossil fuel technologies.

4. Providing clean, safe and connected mobility

4.1. Investment need/opportunity

Surface transport has been the largest contributor to UK CO_2 emissions since 2015, when it overtook electricity supply (Dowling et al., 2022)**.** The response to this requires at least three types of transport and mobility measures at the urban scale: (1) the expansion of public transit systems, (2) support to grow low-carbon private transport, especially battery electric vehicles (BEVs) and (3) investments to facilitate active transport.

The Glasgow Transport Strategy 2022 sets a series of key objectives for 2030 (Glasgow City Council, 2022d)**.** The main goals are to reduce car vehicle kms in the city by at least 30% (from a 2019 baseline) and to make the remaining trips cleaner, lower carbon and more efficient. To deliver on these objectives, the city will seek to work with communities to deliver liveable neighbourhoods offering safe and enjoyable non-motorised transport infrastructure, and reduce the road-space dedicated to vehicles, as well as invest in low-carbon public and private transport infrastructure.

The recently adopted 'Active Travel Strategy 2022-2031' sets out clear actions to reduce car usage and increase physical activity (Glasgow City Council, 2022a)**.** Measures include making the 'Spaces for People' cycle lanes permanent and building on the national commitment to '20-minute neighbourhoods'. In addition, Glasgow's 'Vision Zero' envisages no-one to be killed or seriously injured on the City's roads, streets, cycle ways and footpaths by 2030 (Glasgow City Council, 2020b).

Glasgow already has relatively high uptake of public transport. 16% of trips in Glasgow are undertaken by bus, compared to for example just 6% in Cambridgeshire & Peterborough (Dowling et al., 2022).

The potential benefits of active travel are potentially large for Scotland, and especially large for Glasgow. Across Scotland as a whole, the annual economic benefit delivered from improved health as a result of commuting to work by walking has been estimated to be approximately €700m, and €80m for cycling to work (Baker et al., 2021), while a recent Sustrans study estimates the combined benefits of current walking and cycling levels are worth £438m (Sustrans, 2022).This partly reflects that walking is by far the most popular mode of transport for Glaswegians, with 53% walking five days a week, compared to 28% driving and 6% cycling at least five days per week. A further study estimates that the benefits to Glasgow residents from increasing active travel (walking and cycling) could be around twice as high per-person as for other UK cities – reflecting the relatively low life expectancy and health of Glasgow residents (Dowling et al., 2022).

The Glasgow Green Deal includes providing a sustainable transport system for people and for goods. This combines multiple objectives, including enhancing affordability and inclusivity, ensuring accessibility, and making sure that transport options are low carbon, clean and safe, integrated and reliable. A key related project is the development of the Clyde Metro which will improve connectivity across the Glasgow City-Region. Currently at feasibility study stage, the expected total cost of the initial investment is around £17 billion. In addition, the Council intends to replace its current fleet with around 1,400 hydrogen fuel cell and battery electric vehicles EVs, and to scale up the production of hydrogen fuels in the coming years.

4.2. Conventional benefits

4.2.1. Reducing congestion and promoting modal shift to public transport

Congested roads and long commuting times come at a significant cost to the economy. International studies suggest that congested urban areas create a significant dent in gross domestic product (GDP) and welfare; mostly driven by time wasted, but also because it lead to unnecessary fuel expenditure, air pollution, and accidents, among others. One study found that traffic congestion cost around 1.1 to 1.5 percent of GDP in New York, Toronto and London (Gouldson et al., 2018).

The extent to which public investments to reduce congestion are cost effective depends on local context. A 2006 study of 85 urban areas in the United States found that benefit-cost ratios averaged 1.34, but could be less than one in some urban areas (Harford, 2006).

In Glasgow, faster journeys could deliver around £15.8 billion in social benefits (Dowling et al., 2022). However, much of this is likely to be most effectively delivered through promoting active travel; this study suggests that the costs of investing to promote a shift from cars to buses would likely outweigh the benefits.

There is limited generalisable evidence on the benefits of mass transit systems, as the costs and benefits are highly context specific. Investing in mass transit systems such as bus rapid transit or metro systems would be expected to deliver all of the benefits identified above, although the extent of these benefits depends on how many trips are replaced and detailed traffic flow modelling. The Clyde Metro is currently undergoing feasibility studies which should develop the case for the benefits relative to the £17 billion investment cost and operating costs.

4.2.2. Promoting active travel - cycling and walking

In general, promoting active travel can yield significant benefits and comes at relatively low investment cost. Converting urban roads to bicycle use was found to yield benefits 10–25 times greater than costs in New Zealand (Macmillan et al., 2014), while a cost benefit analysis in three Norwegian cities found that cycling networks had benefits at least 4-5 times the investment cost (Sælensminde, 2004). A wide-ranging review of evidence in 2018 found that switching the public from car to active travel modes consistently results in a positive BCR, with a range of up to 360 and a median of 9 (Gouldson et al., 2018).

In the UK, cycling schemes and walking schemes have been found to deliver high social benefits. A UK Department for Transport 2015 Review consistently found positive BCRs across a range of active transport interventions. For example, it found that cycling demonstration towns had a BCR of 2.59 based on adult health benefits alone and that 'cycling ambition grants' were delivering a BCR of 5.5. Under conservative assumptions, it found that the *'Transport for London Cycling Vision'* was expected to deliver a BCR of 2.9 (Department for Transport, 2015).

Glasgow specific evidence further strengthens the case. In Glasgow, setting up cycle routes and shifting trips away from cars would cost £69 million and deliver fuel and operational savings alone worth £419 million, implying an indicative BCR of 6.1. Wider economic benefits would amount to £11.3 billion implying an indicative BCR of 170. Switching to walking instead of car use would deliver £951 million in fuel and operational savings, and over £20 billion in wider social benefits, at no specific investment cost (Dowling et al., 2022). Likewise, Glasgow's active travel strategy is estimated to provide a £1.8 billion benefit for the City (Glasgow City Council, 2022e). These plans include 270km of active travel infrastructure at a cost of £475m over the next decade, delivering a BCR of around 3.8. The benefits include improved air quality, reduced journey times, lower GHG emissions, and improved drainage to mitigate the risks of surface water flooding (Glasgow City Council, 2022c).

4.2.3. Vehicle electrification

The shift to BEVs is expected to bring a range of benefits from GHG emissions reductions to lower noise pollution and lower lifetime costs. BEVs reduce GHGs by at least 60% compared to diesel or petrol cars, and have zero exhaust, which means a significant reduction in other local air pollutants that are harmful to health, delivering health improvements and savings for the National Health Service (Local Government Association, 2022).

Electrification of transport is accelerating and will offer increasing opportunities private car owners and freight. The private business case for BEVs for freight is strengthening: BloombergNEF suggests that they will reach price parity with internal combustion engines in all light vehicle segments in Europe by between 2025 and 2027 (Soulopoulos et al., 2021); while McKinsey projects that electric trucks will achieve parity in cost of ownership with internal combustion engines between 2023 and 2030 (depending on truck size and distance travelled) (Heid et al., 2017).

Accelerating the shift to electric vehicles in Glasgow will increase costs but deliver net social benefits. Electrification for private vehicles is estimated to cost around £2 million. This is associated with £1 million in operational savings and a further £2 million of wider social benefits, implying an indicative BCR of 1.5. Electrification of the bus network would deliver slightly less fuel and operational cost savings than the estimated £319 million investment need, but would deliver almost £700 million of wider social benefits, implying an indicative BCR of 3.1. Similarly, electrification of freight would currently require over £600 million in investment unlock £200 million in savings, and deliver over £1 billion in wider social benefits, implying an indicative BCR of 2.1 (Dowling et al., 2022).

The success of public funding to accelerate deployment of electric vehicles is less clear-cut. For example, the UK National Audit Office's recent report on support for ultra-low emission cars and infrastructure over the last decade found that, while the infrastructure has been successfully deployed, it has not delivered emissions reductions in line with expectations, and is not able to demonstrate value for money. The £1.1 billion total spend was dominated by plug-in-car grants to reduce the cost of purchase of EVs comprising £1 billion, with just over £100 million allocated to installing charge-points and on awareness campaigns (NAO, 2021).

4.2.4. Summary

Table 4 summarises the key findings in relation to the conventional economic benefits in this area of focus.

Table 4 BCRs from place-specific low carbon transport investments in low-carbon transport

	Source / context	Investment (£ millions)	Energy and operational savings (£ millions)	Wider social benefits (£ millions)	BCR
Reducing congestion	Various				1.34
Active travel	Active travel				2.6 - 360
Car trips to cycling (shift)	Glasgow (Source:(Dowling et al., 2022))	69	419	11,327	6.1 – 170
Car trips to buses (shift)		751	- 244	- 871	n/a *(negative benefits)*
Car trips to walking (shift)		0	951	20,605	n/a *(positive only - zero cost)*
Electrification of private transport (improve)		2	1	2	1.5
Electrification of bus network (improve)		319	305	690	3.1
Electrification of freight (improve)		616	212	1,074	2.1

Note: BCRs for interventions identified in (Dowling et al., 2022) should be considered indicative as the costs and benefits are cumulative undiscounted values.

Transport interventions will also need to consider who stands most to benefit and ensure inclusive access to the benefits of investments. For example, the Sustrans study on active travel finds that men are far more likely than women to cycle or walk, and the relatively wealthier socio-economic groups are more likely to walk or cycle than lower socio-economic groups. This suggests that interventions will need to designed carefully so as to encourage usership among those not currently well represented in the active travel statistics. Similarly, the large scale investment in the Clyde metro will need to consider how to promote usership and accessibility for all.

4.3. Economic activity and employment benefits

Investment in multimodal transit supports higher direct and induced employment compared to conventional road construction. One study found that, for each US$1 million invested, cycling projects support 11.4 jobs, pedestrian projects support 9.9 jobs, while conventional road projects support only 7.8 (that is, 17.0, 14.8, and 11.7 jobs per £1 million respectively).

These estimates include direct, indirect and induced jobs and are associated with the construction of the infrastructure, and so are unlikely to be permanent and may be best thought of in terms of job-year increases (Garrett-Peltier, 2011). A wider review article noted that improved accessibility of transport networks is also likely to shift consumption patterns and support further induced employment in other sectors as a result (Gouldson et al., 2018). For example, it reported that while US$1 million spend on petrol and vehicle expenses supports around 13 jobs, spending on a typical household bundle of goods would support around 17 jobs, while spending on public transport supports 31 jobs (per £1 million, 19.4 jobs, 25.4 jobs, and 46.3 jobs respectively).

Low-carbon transport has strong potential for local job creation, as it is often replacing private car use with higher - employment-generating - public transport modes. Much of the employment in low carbon transport would be long-term, as people are required to operate and maintain public transport systems. Across the UK as a whole it has been estimated that a shift in transport use consistent with net zero could support more than 350,000 (net of around 160,000 job losses in the maintenance of private internal combustion engine (ICE) vehicles). These are direct job estimates only, based on estimates that driving buses requires 0.4 FTEs per 10,000 bus miles, maintaining buses a further 0.1 FTEs per 10,000 bus miles and that there are 4.1 FTE jobs required for railway operation and maintenance for every 10,000 train miles (Chapman et al., 2018). However, the distribution of these employment opportunities could be quite different from those associated with road construction and vehicle maintenance etc.

