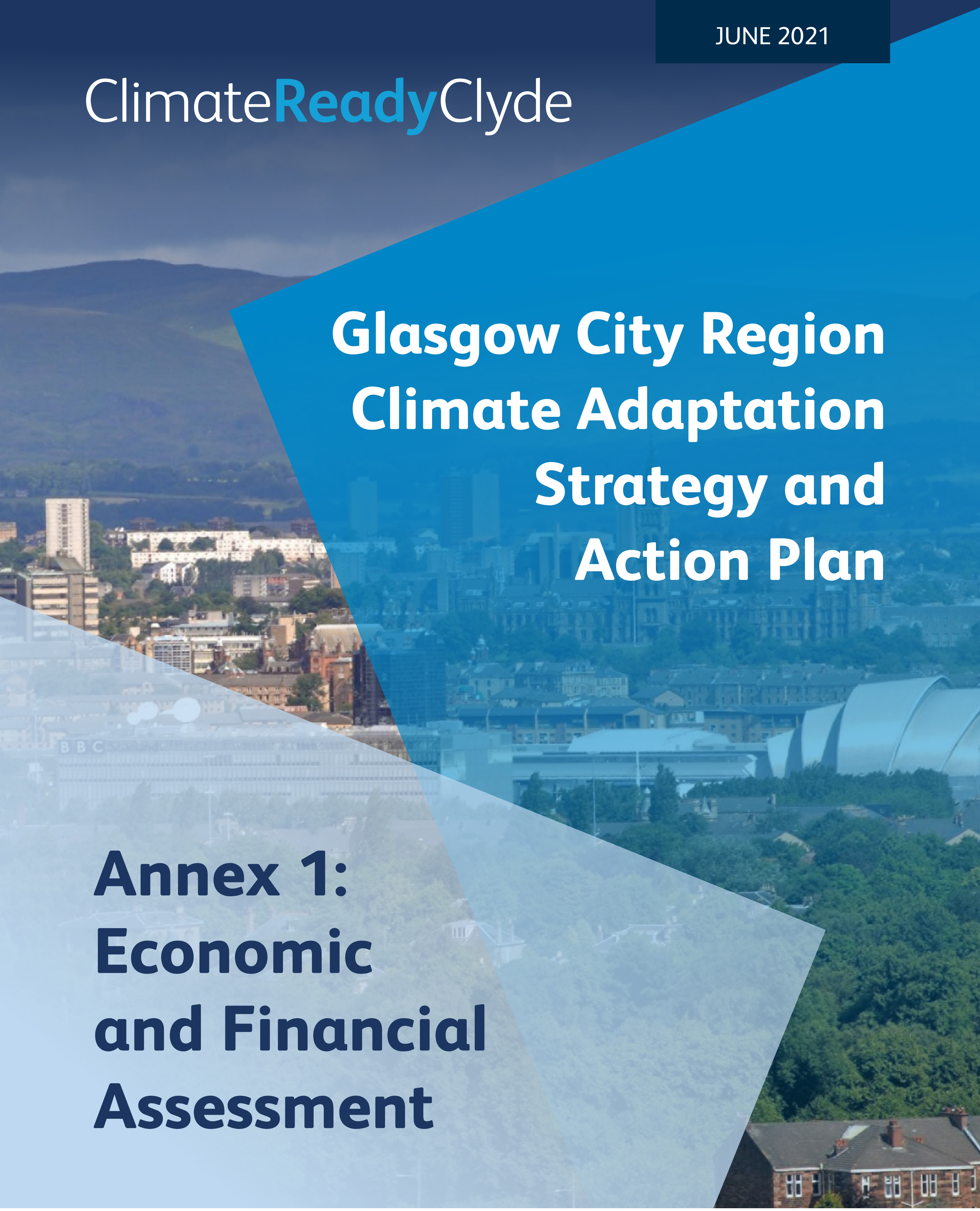

JUNE 2021

ClimateReadyClyde

Glasgow City Region Climate Adaptation Strategy and Action Plan

Annex 1: Economic and Financial Assessment

sniffer
knowledge brokers
for a resilient Scotland

creative carbon scotland

Climate-KIC
Co-funded by the European Union

Paul Watkiss Associates

Deep Demonstration
Resilient Regions
GLASGOW CITY REGION
Clyde Rebuilt

Funded and produced on behalf of the following organisations:

Produced by:

Resilient Regions: Clyde Rebuilt

Resilient Regions: Clyde Rebuilt is a project seeking to catalyse a transformational approach to addressing the impacts of climate change in Glasgow City Region. It is led by Climate Ready Clyde (CRC), a regional climate initiative made up of stakeholders from the City Region, with technical, cultural, economic and governance expertise from Sniffer which supports CRC. It also has cultural expertise and understanding of creative arts in sustainability from charity Creative Carbon Scotland, specialist climate change and economic expertise from research consultancy Paul Watkiss Associates and EIT Climate-KIC. The project is funded by Climate Ready Clyde's fifteen members and EIT Climate-KIC, Europe's leading climate innovation initiative. The project developed Glasgow City Region's Adaptation Strategy and a transformational adaptation portfolio blueprint.

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EIT Climate-KIC's Deep Demonstrations

Unprecedented systemic crises threaten existing communities and future generations and will require urgent global action and collaboration. Regions are often responsible for (decentralised) resilience and adaptation planning and implementation, but they face multiple climate related shocks and stresses which affect their communities, landscapes and economies in different ways.

The need for climate adaptation and resilience strategies to address ongoing challenges, change the status-quo of 'reactive' climate measures and cope with more and increasing climate-related disasters, has given rise to the opportunity to focus on enabling and investing in climate resilience holistically.

EIT Climate-KIC's Deep Demonstrations accelerates learning about how to change the world in the context of urgency, diversity and radical uncertainty. They are inspirational examples of what's possible, have been designed to create a transformative impact and ultimately seek to achieve rapid systemic change, for the benefit of all citizens.

The *Forging Resilient Regions Deep Demonstration* works to accelerate the transition from climate-vulnerable to climate-resilient regions, where people, communities, and systems are able to withstand shocks and slow-onset stresses and transform into flourishing communities.

Contending that 'Business as usual' innovation is not delivering climate action fast enough, Deep Demonstrations use systems innovation to generate options and pathways for radical transformations. It starts with a demand-led approach, working with regional governments committed to fundamental transformation to a net-zero emissions, resilient future. It offers a fresh approach to innovation, combining research, entrepreneurship, education, policy, technology and sustainability, to maximise the potential for change in places and across value chains.

Deep Demonstrations involve an iterative, non-linear four-phase process of Intent, Frame, Portfolio and Intelligence.

The Deep Demonstration iterative process

In Intent, we listen to understand local or sectoral challenges and current commitments with regard to resilience and decarbonisation. We collaboratively develop the regional transformation vision through deep listening activities, workshops and interviews with government bodies, businesses and communities. By bringing together as wide an array of stakeholders as possible, we learn about what creates the fastest pathways to change in regions.

In Frame, we map out the relevant systems (which we want to transform) to identify where and how innovation can play a