While the Clyde Metro is undergoing feasibility studies that should give more clarity, the investment could support around 250,000 jobs spread over the implementation period. This is estimated based on a total investment of £17 billion and using a (crude) multiplier of 15 jobs per £ million based on the literature review above. Given the size of this project, more detailed employment estimates should emerge from the feasibility studies underway and which may well suggest somewhat lower estimates. While the upstream manufacturing jobs would be located outside the City region, spending on public transport projects is likely to support substantial indirect and induced jobs within the City region. There would also be long-term need for skills in maintaining and operating the system, and for construction.

5. Ensuring competitive industry and a circular economy

5.1. Investment need/opportunity

Scotland's current consumption and production habits are unsustainable. The Scottish Material Flow Accounts shows that Scotland's Raw Material Consumption (RMC) is around 18.4 tonnes per person per year. This is around 38% higher than the global average and twice as high as the level identified in the report as sustainable according to a range of experts. The accounts also demonstrated that Scotland displayed higher levels of domestic extraction tan the EU average (Lenaghan & Pratt, 2021).

Trends such as these have led to growing calls for Scotland generally, and Glasgow specifically, to move towards a circular economy. The Circular Economy Route Map for Glasgow (Glasgow City Council, 2020a) identifies a wide range of recent and/or ongoing activities, many of which have been developed through partnership between the Glasgow Chamber of Commerce, Zero Waste Scotland and Glasgow City Council. These include studies to track inflows and outflows of materials in the city, events on the circular economy to raise awareness, and circular economy platforms to crowdsource ideas. These developments have been facilitated by the broader strategic framework set out by the Scottish Government (Scottish Government, 2016). An OECD review identified that the work undertaken to date on the circular economy in Glasgow had 'translated into meaningful and clear messages for all businesses' and reported that 6% of employment in the city was already linked to circular economy activities (OECD, 2021).

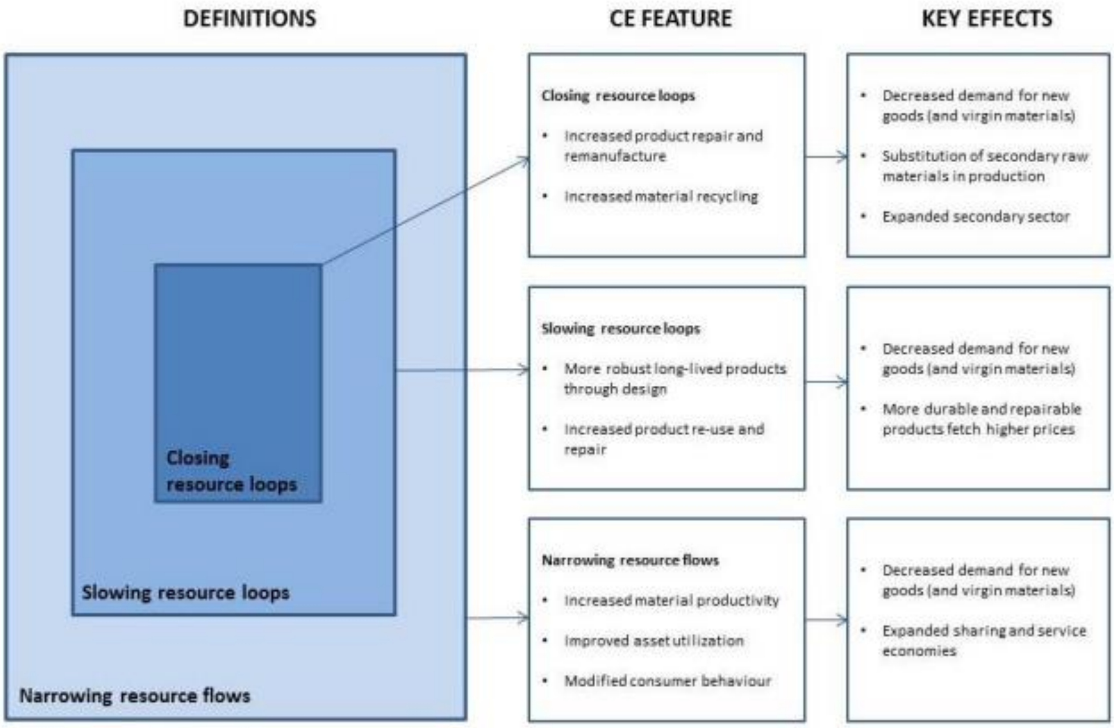
Looking forward, Glasgow intends to leverage a wide range of investments, as well as undertake broader policy reform, in order to realise its vision of becoming a fully circular city by 2045. The Glasgow Greenprint (invest Glasgow, 2021) identifies a number of specific investments linked to the circular economy including:

- The development of the Clyde Future Fashion Park, which aims to be a large-scale advanced manufacturing facility to support design, manufacture, re-commerce and recycling of clothing. Its objectives will be supported by the intention to introduce a textile collection service within the city.
- The development of a £100m-£150m Advanced Manufacturing Innovation District in Renfrewshire
- The development of an £80m Scottish Marine Technology Park

More broadly, the Circular Economy Route Map sets out 30 actions that the City intends to undertake in relation to new policies, change planning processes, shifting production, providing people with new skills, and enabling action by the public and private sector to support the transition to a circular economy.

The wide range of different activities associated with the transition towards a circular economy means that a conceptual framework can be valuable. Figure 5 provides one such approach. This identifies three key aspects to the transition: narrowing resource flows so as to increase the productivity with which production uses materials, ensuring better asset utilisation and changing consumer behaviour to reduce waste; slowing resource loops which involves ensure products last for longer and that opportunities for re-use are exploited; and closing resource loops which involves making sure that products are recycled at end of their (first) life as well as product repair and remanufacture. This conceptualisation echoes the common slogan: 'reduce, reuse and recycle'.

Figure 5 **One way of conceptualising the circular economy**



Source: (McCarthy et al., 2018)

5.2. Conventional benefits

There is strong evidence of all elements of the circular economy - narrowing resource flows, slowing resource loops and closing resource loops - can generate significant economic benefits, at least in specific sectors. For example:

- **In relation to narrowing resource flows, there is widespread evidence that there are significant savings available to firms, household and local authorities from improving their resource efficiency.** One 2017 study found that across the UK, there are around £5.7-£7.2 billion of savings available to firms from improving energy efficiency, reducing raw material consumption or the generation of waste or reducing water consumption, all of which have 'no or low cost'[10] (Oakdene Hollins, 2017). A complementary 2018 study, focusing on the chemicals, construction and metals sectors identifies financial savings associated with resource efficiency of £306m, £1,589m and £858m respectively (Oswald et al., 2018). In relation to both studies, while it is not

[10] This is defined as having a payback of less than one year.

possible to convert their findings into BCRs, their focus on no or low cost implications implies that these ratios would be high. A further study exploring initiatives to reduce food waste in the UK found that a nationwide initiative had generated financial benefits that were 250 times greater than its financial costs; that initiatives by London boroughs to reduce food waste returned a BCR of 92 (including benefits to households) and that for firms the BCR was around 14 (Hanson & Mitchell, 2017). These ratios all focused purely on financial benefits and cost including, in relation to households, expenditure savings that can contribute to improving household budgets. The inclusion of wider societal benefits, such as reduced GHG emissions, as well as any societal costs, would plausibly further increases these ratios.

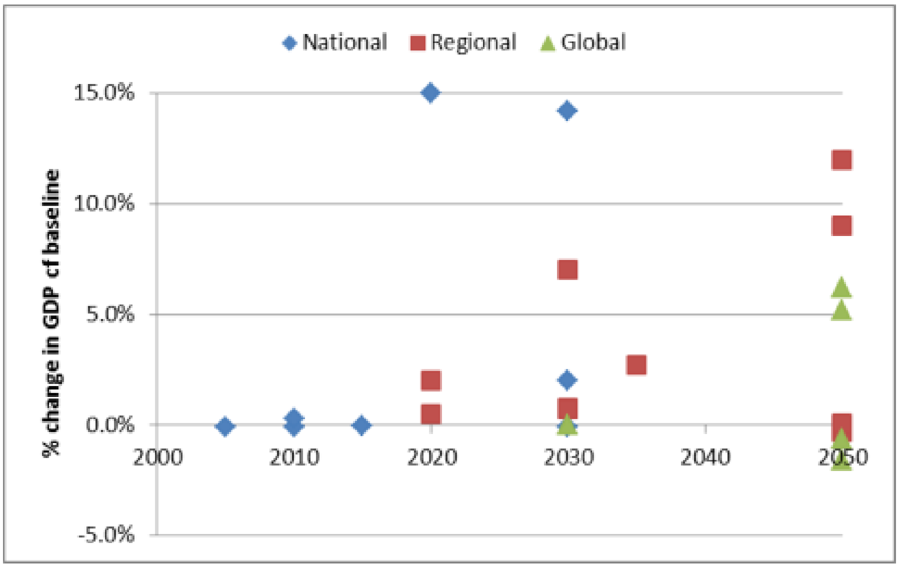
- **Similar findings existing in relation to slowing resource loops.** For example, a study looking at the global fashion industry – a sector which has been identified as having a particular need to become more circular – found that expanding the rental market for clothing so that each item was used for longer had a marginal abatement cost of around -US$4900/t$CO_2$ (-£3270/tCO_2 using PPP exchange rates) and that increasing the average length of clothing life from 3 years to 4 years by greater use of repairs has a marginal abatement cost of -US$300/t$CO_2$ (£200/ tCO_2) (McKinsey & Company, 2020). As with the studies above, it is not possible to express these findings in terms of a BCR but the fact that, even before the valuation of any emission reductions, these interventions have operating cost savings that easily offset any capital costs implies they are likely to have (very) high BCRs.
- **It is likely that the costs of closing resource loops are relatively higher than either of the above two elements but, nonetheless, benefits are likely to exceed costs.** Illustratively, the recent UK wide impact assessment to reform the UK's packaging producer responsibility system, placing the costs of managing packaging waste onto producers, which is expected to increase recycling (as well as encouraging packaging reuse and reducing excess packaging waste) has benefits that just exceed the costs, with a BCR of 1.01 (Defra, 2022). Similarly, a study examining the costs and benefits of recycling tyres in Europe at the end of their life found that this was likely to have a BCR of 1.52 -1.55 (Gigli et al., 2019).

The system-wide nature of the switch to a circular system means that many economic analyses have focused on its likely macroeconomic implications. Increasing circularity requires different interventions in different sectors, each of which carries different costs and benefits. This means that it is difficult to gain a comprehensive understanding of the attractiveness of the shift to a circular economy through studies of individual interventions. Many researchers therefore focus on what the wider macroeconomic implications of enhanced circularity. In particular, these studies allow the implications associated with decreased economic activity in resource extractive sectors to be taken into account.

An OECD review of this literature shows that the enhanced circularity is like to bring macroeconomic benefits (McCarthy et al., 2018)**.** Looking across a wide range of modelling analyses, the authors find that most studies report either aggregate economic growth is relatively unaffected or that enhanced circularity can deliver significant improvements in economic activity. Figure 6 provides the graphical summary of this analysis.

Figure 6 **Previous analyis suggest that the macroeconomic implications of the enhanced circularity**

are likely to be benign



Note: Geographic coverage – national, regional, global – refers to the area that results were reported for. Some models have global coverage but only report results for a particular region.

Source: (McCarthy et al., 2018)

However, the results of these macroeconomic analyses need to be treated with care. At least three considerations are important (Best et al., 2018):

- First, the typically positive impacts on GDP may be driven by different mechanisms in different macroeconomic models. In some cases, increased GDP may be the result of circularity improving productivity. These modelling results are broadly conceptually consistent with the more granular assessments looking at whether the benefits of particular circularity investments or interventions exceed their costs. In other cases, however, the positive economic impacts result from an expectation that the shift to a circular economy will allow for spare labour and other resources in the economy to enter into productive use. While these so-called demand side benefits may be important, especially when economies are not operating at full employment, they would normally be excluded from a conventional assessment of costs and benefits of government supported interventions (see Annex for more discussion).
- Second, some of the modelling assumes that the improvements in circularity do not require any costs to be incurred/investments to be made. For models which derive positive GDP effects from enhanced productivity, an assumption that these productivity gains can be delivered without the need for any investment would lead to economic benefits that may be implausibly high.
- Third, the focus on GDP within these studies means that they do not capture many of the benefits from the transition to a circular economy that would increase human welfare but which would not be reflected in GDP estimates, for example, reduced CO_2 emissions or reduced air, water and soil pollution.

A final set of economic analyses on the impacts of increasing circularity tends to find that it is associated with improvements in firm performance. For example, one study shows that, across a wide sample of European firms, increases in resource efficiency are associated with increases in market share, especially in firms in the waste management sector as well as the metals, paper and wood sectors (Flachenecker, 2018). These results has been corroborated in a more recent study (Darmandieu et al., 2021): in their analysis, the more that small and medium-sized enterprises (SMEs) adopt circular practices, the lower are their production costs, and that this impact is particularly large when firms have consciously made investments to improve the circularity of their business.

In summary, while it is difficult to express the conventional economic benefits of circularity in terms of (a range of) benefit-cost ratios, there is strong evidence for positive conventional economic benefits from increased circularity. The wide range of different activities and investments associated with enhanced circularity means that representative BCRs are difficult to establish, but there is good intervention specific evidence that, in most cases, benefits exceed costs. This is particularly evident for interventions associated with narrowing resource flows and slowing resource loops. These positive impacts are further reinforced by macroeconomic analyses of the implications of economy-wide efforts to enhance circularity, although these results should be interpreted with care. Finally, firm-specific evidence tends to find that firms that invest in circular business practices have lower costs and/or larger market shares than their peers.

5.3. Economic activity and employment benefits

Macroeconomic assessments tend to show that increasing circularity is associated with increasing employment opportunity. As an illustrative example, a study for the European Commission (Cambridge Econometrics et al., 2018) found that an 'Ambitious' scenario for moving towards a circular economy in the European Union[11], could lead to an increase in employment of around 0.3% (650,000 – 700,000 jobs). This assessment took account of increases in employment especially in the waste management sector, being offset by decreases in employment in the mining and extraction sectors and in manufacturing sectors that process raw materials. It further finds that this shift in employment will not have a transformative effect on the labour market in terms of requiring new skills development, with most of the new jobs supported likely to require generic transversal problem-solving and communication skills rather than a niche highly specialised skill set. The modelling analysis implicitly assumes that there are spare resources available within the economy. It does not provide a detailed geographic breakdown of the job growth potential.

The potential for waste recycling to support jobs is further illustrated in other studies. One study for the Trades Union Congress (TUC) found that the construction of plastic plants would be associated with 16.9 gross jobs per £m of annual investment. These are direct and indirect temporary jobs, focused only on the construction of the facilities, as such they are probably best considered as job-year benefits. Moreover, the estimate does not appear to take account of reduction in employment elsewhere in the economy, for example, those employed in exporting plastics (Minio-Paluello & Markova, 2020). The application of this ratio to the planned £20m investment in a new material recycling facility (MRF) in the City would imply around that

[11] The analysis focuses on five key sector (food products and beverages, motor vehicles, construction, electronics and electrical equipment and waste collection and treatment) with 'ambitious circularity' defined separately for each sector.

around 340 job-years would be supported during the construction phase of this plant. Another analysis suggests that there may be around 1-2.9 direct gross jobs supported for every 1,000 tons of waste recycled[12]; this estimate appears to focus on permanent jobs but without taking into account any potential that there could be reductions in employment elsewhere in the economy (Chapman et al., 2018).

A further recent study looks suggests the potential for a significant number of jobs to be support in the UK generally, and Scotland specifically, from adopting more circular business practices (Alvis & Avison, 2021)**.** It explored 3 scenarios for the potential growth of the circular economy in the UK by 2035, as shown in Table 5 below finding, as shown in Figure 7 that moving from a 'business as usual' scenario to a 'transformation' scenario could be associated with an additional 32,500 permanent jobs in Scotland by 2035, with this job growth particularly focused in remanufacturing. It suggests that these jobs will be particularly helpful in supporting the levelling-up agenda with elementary, process-plant and machine operatives and skilled trades occupations being particularly well represented in the new jobs being supported. Using a simple ratio that, at present, Glasgow City accounts for just over 18% of employment (by workplace) this would imply just less than an additional 6000 jobs in the city. The study takes account of potential jobs losses in extraction and manufacturing activities but does not attempt to assess whether the new jobs created would be filled by people previously unemployed or not (i.e. the figures relate to gross job creation).

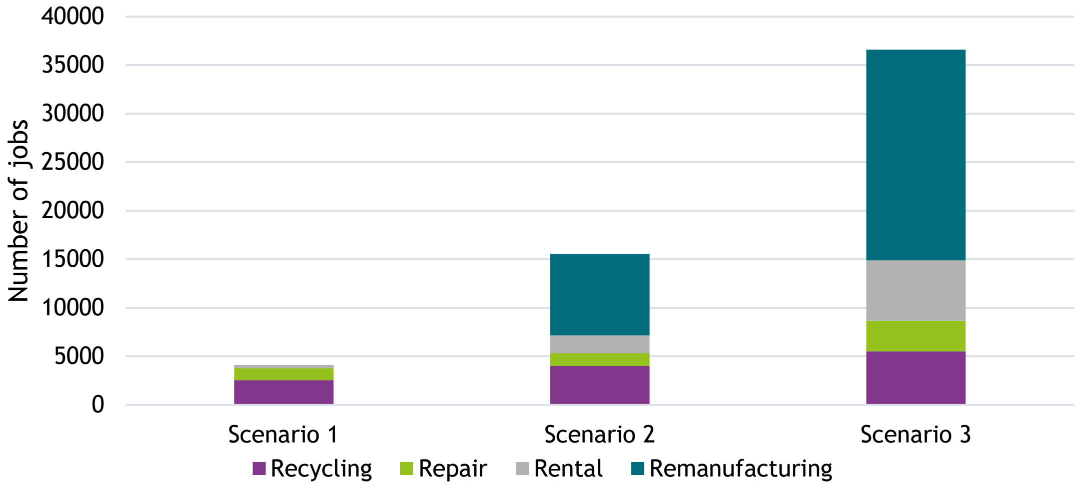
Table 5 Alternative scenarios for future circularity in the UK

	2019	2035 scenarios		
		Business as usual	Growing potential	Transformation
Recycling rate (all waste streams)	48%	65%	75%	85%
Remanufacturing rate	1%	1%	20%	50%
Reuse growth	0%	10%	10%	25%
Rental and leasing growth	0%	5%	30%	100%

Source: (Alvis & Avison, 2021)

[12] With higher jobs intensity for the recycling of municipal solid waste (2.9 jobs per 1000 tonnes) followed by commercial and industrial (1.5 jobs per 1000 tonnes) and construction waste (1.0 jobs per 1000 tonnes)

Figure 7 The adoption of more circular business practices could be associated with more than 32,000 additional gross jobs in Scotland by 2035



Note: Scotland data source from correspondence with report authors

Source: (Alvis & Avison, 2021)

6. Infrastructure and connectivity

6.1. Investment need/opportunity

This area of focus covers a range of different investment needs and opportunities. The key areas, and the associated evidence on the investments that are envisaged in the Glasgow City Region, relate to:

- Renewable heat networks - heat networks connect a (renewable) heat generating plant, often at neighbourhood level, to any combination of residential, commercial or public buildings. The Climate Change Committee (CCC) estimates that at a UK-wide level, to meet net zero by 2050, 18% of total UK heat demand is to be delivered through heat networks (with the underlying heat derived from low-carbon sources) (BEIS, 2020b), with modelling suggesting that this will need to be concentrated in urban areas where there is dense heat demand (Foster et al., 2015). Currently, only around 2% of national heat demand is met through heat networks. Within Glasgow, the Glasgow Greenprint envisages using the heat generated by the Glasgow Recycling and Renewable Energy Centre to support two heat networks: one at Polmadie which could also be connected to the second scheme in the Gorbals District. In addition, the Scottish Event Campus expansion, Climate Neutral Innovation Centre and Clyde Gateway projects all include plans to make extensive use of renewable heat. More generally, the River Clyde offers an abundant energy source with the section in line with the city centre capable of providing in excess of 250MWth peak or 2000GWh annually (invest Glasgow, 2021) while Swedish energy and heat provider Vattenfall plans to use this and other sources to connect 450,000 homes to heat networks in Glasgow by 2050 (Vattenfall, 2022). To support these investments, Glasgow City Council is in the process of developing its Local Heat and Energy Efficiency Strategy which will designate zones in the city for connection to renewable heat networks, as part of a wider plan to designate certain areas of the City as areas earmarked for novel approaches to infrastructure transformation (Slater, 2022) .
- Smart grids play a crucial enabling role in facilitating the decarbonisation of the electricity sector by supporting the adoption of technologies that allow electricity demand to be shifted in time (demand side response measures) which are essential for allowing a large scale increase in intermittent renewable electricity supply to proceed in a cost effective way. The Scottish Government's vision for the electricity sector foresees: 'the use of smart grid systems which create opportunities for flexibility and thriving local markets for both the generation and use of electricity' (Scottish Government, 2019). Specifically within Glasgow, the Scottish Event Campus has plans to develop a Smart 5G Micro-Grid (invest Glasgow, 2021).
- Smart meters act as complements to smart grid technologies providing real time information to customers and suppliers regarding energy consumption. This further supports flexibility and demand side response in the electricity sector; while the additional information makes it easier for consumers to reduce energy consumption. Since the start of 2022, all gas and electricity suppliers have had binding annual installation targets to roll out smart and advanced meters to their remaining non-smart customers by the end of 2025 (Ofgem, n.d.).

- Electric charging stations for low-carbon private transport which will facilitate the uptake of electric vehicles. Glasgow already has more electric charging points than any other local authority in Scotland (Callaghan, 2022). Further expansion coincides with the introduction of the 2nd phase of the Low Emission Zone from 2023, and will also support the Scottish government's ambition to phase out all petrol and diesel cars in Scotland by 2032.
- Broadband expansion which, among a range of other benefits, and alongside other digital technologies, can support more flexible working arrangements that reduce emissions associated with commuting, and improve the efficiency with which a wide range of assets can be used. As part of its Digital Housing Strategy, the City Council has committed to '*work towards ensuring all of Glasgow's population are connected to the internet and have a broadband connection and a consistent level of access to online services*' (Glasgow City Council, 2022b).

6.2. Conventional benefits

The expansion of heat networks can be expected to deliver a positive social return. For example, the UK government's impact assessment for the Green Heat Network Fund suggested that every £1 invested in green heat networks would, on average, deliver £2.40 worth of benefit (BEIS, 2020b). These benefits are primarily from the reduction in greenhouse gas emissions provided by heat networks, but are also driven by reductions in fuel costs and improvements in air quality. These latter benefits can be particularly valuable for deprived households. This analysis was undertaken before a recent upward revision in the value of GHG savings used by the UK government (BEIS, 2021c). The application of these higher values would further increase the BCR. It should be noted that these are values predicated on the development of heat networks in locations where there are suitable heat sources and a sufficiently dense heat demand.

The development of smart grids can generate a range of benefits. As well as the reduction in greenhouse gases, benefits can include (Jiménez & Filiou, 2012):

- reduced meter reading and operational costs
- a quicker detection of problems on the grid and less time between any breakdown and the restoration of supply
- deferred generation, transmission and distribution capacity and reinforcement investments
- reduced technical and commercial losses
- electricity cost savings; and
- reduction in air pollution.

A consultancy report commissioned by the Joint Radio Company in 2021 suggests that the nationwide introduction an electricity smart grid in the UK could deliver £12.7bn of net benefits (Gemserv, 2021). The greatest benefits are expected to be from avoiding network reinforcement and additional generation. It explores a variety of ways in which these benefits might be delivered, identifying the present value of costs being between £1bn and £2.4bn depending on the technology used. This implies a BCR of 5.2-13.2.

The value for money for the rollout of smart meter technologies has been controversial but the latest analysis developed by the Department for Business Energy and Industrial Strategy

(BEIS) still suggest that it still represents good value for money with a potential BCR of 1.9. A National Audit Office (NAO) report identified that the initial roll out of smart meters had encountered a number of difficulties, with significant technical delays preventing the expected roll out of the more advanced (SMETS2) smart meters, with particular problems in Scotland (National Audit Office, 2018). In response to these challenges, and as noted above, there has been a change in regulatory framework so that every energy supplier has been set an annual target for smart meter roll out. The impact assessment accompanying this regulatory change, and which takes account of the latest information on costs, suggests it would have a BCR of 1.9 (BEIS, 2021b). The analysis suggested that the highest benefits are associated with energy savings (implying lower energy bills, bring particular benefits for those in energy poverty), avoided site visits and environmental benefits, including the value of GHG savings. If the recent change in carbon price values was applied to this analysis then the BCR would be higher again.

It is difficult to calculate a BCR for the roll out of electric vehicle charging infrastructure. This is because it is difficult to separate out the costs and benefits of investment in charging infrastructure from the wider costs and benefits associated with the transition towards electric vehicles and the phase out of internal combustion engine vehicles (see section 4). However, a recent assessment of the benefits of a *planned* roll out of charging infrastructure in new non-residential car parks with over 10 spaces, so as to avoid the costs associated with subsequent retrofitting the infrastructure at a later point in time reported a BCR of 1.5 (Department for Transport, 2021).

Most studies investing the economic impacts of broadband rollout focus on its impacts on GDP (growth) and other macroeconomic variables, rather than calculating the (potential) benefits and costs. These studies tend to find that improves productivity boosting output, with, for example, a typical result being that a one percent increase in broadband adoption generating a 0.023 percent increase in GDP growth. In turn, these increases in GDP are associated with increases in employment, although some studies find that employment gains are concentrated among high-skill workers (Bertschek et al., 2016). There are fewer studies that explore the impacts of new generation broadband, offering faster speeds. However, one recent study found that a 1 per cent increase in adoption of end-to-end fibre-based broadband (over basic broadband) was associated with a 0.002-0.005 percent increase in GDP. The authors tentatively suggest that these results imply that 50% deployment of fibre broadband would deliver greater GDP than its costs, but that 100% deployment would not (Briglauer & Gugler, 2019).

Some consultancy studies provide estimates of the benefits for Glasgow and/or Scotland, but, for the reasons discussed below, these results need to be treated with care.

- A study by Oxford Analytica for Virgin Media O2 suggests that the UK achieving 'digital connectivity leadership', as measured using an index it constructs, could lead to an increase in GDP of £1.24 billion in the Glasgow City Region and £5.3 billion across Scotland as a whole. However, the robustness of the econometrics underpinning this analysis is unclear (Virgin Media O2 & Oxford Analytica, 2021).[13]

[13] Specifically it is not clear whether the authors control for the possibility that as well as digital

- A study by the Centre for Economics and Business Research for BT Openreach suggests that the roll out of full fibre broadband could lead to an increase of just over 75,000 people (re-) entering the labour force, boosting Scottish gross value added (GVA) by £1.9bn. However, the relationship between fibre broadband and economic participation is assumed rather than estimated (Openreach & Centre for Economics and Business Research, 2021).

Table 6 **summarises the key findings in relation to the conventional economic benefits associated with infrastructure and connectivity investments.**

Table 6 Indicative Benefit Cost ratios for infrastructure and connectivty opportunities

	Indicative Benefit Cost ratios
Heat networks	2.4
Smart grids	5.2-13.2
Smart meters	1.9
Electric charging infrastructure	1.5 (BCR relates to benefits from early versus late roll-out)
Broadband	Typical results expressed in terms of impact on GDP or GDP growth but with positive impacts ordinarily found.

6.3. Economic activity and employment benefits

An Institute for Public Policy Research (IPPR) study suggests that the construction of heat networks is associated with 15 jobs in that year (i.e. job years) for every million pounds of annual spending (Emden et al., 2017)**.** This analysis appears to include both direct and indirect jobs, but it is not clear whether it also includes induced jobs. This figure does not take into account any possibility of reduction of jobs from fossil fuel heat provision; it also does not take into account the possibility that those employed might have previously had employment elsewhere.

This suggests that the initial plans for Glasgow's heat network might support around 120 jobs per year, or just under 600 job-years. This assumes that the £40m associated with the heat network plan would be spent over 5 years, in line with the IPPR assumption. The exploitation of the heat from the River Clyde could potentially facilitate many more jobs.

There are three estimates that provide a sense of the employment that could be supported by smart grid investment:

- One US study finds that every US$1m of annual investment in smart grids in the US is associated with 6.76 direct and indirect jobs (3.66 direct, 3.10 indirect) in that year (Garrett-Peltier, 2017). Assuming the same structure between the US and UK and

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connectivity increasing GDP, GDP might also improve digital connectivity.

converting this to sterling would suggest that every £1m investment in smart grids would be associated with 10.12 direct and indirect jobs.

- A study by Monitor Deloitte for E.DSO and Eurelectric identifies a representative ratio of 12-17 jobs supported per million EUR invested, although the source for this is not identified. The report implies that this is direct and indirect jobs in the year in which the investment is made. In PPP terms, the EU and UK exchange rate is almost identical[14], implying the same rate per million GBP invested (Deloitte et al., 2021).
- Liebenau suggests that a £5bn one-off annual investment in smart-grids would support 173,500 jobs in that year, although in contrast to the above estimates this includes induced jobs as well (Liebenau et al., 2011) . This implies 34.7 jobs per £1m investment.

In summary, this suggests a range of between 10 (direct + indirect) and 35 (direct + indirect + induced) jobs in that year per £m of spend. These are all gross job estimates and do not account for the possibility that people may previously have been employed elsewhere. Many of these jobs will be in the construction industry.

Evidence on the jobs supported by smart meter deployment is more limited. The UK government reports that the deployment of smart meters in the UK – which, apart from in 2020, has been proceeding at a rate of around 4 million or more per year since 2017 – is supporting around 15,000 jobs. This is an estimate which appears to include the supply chain i.e. indirect jobs. It is a gross job estimate that does not account for the possibility that people may have been deployed elsewhere (BEIS, 2021b).

One recent study provides an indication of the jobs that might be associated with the deployment of public electric vehicle charging infrastructure. It identifies potential employment implications across the value chain. However, focusing on jobs associated with installation and maintenance, which are the jobs that are most likely to be within the local/regional economy, it finds that that an increase in the stock of charging points of ~40,000 might be associated with an additional 800 permanent jobs by the end of the period. These are gross job estimates (Thiel et al., 2019). This implies an additional 2 permanent installation and maintenance gross jobs for every 100 additional public charging points.

Finally, broadband deployment appears to offer a significant short-term employment support potential . Liebenau find that a one-off annual £5bn investment would be associated with 211,000 new jobs (76,500 direct jobs and 134,500 indirect and induced jobs) (Liebenau et al., 2011) in that year. This equates to 42.2 jobs in the year of investment per £m of annual investment (15.3 direct jobs and 26.9 indirect and induced jobs). This is around 33% higher than the same study estimates for smart grid investment. World Bank analysis shows that this finding is broadly comparable with those in other jurisdictions (Kelly & Rossotto, 2012). A more recent analysis, looking specifically at accelerated full fibre broadband rollout, suggested a slightly lower of ratio of 15.1 jobs in the year of investment per £m of annual investment, although this only focused on direct and indirect jobs (Minio-Paluello & Markova, 2020). All of these are estimate of gross jobs, and are expected to be heavily concentrated in the

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[14] OECD report a PPP exchange rate for the EU27 of €0.66:US$1 in 2021 while, as per footnote 6 the UK: US PPP exchange was £0.669:US$1 in 2021

construction sector.

Table 7 summarises the results of the review.

Table 7 Job intensity estimates for infrastructure and connectivty opportunities

	Job-years per £m of annual investment if available	Other estimate of job intensity	Implication for Glasgow
Heat networks	15 (direct + indirect; gross)		Expansion of heat network might support around 120 jobs per year, or just under 600 job-years
Smart grids	10 (direct + indirect; gross) – 35 (direct + indirect +induced; gross)		
Smart meters		Annual roll out of ~4m smart meters supporting around 15,000 direct and indirect jobs (gross)	
Electric charging infrastructure		100 extra public charging points associated with 2 permanent installation and maintenance jobs (gross)	
Broadband	15 (direct+ indirect; gross) - 42 (direct + indirect +induced; gross)		

7. Conservation, restoration and valuing of nature

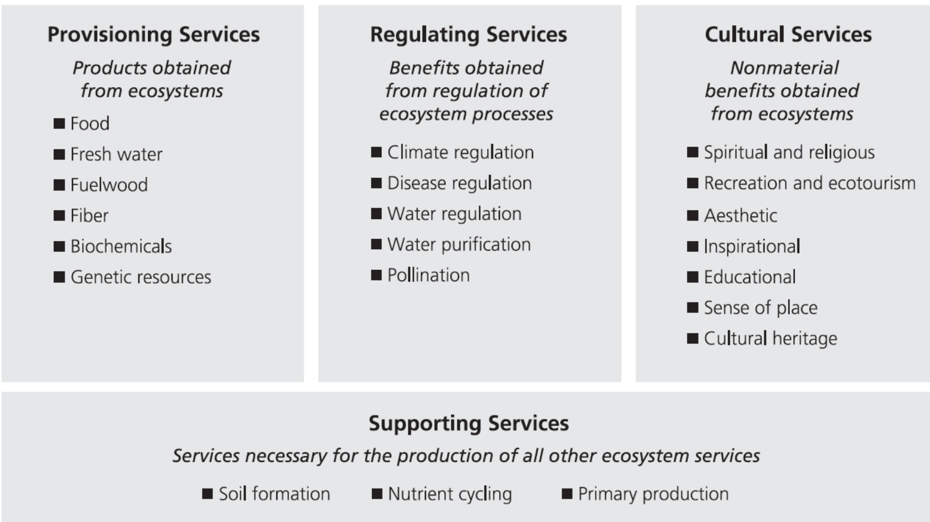
7.1. Investment need/opportunity

The natural environment (natural capital assets) in the urban environment provide a range of ecosystem services that can generate high economic benefits. These include provisioning services (e.g., food production), regulating services (e.g., carbon sequestration), and cultural services (e.g., recreation, well-being). Box 3 sets these out in more detail. However, these economic benefits are not fully recognised in market prices and decision-making processes which can lead to an under-investment in nature. These assets, services (and benefits) arise in a range of locations; they are not just from designated or protected sites.

The Green Deal includes a placed based priority for conservation, restoration and valuing of nature. This will help enhance these assets and services and help ensure the economic benefits are recognised. Note that the Green Deal action around forestry, including the Clyde Climate Forest, is included in the next section on residual emissions.

Box 3 Key terms related to the employment benefits associated with Green Deal investments

The economic benefit of nature is usually framed using the ecosystem service-based classification from the Millennium Ecosystem Assessment (see figure), i.e., Provisioning Services; Regulating services; Cultural Services and Supporting Services.



Natural capital is the elements of nature that directly or indirectly produce value to people. It includes ecosystems, species, freshwater, land, the air and oceans, as well as natural processes and functions. Natural capital provides the stock of assets, from which flows of benefits (ecosystem services) are generated.

There are different types nature-based investments that Glasgow can introduce: these include creation or restoration of nature sites, but also nature-based solutions and green infrastructure.

Investing in nature creation, restoration and maintenance includes activities such as peatland restoration and other efforts to enhance natural habitats. These can generate high economic benefits, for example, peatland restoration leads to high economic benefits from carbon sequestration, but also improves watershed management and can have positive benefits downstream.

However, investing in nature is broader - it also includes nature-based solutions and green infrastructure that can be used as alternatives to traditional engineered schemes. Nature-based solutions are actions that sustainably create, restore or manage, natural and modified ecosystems to address societal challenges, providing economic and biodiversity benefits (adapted from (IUCN, 2022)). Green infrastructure is a strategic, planned network of natural, semi-natural and artificial components that are designed and managed to deliver a wide range of ecosystem services and quality of life benefits (Fairbrass et al., 2018). Green infrastructure may be embedded in new developments or investment may be undertaken to upgrade existing green infrastructure or to retrofit existing assets with green infrastructure. Example investments include:

- Green spaces. This includes parks, playing fields, woodlands, wetlands. However, it can also include street trees or greening streets, converting paved places into green ones, reducing sealed surface, etc. These can have a wide range of benefits, from health and well-being to climate adaptation and resilience.
- Natural flood management. This includes schemes to reduce run-off or flood risk, either in upstream catchments, in coastal zones or estuaries, or in urban areas.
- Sustainable drainage systems. These involves smaller local schemes which mimic nature and typically manage rainfall close to where it falls. They can be designed to convey surface water, slow runoff down, or store water in natural contours and allow water to soak (infiltrate) into the ground or evaporate, and can reduce localised flooding.
- Green roofs and walls. These integrate nature into buildings, and which can have benefits from reducing winter heating and providing summer cooling.

The Green Deal indicates potential green infrastructure financing needs of £0.1 billion in total by 2030.

7.2. Conventional benefits

Investing in nature - across all of the different categories identified above - can provide numerous benefits for GCR. These include mitigation benefits, adaptation and resilience benefits, as well as broader economic, health and well-being improvements. Some of the most important benefits are (Matthews et al., 2015):

- Amenity and recreational benefits.
- Air quality improvements.
- Carbon sequestration (mitigation)
- Adaptation benefits, for example by reducing urban heat island effects and reducing water runoff and flood risks.
- Improved physical health and mental well-being (health).

Sometimes these benefits are reflected in market prices that can provide direct and indirect financial benefits. For example, values for assets in the built environment may increase following investments to improve the urban landscape.

There are high economic benefits from traditional conservation investments, such as creation, restoration and maintenance of protected and non-protected nature sites. Looking at the restoration of peatlands as one option being considered in the region, it is estimated that the annual benefits of peatland restoration could be over £400/ha/year (Glenk et al., 2018; Harlow et al., 2012). These values are driven by carbon sequestration benefits, but also include water management and broader biodiversity benefits. These high benefits lead to positive economic (societal) BCRs with the BCRs for investing in Scottish peatland restoration having been identified previously as being as high as 5 (Pettinotti, 2014).

Other UK Cities report high economic benefits from investing in nature in urban sites. Studies for Greater Manchester (Dennis & James, 2016) and Birmingham (Horlzinger et al., 2014) assessed urban green spaces and found they delivered high economic benefits. These arise from the combination of recreation benefits, flood regulation, water quality improvements, and more. These benefits increase further when carbon sequestration and air quality benefits are taken into account.

Investing in green infrastructure and nature-based solution can also deliver economic benefits. Many of these benefits derive from emissions reduction (and carbon sequestration). However, they also deliver adaptation and resilience benefits including flood management improvements while they can also play an important role in urban cooling, which will become important for Glasgow in the future. Quantification is site specific, but often (but not always) show positive economic benefits, albeit modest. For example, one study found positive BCRs for greening urban spaces of 1.5 (Mendizabal & Peña, 2017). Similarly, a cost-benefit analysis of five catchment-wide sustainable urban drainage system (SUDS) schemes in London and found BCRs of between 0.9 and 1.8 (Ossa-Moreno et al., 2017).

Investment in environmental conservation and restoration are likely to benefit vulnerable people the most. People who are socially, economically, culturally, or otherwise marginalised are especially vulnerable to climate change risks and other forms of environmental degradation. Restoration and conservation investment may therefore generate higher relative benefits for these groups.

There are, however, some caveats. Nature investments often take time to establish, meaning that benefits increase over time but which means they are perceived as relatively low when measured in present values terms. Green infrastructure may also include higher maintenance costs than traditional infrastructure investments. In urban areas, investments that involve land use change are expensive, because of the opportunity cost of land, and there can be issues around space availability.

Targeted interventions can address these barriers. Investments need to be carefully planned. For example, analysis in the GCR Adaptation Strategy suggests that costs could be reduced by targeting green infrastructure or green spaces (where appropriate) towards derelict sites (Climate Ready Clyde, 2021b).There may also be opportunities to blend green investments with traditional investment, for example, including SUDS schemes in planned developments.

In summary, the available evidence suggests BCRs of 0.9-2.1 for green infrastructure and nature-based solutions are typical, and that traditional conservation investments may have BCRs as a high as 5.

7.3. Economic activity and employment benefits

Investments in conservation and restoration of the natural environment have positive benefits on employment. Such investments prevent the loss of jobs that depend on ecosystem services, and may also contribute to job creation. One study found that 5 per cent of jobs in the UK rely directly on ecosystem services and hence on the effective and sustainable management of the environment. This includes jobs in farming, fishing and forestry, but also those that rely on natural processes (ILO, 2018).

Restoration and conservation activities support jobs, both directly and indirectly, with estimates ranging from 16 to 40 job years per US$ million invested, equivalent to 24 to 60 job years per £1m. One US focused study suggested that reforestation, land and watershed restoration and sustainable forest management can support up to 40 jobs per US$ million invested, including 18 direct, 13 indirect, and 9 induced jobs[15]. They also estimate that conservation activities (parks land and water conservation) creates up to 20 jobs per US$ million invested (11 direct, 4 indirect, 5 induced)[16] (Garrett-Peltier & Pollin, 2010). Slightly lower estimates are provided by Nielsen-Pincus and Moseley (2013) who found that a sustained program of restoration projects in Oregon in the US had resulted in a range of benefits in Oregon's economy including, on average, 16 jobs supported per US$ million dollars invested in ecological restoration (24 jobs per £1m) as well as increased local organizational capacity and business opportunities especially in rural areas (Nielsen-Pincus & Moseley, 2013). This appears likely to be an estimate of direct, indirect and induced jobs. A further study analysed 44 'blue infrastructure' restoration projects and found that, on average, 17 jobs were supported for every US$1 million (25 jobs per £1m) spent on these developments (Edwards et al., 2013). This was a measure of direct, indirect and induced jobs.

These benefits vary depending on location, geographic scale, and restoration type. BenDor et al. (2015) report the findings of the U.S. Department of Interior estimates of the economic impacts of its restoration investments. Based of input-output model for a sample of nine projects of different size (from several thousand dollars up to US$25 million), it was found that there was a very wide variation in the local economic effects, ranging from 5.8 to 27.2 jobs supported per US$1 million invested. The author suggests 'that economic impacts are not comparable across different geographic scales' (BenDor et al., 2015).

Recent studies have highlighted that nature-based solutions should be a key priority for post-COVID green recoveries. Recent studies identify three characteristics that investments for a 'good' green recovery should have (Hepburn et al., 2020), namely that they:

- can be introduced quickly;
- are labour-intensive in the short-run;
- have high economic multipliers in the short-term that extend in the long-run;

Natural capital investment (nature-based solutions for ecosystem resilience and regeneration

[15] The equivalent figures per £1m of investment are: total – 59; direct – 26; indirect – 19; induced – 9.
[16] The equivalent figures per £1m of investment are: total - 30; direct - 16; indirect - 6; induced - 7 (numbers do not sum due to rounding).

including restoration) are identified as having all three characteristics. Furthermore, most jobs needed for restoration and nature-based solutions require little training and provide an opportunity to quickly hire low-skilled workers such as in earthworks and landscaping (Jaeger et al., 2021), although there will also be opportunities for GIS specialists, hydrometric specialists, ecosystem monitoring specialists, ecologists, botanists, integrated water resource managers. There is significant between the occupations supported by this area of focus and those supported by the adaptation/resilience area of focus discussed below in section 9.

In summary, there is good evidence on the employment support potential from investments in this area of focus. As reported earlier, the Green Deal indicates potential green infrastructure financing needs of £100 million in total by 2030, equivalent to around £12.5m per year. Based on evidence drawn from literature, employment benefits could be in the range of 24 to 60 per £ million invested per year, or 300-750 jobs in each year of spend, with some of these jobs becoming permanent. However, more detailed analysis of specific interventions would be warranted, and the adjustments undertaken in more detailed analysis may lead to lower numbers.

8. Tackling residual emissions

8.1. Investment need/opportunity

Even if Glasgow is successful in rapidly decarbonising its economy, there are likely to be some GHG emissions that remain difficult to eliminate, especially in the short-medium term. These might include, for example, combustion emissions associated with the generation of high-grade heat in industrial activities. For the city to achieve net zero, it will need to address these residual emissions by removing carbon dioxide from the atmosphere at the same pace that activities that cannot be decarbonised are adding to atmospheric concentrations of GHG emissions. There are two main ways in which carbon dioxide removal (CDR) can be achieved:

- natural solutions, such as forestry, that sequester CO_2 as part of the process of photosynthesis; and
- technological solutions that use a range of man-made processes to remove CO_2 from the atmosphere.

An alternative approach to tackling residual emissions would be through offsetting. This is discussed in Box 4 below.

The Clyde Climate Forest represents one of the most important ways that Glasgow is tackling residual emissions. This envisages the planting of 18 million trees in the urban and rural parts of the Glasgow City Region. This consists of three components (GCV Green Network, 2021):

- Urban trees: the plans envisage that the average tree canopy cover in urban Glasgow will increase from 16.6% to 20%;
- Connected native woodlands: the targeted planting of 101 native woodlands to reverse habitat fragmentation; and
- New forests: up to 1000 hectares per year of new forest and woodlands across the region.

The total estimated budget for the forest is £107m. In addition, through the Climate Smart Forest Economy Programme in Glasgow intends to increase the use of climate smart forest products by catalysing demand in sectors where these products can generate significant emission reductions, such as construction. This is expected to enhance the long term sustainability of expanding forest cover in the region (Climate-KIC, 2022).

On an absolute basis, Glasgow's ambitions match - and indeed exceed - those recommended as being needed for the UK as a whole. The Climate Change Committee has identified that tree cover should increase from 13% to 17% at least, which requires planting approximately 30,000 hectares of woodland each year (Committee on Climate Change, 2020a). For its duration, the Clyde Climate Forest intends to deliver up to 3% of this target, despite the land area of the Glasgow City Region only accounting for 1.4% of the UK's land area[17].

[17] Glasgow City Region land area: 3,338km^2, United Kingdom land area: 242,495km^2

CDR might also be achieved using technological solutions. Examples of technological CDR include:

- Bioenergy with Carbon Capture (Use) and Storage: CO_2 that is sequestered in biomass which is then combusted to generated energy, with the associated CO_2 then captured and either stored or used without entering the atmosphere[18].
- Direct air capture: artificially separating and capturing CO_2 directly from the atmosphere
- Enhanced weathering: using minerals to absorb atmospheric CO_2. This might be achieved by crushing rocks that react with CO_2 and spreading them on the land.
- Ocean liming: dissolving lime or crushed minerals into the ocean to increase its alkalinity so that it absorbs more CO_2.
- Bioplastics: manufacturing plastics by using biomass e.g. microalgae, that absorb CO_2.

At present, there are no specific plans for deployment of CDR technologies in the Glasgow City Region. The Committee on Climate Change net zero roadmaps envisages technological (or engineered) contributing to around 55 $MtCO_2e$ of removal by 2050, approximately 10% of current emissions (Committee on Climate Change, 2019a).

An additional way in which many organisations intend to reach their net zero goals is through the use of offsets. This involves the purchase of certificates which correspond to emission reductions/removals outside of the area for which that organisation is responsible. For Glasgow, this would relate to the purchase of certificates associated with emission reductions and removal beyond its geographic area. Offsets are a potentially cost-effective way for organisations to reach their net zero goals but have also proved to be controversial. Box 2 discusses the Oxford Offsetting Principles (Allen et al., 2020) which have been developed to guide organisations in purchasing offsets in a way that is consistent with their, and broader global, net zero ambitions.

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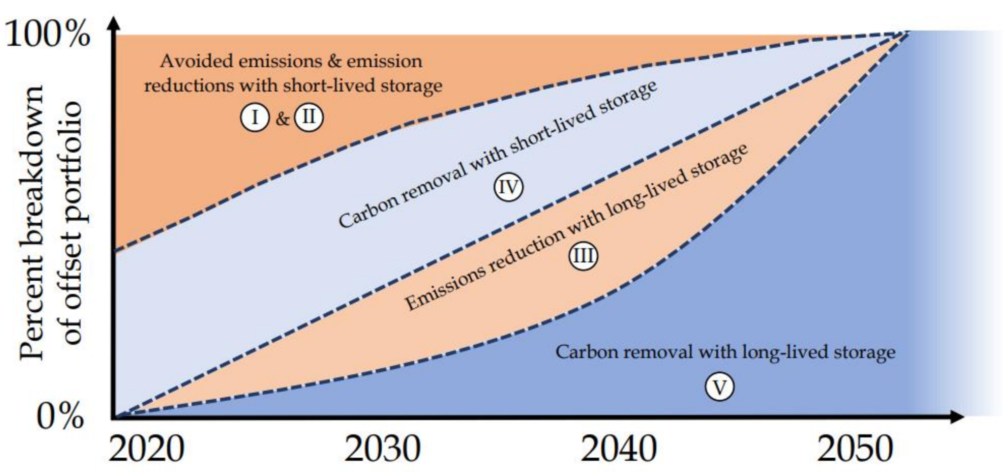
[18] Note that carbon capture use and/or storage (CC(U)S) of CO_2 emissions derived from sources other than biomass does not constitute CDR as in this case, the CC(U)S is only preventing an increase in carbon dioxide concentrations in the atmosphere, rather than reducing concentration.

Box 4 Oxford offsetting principles

The Oxford Principles for Net Zero Aligned Carbon Offsetting (the 'Oxford Offsetting Principles') aim to set out the principles that need to be followed in order that its use helps achieve a net zero society. It consists of 4 principles.

1. **Cut emissions, use high quality offsets, and regularly revise offsetting strategy as best practice evolves.** This requires that organisations prioritise emission reduction as much as possible and only use offsets for hard to reduce emissions. It also requires that organisation focus on purchasing high quality offsets implying that they are verifiable and have been correctly accounted for, have a low risk of non-additionality and reversal, and avoid creating negative unintended consequences for people and the environment. Organisations should also be transparent
2. **Shift to carbon removal offsets over time.** Reaching net zero requires the large scale expansion of carbon removal from the atmosphere. This principle requires that offset purchasers consciously support this requirement by purchasing offsets associated with removals.
3. **Shift to offsets with long-lived storage.** In addition to switching towards carbon removal, this principle requires that the atmospheric removals are stored in ways that are likely to be close to permanent rather than where there is a reasonable probability that the emissions could be returned to the atmosphere within decades. This principle requires an increasing focus on offsets associated with options that store CO_2 in geological reservoirs or mineralising carbon into stable forms, rather than storage in trees and other biological reservoirs.
4. **Support the development of net zero aligned offsetting.** This relates to supporting principle 2 and 3 by using long-term agreements, forming alliances, and supporting the restoration of natural habitats for their intrinsic benefits (so as to ensure that principle 3 does not lead to reduced focus on ecosystem protection.

The chart below shows the stylised implications of principle 2 and 3 to offset portfolio composition.



Source: (Allen et al., 2020)

8.2. Conventional benefits

Forestry projects generally, and urban forest projects specifically, can deliver a wide range of benefits. These include carbon sequestration[19], improvements in air quality, the aesthetic and amenity value that people attach to forests, biodiversity, noise reduction, increased economic activity from the sustainable harvesting of wood products, and tourism. However, there are also a range of costs associated with trees and forest projects, especially in urban settings. This includes not only the direct cost of planting and maintenance, but also the indirect cost including damage to buildings and pavements by tree roots, damage and injury from falling trees, disruption to traffic during maintenance, carbon emissions through operating machinery, blockage of drains by leaf litter.

Most studies identify that the benefits of forestry projects exceed their costs, perhaps delivering a BCR of 2.5-3. For example:

- A comprehensive review of 34 studies exploring the benefits and costs of urban forests, with a strong skew to the US, found that the median benefit: cost ratio across the different studies was 2.72 (with the mean of 5.43). The most significant benefits included the aesthetic/amenity value of the urban forests, the shading/cooling function, and their role in regulating water and improving air quality (Song et al., 2018).
- A UK-focused study looking at afforestation projects generally, not specifically in urban areas, found a BCR of 2.79, almost exactly the same as the ratio identified above. However, this likely underestimates the full benefits of afforestation as it only captures the carbon sequestration, recreation and air pollution benefits of forestry, excluding benefits associated with improved water quality, reduced flood risk, increased biodiversity, noise regulation or temperature regulation (Dicks et al., 2020).[20]

The planting of individual trees with street settings may be somewhat lower. A 2018 study found that, over 50 years, urban trees planted using a 'RootSpace system', which ensures uncompacted soil for root development and growth may deliver a BCR of 1.5, but that street trees planted without this system were unlikely to deliver benefits greater than their costs (GreenBlue Urban, 2018)[21].

There are no detailed studies exploring the costs and benefits of technological CDR. The CCC estimates that the abatement cost of technological CDR may be up to £300/tCO_2, although there is a high degree of uncertainty around these estimates. This is lower than the UK government's central estimate for carbon values from 2035 onwards implying that, if the CCC's cost estimates are realised, technological CDR projects delivering emission reductions after 2035 would have a positive BCR.[22]

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[19] Although the emission reduction benefits require trees to remain standing, and the flow of carbon sequestration slows as trees reach maturity.
[20] In addition, this study used the UK government carbon price values recommended at the time, which are lower than those currently in place.
[21] Analysis based on figures in Table 1 of this source.
[22] It is important to note that in an important sense this result is 'by design' as the carbon price series for use in appraisal has been set on the basis of what is likely to be required in order for the

In summary, the evidence suggests BCRs of around 1.5 for the planting of individual trees in urban settings, rising to 2.5-3 for urban forest creation or restoration.

8.3. Economic activity and employment benefits

Studies identify that tree planting and ongoing maintenance of woodlands could support modest additional employment and gross value added (GVA). Table 8 presents evidence from the most recent UK-focused study exploring this issue and its implications for the Clyde Climate Forest. This suggests that each year of planting of the forest could be associated with 250 jobs and boost GVA by £12.2m, and that the ongoing maintenance of the forest would be associated with 540 job-years, boosting GVA by £28.2m. Placing these figures in the context of the GVA of the Glasgow City Region in 2017, each year of planting could be associated with an increase in Glasgow City Region of 0.03% and that ongoing maintenance of the Clyde Climate Forest could lead to a 0.07% increase in GVA compared to that seen in 2017. These figures include both direct, indirect and induced effects and do not account for any loss in employment on the land that becomes forested. However, they are net jobs, accounting for the wider macroeconomic impacts associated with increased spending on forestry. While not stated explicitly in the underlying study, it is plausible that the direct jobs associated with the planting and maintenance of the forest would not require specialised skills.

Table 8 The GVA and employment impacts associated with forestry projects are modest

	Jobs supported per 100 hectares	GVA per 100 hectares	Jobs supported by Clyde Climate Forest (max)	GVA supported by Clyde Climate Forest (max)
Tree planting	25 temporary jobs in year of plant	£1,221,900 (in year of planting)	250 temporary jobs in each year of planting	£12,219,000 in each year of planting
Ongoing maintenance (assuming maintenance needed for 100 years)	6 job years	£313,900 per year	540 job years	£28,251,000 per year when all planting complete

Source: (Dicks et al., 2020)

UK to hit its net zero target.

9. Adaptation and resilience

9.1. Investment need/opportunity

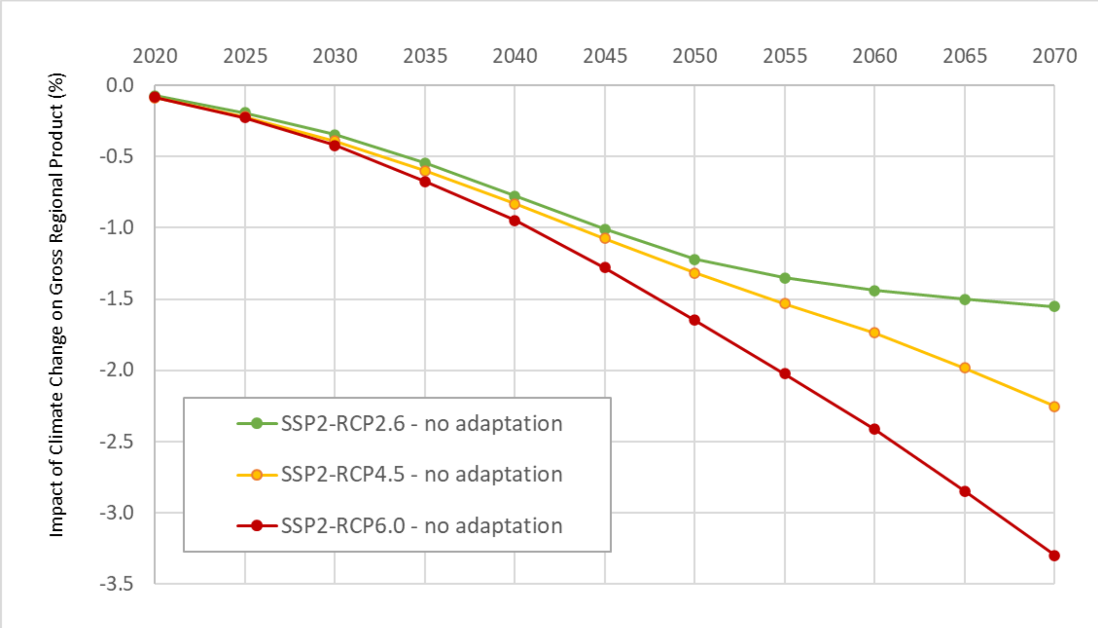
Climate change is an important economic, financial, and social risk for Glasgow City Region. Previous work for Climate Ready Clyde assessed these risks, undertaking a GCR Climate Risk and Opportunity Assessment in 2018 (Climate Ready Clyde, 2018). This identified approximately 70 risks and opportunities in the region, split across six themes.

An initial study assessed the potential economic costs of these risks in terms of social welfare, considering both market and non-market impacts (Watkiss & Hunt, 2019). This concluded that the future economic costs of climate change in GCR are likely to be dominated by river, surface and coastal floods, leading to property damage for residential houses, business and industry, and damage to infrastructure. It also found that many of these economic impacts will disproportionately affect socially deprived and vulnerable groups. The analysis also identified potentially significant economic costs (non-market) from increasing heat extremes (health related mortality and morbidity) in the longer term. However, the analysis also found that economic benefits for the City Region. These are dominated by the financial and economic benefits of reduced winter energy use for heating, for both the residential sector and business/industry, as well as reduced cold related impacts, for both market sectors and to health and well-being.

Subsequent work as part of the Glasgow City Region Adaptation Strategy and Action Plan estimated the total economic costs for the Region (Climate Ready Clyde, 2021b). This used a macro-economic model to estimate climate change impacts in terms of the percentage impact on regional GDP[23]. Figure 8 presents the main results.

[23] These results were developed using a Computable General Equilibrium (CGE) model. As such they capture the impacts of climate change on GDP. There may be additional costs associated with climate change not reflected in GDP that are therefore not captured in this modelling analysis.

Figure 8 Economic Costs as a % of Regional GDP for South Western Scotland



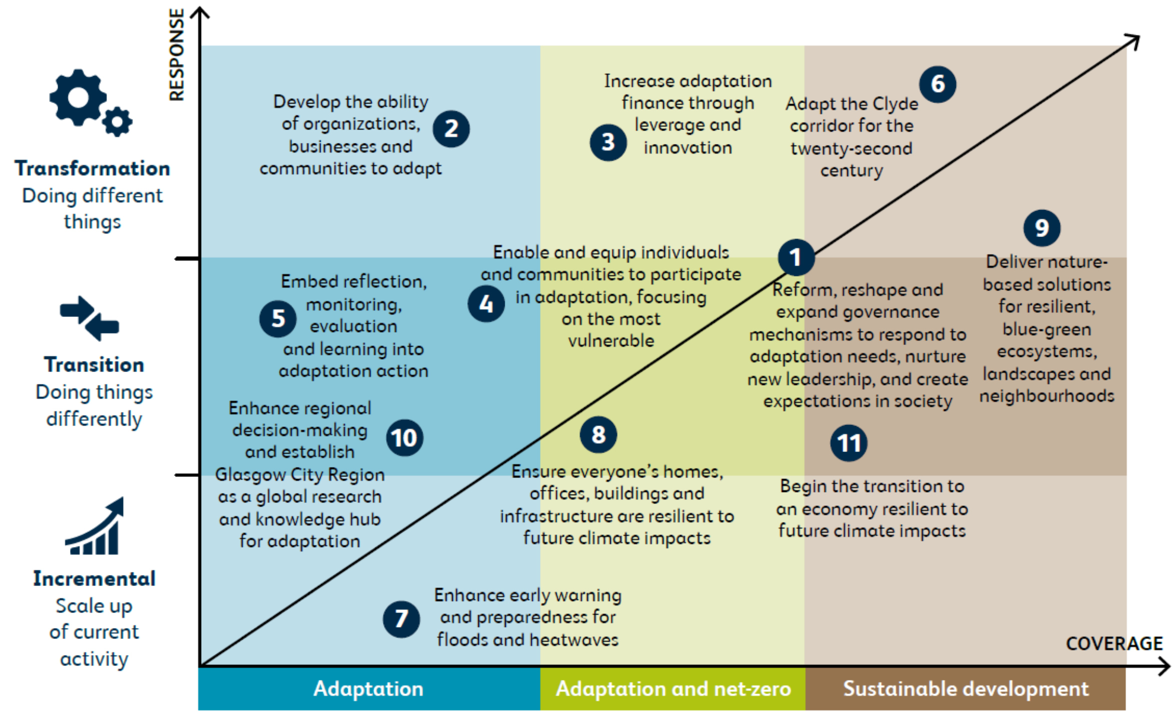
Source: (Climate Ready Clyde, 2021b)

This indicates that the economic costs of climate change in the Glasgow region could be 0.3 to 0.4% of regional GDP in 2030, rising to approximately 1.0 to 1.3% of regional GDP by 2045. The ranges reflect low and high warming scenarios, respectively (RCP2.6 and RCP6.0). Importantly, there is little difference between the low and high scenarios in the next twenty years, indicating important climate change impacts are already locked-in to the system.

The near-term impacts of climate change in Glasgow City Region can be reduced with adaptation. The same analysis also estimated that adaptation could reduce these the annual damage costs shown above significantly – probably by an order of magnitude. In recognition of these threats and opportunities, one of the eight place-based ‘areas of focus’ identified in the Glasgow Green Deal is for delivering adaptation and resilience.

The Green Deal sets out the priority for adaptation and resilience measures is to implement the Regional Adaptation Strategy in its entirety. This Strategy provides the strategic direction for Glasgow City Region through to 2030 which is intended to realise a vision of a city that flourishes in a future climate. It set out 11 interventions supported by 42 sub-interventions. Figure 9 shows these 11 interventions, using a matrix that considers the type of adaptation, from incremental to transformational, and the nature of the intervention, from adaptation focused to wider sustainable development.

Figure 9 Interventions in the GCR Adaptation Strategy



Source: (Climate Ready Clyde, 2021b)

There has not been a detailed analysis of the financing needs for delivering the Adaptation Strategy, although an initial resource mobilisation plan exists (Climate Ready Clyde, 2021c). However, an initial assessment (Climate Ready Clyde, 2021a) looked at the potential adaptation finance needs for the region by combining Local Authority level and National Health Service board spending from the Scottish Local Government Finance Statistics and applying an adaptation cost mark-up on top of current finance flows. This suggests an adaptation gap of around £187 million/year. The Green Deal is broadly in line with this indicating potential adaptation and resilience financing needs of £1billion in total by 2030.

9.2. Conventional benefits

A growing number of studies that find adaptation delivers high economic (societal) benefits. While adaptation is context- and site-specific, there is growing evidence that adaptation can deliver positive economic benefits, as captured in benefit-to-cost ratios (Global Commission on Adaptation, 2019). In its Climate Change Risk Assessment 3 advice report, the CCC identified the economic (societal) benefit to cost ratio of adaptation. It undertook a review and found many early adaptation investments deliver high value for money, with benefit-cost ratios typically in the range of 2 to 10 (Climate Change Committee, 2021).

There are certain adaptation actions that deliver high economic benefits in the short term; these should be the focus for the adaptation and resilience actions in the Green Deal. There are challenges with identifying and selecting the highest value for money adaptation measures. First, many of the benefits of adaptation arise in the future when climate impacts are higher. Second, there is considerable uncertainty around the level of future climate impacts, and thus around the benefits that adaptation will deliver. To address these issues, a greater focus has been put on prioritizing early adaptation where there can be confidence that there will be net economic benefits. This approach was used as part of the UK Climate Change Risk Assessment (CCRA3) (Watkiss & Betts, 2021). It identifies three priority investments:

- To address the current adaptation gap with ‘no-regret’ or ‘low-regret’ actions that reduce risks associated with current climate extremes and variability, as well as building future climate resilience.
- To intervene early to ensure that adaptation is considered in near-term decisions that have long lifetimes and therefore reduce the risk of ‘lock-in’, such as for major infrastructure. This can include the use of decision making under uncertainty concepts (i.e. flexibility, robustness).
- To fast-track early adaptive management activities, especially for decisions that have long lead times or involve major future change. This can enhance learning and allows the use of evidence in forthcoming future decisions (option value.

The 11 interventions of the GCR Adaptation Strategy to 2030 align with these priorities, creating a portfolio of investments, in line with best practice[24].

There are high economic benefits associated with the GCR Adaptation Strategy. An analysis of the eleven interventions in the GCR Adaptation Strategy, as shown in Figure 10 found the direct interventions in the Strategy (e.g., flood resilience, nature-based solutions, heat alert and flood warming, and capacity building) would all generate positive and high BCRs. It was not possible to quantify the BCRs of all of the interventions, notably those associated with process and governance, but these are necessary to address market failures, and thus act as enablers to deliver the wider economic benefits of adaptation across the strategy (Climate Ready Clyde, 2021c).

Figure 10 **Indicative Economic (Conventional) Benefits for GCR Adaptation Strategy**

[24] The three ‘building blocks’ each involve a different timescale of risk and investment. No- and low-regret options are implemented now and deliver benefits now. Addressing lock-in involves immediate decisions now, but targets risks that will arise in the future. Early adaptive management seeks to inform future investment for future risks. While all involve some action in the next five years, the nature of investment is very different.

Interventions

Intervention	Economic case	Illustrative cost benefit ratios
1 Reform, reshape and expand governance mechanisms to respond to adaptation needs, nurture new leadership, and create expectations in society	Good (enabling activity)	
2 Develop the ability of organisations, businesses and communities to adapt	Good (enabling activity)	>10:1 in climate sensitive sectors
3 Increase adaptation finance through leverage and innovation	Very Good (enabling activity)	
4 Enable and equip individuals and communities to participate in adaptation, focusing on the most vulnerable	Strong	
5 Embed reflection, monitoring, evaluation and learning into adaptation action	Good (enabling activity)	
6 Adapt the Clyde Corridor for the twenty-second Century	Strong	6:1
7 Enhance early warning and preparedness for floods and heatwaves	Very Strong	10:1
8 Ensure our homes, offices, buildings and infrastructure are climate resilient	Strong	4:1 (infrastructure)
9 Deliver nature-based solutions for resilient, blue-green landscapes and neighbourhoods	Strong	3:1 (indicative)
10 Establish Glasgow City Region as a global research and knowledge hub for adaptation	Good (enabling activity)	
11 Begin the transition to a climate-resilient economy	Good (enabling activity)	
Overall Adaptation Strategy	**Strong**	**Positive BCR**

Source: (Climate Ready Clyde, 2021c)

The analysis show the high potential economic costs and benefits of the eleven interventions. Whilst it has not been possible to create an overall cost-benefit ratio, the individual interventions all show a positive economic case, and where BCRs are quantified, these are vey high, ranging from 3 to 10 for proposed interventions. In general, adaptation and resilience is expected to benefit people with low income the most, as for them, even the modest changes expected in future decades due to climate change could have important impacts on household budgets, especially under higher warming scenarios (Watkiss et al., 2016) . Vulnerable groups such as people with disabilities, the elderly, and children - who are usually the most-hard hit by extreme events - will also significantly benefit from adaptation and resilience interventions.

9.3. Economic activity and employment benefits

There is evidence that adaptation investment can prevent the loss of many jobs due to climate change, and support new employment. A study for the European Commission estimated that adaptation-related expenditures associated with the European Union (EU) Adaptation Strategy would create or support around 500,000 additional jobs in the EU by 2050, directly and indirectly, and that the adaptation measures would save some 136,000 jobs that would otherwise be lost because of the negative impacts of climate change (Triple E Consulting, 2014).

Adaptation and resilience investments will benefit some sectors more than others. The sectors most often included in adaptation strategies, including the GCR Adaptation Strategy, are infrastructure (including energy infrastructure), water (including flood-prevention measures), agriculture (including forestry, fisheries and husbandry), biodiversity conservation, and health (ILO, 2018). This means that most of the jobs expected to be created or supported are in business, public services and the construction sector.

Investment to build or enhance the resilience of infrastructure has positive impacts on employment and economic activity. Analysing employment data in Europe and globally, one study found that that output and employment multipliers of infrastructure investment can be substantial. In the UK, they estimated that the construction sector has an output multiplier of 4.9, and an employment multiplier of 20.7 for every £ million invested in the sector (Ernst & Sarabia, 2015). A further study, looking at the local economic impact of flood-resilient infrastructure projects in U.S. metropolitan areas from 2003 to 2018 and found that every US$1 million investment is associated with an increase of 40 jobs in the construction and retail trade industries, with 25 in the construction industry and 15 in retail trade. The equivalent figures for £1m, using current PPP exchange rates, would be 60 total jobs, 37 construction jobs and 22 retail jobs[25]. Interestingly, the authors found that, the job gains in the retail trade sector were more likely than those in construction to be sustained two to three years after. However, they also found evidence of significant regional heterogeneity. Flood-resilient infrastructure was also found to encourage the formation of new businesses (four per 1 US$ million invested equivalent to six per £1m invested) and have a positive impact on local businesses and therefore local economies (Kahn et al., 2019).

The Glasgow City Region already benefits from a burgeoning 'adaptation economy'. There a range of business opportunities associated with the supply of adaptation goods and services. Recent work for the Glasgow City Region has identified these are already an important part of the regional economy (kMatrix & Climate Ready Clyde, 2019) . The analysis focused on twelve economic sectors that underpin the adaptation economy[26]. The total sales for adaptation and resilience economic activities that can be directly related to climate change in Scotland were estimated at £604m in 2016/17, with Glasgow City Region contributing £146m. In terms of employment, the study estimates that Glasgow City Region is home to companies providing these goods and services, employing around 8,390 people (2016/17 data).

The Adaptation Strategy is likely to have further positive economic and employment benefits, though benefits will be concentrated in some sectors. Table 9 provide a qualitative review of the 11 interventions of the strategy to assess likely impacts on economic activity and employment. All interventions are expected to generate economic activity by supporting those sectors that provide adaptation services (e.g., consulting, finance). Many interventions will have employment impacts, although mostly as a second order effect i.e. employment associated with creating the enabling environment that allows investment in adaptation and resilience infrastructure. Direct job creation/support will likely arise from those interventions that require investment in infrastructure to increase resilience, including blue and green infrastructure for flood protection.

[25] Figures do not sum due to rounding.
[26] Agriculture & Forestry; Built Environment; Disaster Preparedness; Energy; Health; Health Care; ICT; Natural Environment; Professional Services; Transport; Waste and Water

In addition, by reducing climate impacts, all adaptation and resilience interventions will contribute to protecting the livelihoods and jobs of the Glasgow City region inhabitants from the impacts of climate change.

Overall, the analysis identifies that the Adaptation Strategy and Action Plan is likely to have positive outcomes for employment in Glasgow City Region. The Green Deal indicates adaptation and resilience financing needs of £1 billion in total by 2030 or around £125m per year. The level of jobs associated with this investment will vary with each of the 11 interventions in the Strategy - with evidence from the United States suggesting 20 to 60 jobs be created or supported per £million invested per annum in flood-resilient infrastructure, for example, although more detailed analysis would be required for specific interventions and this may lead to somewhat lower numbers as discussed in Box 2. Nonetheless, overall, the case is strong for investment in adaptation and resilience having positive employment benefits for the region, in addition to directly benefiting the region's inhabitants by mitigating the risk of climate change-induced events.

Table 9 The qualitative economic and employment effects associated with adaptation and resilience

Interventions	Actions	Private sectors involved	Economic activity	Impact on employment
Intervention 1. Reform and reshape governance mechanisms so they respond to adaptation needs, nurture new leadership, and create expectations in society	A detailed review of a new institutional landscape needed for adaptation A broader coalition of actors mobilised to deliver the strategy Adaptation leadership that is nurtured and developed News, arts, media and cultural organisations telling stories about the climate crisis and opportunities to adapt	Consulting Media	Enabling environment	Mostly 2nd order effect Improved governance facilitates future investment in adaptation
Intervention 2. Develop the ability of organisations, businesses and communities to adapt	An enhanced programme to increase awareness of the potential impacts of climate change on organisations and communities and opportunities to adapt Establishment of a public/private sector working group / forum and mentoring programme	Consulting Academia	Enabling environment	Mostly 2nd order effect Raising awareness can in turn lead to increasing investment in adaptation
Intervention 3. Increase adaptation finance through leverage and innovation	Strategic use of public sector funds to attract private sector investment A Regional adaptation finance strategy and action plan Mapping and measurement of regional adaptation finance flows Piloting of new approaches to transformative adaptation finance	Consulting Finance	Enabling environment	Mostly 2nd order effect Raising finance will increase adaptation investment
Intervention 4. Enable and equip communities to participate in adaptation	Increased community involvement in the region's governance, decision making, and adaptation planning Resource, training and education for communities and young people to shape their places Collaborations between organisations, communities and artists and cultural practitioners to stimulate creative and relevant adaptation responses with new actors and communities	Consulting Education and Training	Enabling environment	Possible increase in demand for adaptation "trainers" and "experts"
Intervention 5. Embed reflection, monitoring, evaluation, and learning	Foster a learning culture within the City Region to increase the impact of interventions, and to enable citizens to hold organisations to account through a process of monitoring and	CSOs, NGOs	Enabling environment	Mostly 2nd order effect

into adaptation action	evaluation To build networks that further develop relationships with comparably vulnerable Cities and Regions around the world to exchange knowledge and learning			
Intervention 6. Adapt the Clyde Corridor for the 22nd Century	Work through Mission Clyde to govern climate risks for entire river corridor Develop an iterative adaptation pathway for the Clyde which includes long term management of coastal, river and surface water risks, and prioritises the use of natural solutions, such as green and blue infrastructure To raise the resilience of the River Corridor as a national priority, and in frameworks such as the forthcoming Regional Spatial Strategy	Consulting (x-sectors)	Enabling environment	2nd order effect, from prioritisation of green and blue infrastructure
Intervention 7. Enhance early warning and preparedness for floods and heatwaves	Extension of the flood warning scheme in Glasgow City Region. The implementation of a Heat Health Warning System for Glasgow City Region A regional property flood resilience and resistance installation programme Exploration of new insurance models	Consulting Insurance Construction Media	Direct investment	Medium/High, particularly from regional flood resilient and resistance installation programme
Intervention 8. Ensure our homes, offices, buildings and infrastructure are climate resilient	Adaptation embedded in City Region's net zero transition Creation of an adaptation forum for City Region infrastructure Adaptation of existing infrastructure at risk, with policies and regulation to require all new investment to be climate resilient Strengthening of adaptation requirements in the planning system Creation of a regional retrofit framework for climate resilience Creation of a framework for adapting cultural heritage assets Lobby UK and Scottish Governments to reform infrastructure investment frameworks	Consulting Construction	Enabling environment and direct investment	2nd order effect (e.g. from strengthening planning system requirements), plus 1st order effect from adaptation of existing infrastructure (e.g. retrofitting existing infra)

Intervention 9. Deliver nature-based solutions for resilient, blue-green landscapes and neighbourhoods	Delivery of the regional Strategic Green Network Restore ancient native and semi-natural woodland –the Forestry and Woodland Strategy Creation of the Clyde Climate Forest Support for local infill and expansion of nature-based solutions Delivery of large-scale green and blue infrastructure projects to demonstrate benefits to communities Develop and accelerate Green and Blue Infrastructure financing	Landscaping and groundskeeping Forestry Consultancy (environmental consultancy, engineers, geologists, biotechnologists) Construction Scientists Administrative positions Heavy equipment operators Helicopter pilots Mining and quarry workers Nursery workers Project managers	Direct investment	1^{st} order effect
Intervention 10. Establish Glasgow City Region as a global research and knowledge hub for adaptation	Enhanced adaptation research through open invitation to collaborate on publicly available research priorities Glasgow City Region established as a living lab for climate adaptation providing a platform for academics to conduct research into climate resilience and adaptation Develop proposals for a centre of expertise in applied adaptation focused on research into practice	Academia Research Institutes Consultancy (engineers, lawyers, biologists etc)	Direct investment and enabling environment	1^{st} and 2^{nd} order effect
Intervention 11. Begin the transition to a climate-resilient economy	Adopt a climate smart regional economic development approach Deliver a transition that nurtures adaptation skills Climate-resilient supply chains, as part of a net zero, circular economy Develop a Small and Medium-sized Enterprises (SME) support plan	Consultancy (economics, finance, supply-chain expertise)	Enabling environment and direct investment (e.g. funding to SME)	1^{st} and 2^{nd} order effect

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Pengwern Associates is a UK-based consultancy specialising in the economics of climate change, the environment, international development and the linkages between them. Across these areas, it provides advice to support strategy development, decision-making and implementation, drawing on both quantitative and qualitative analysis.

Pengwern Associates was founded in 2018, as a lean and flexible consultancy to collaborate with others across the world to address some of today's most intractable environmental and social problems.

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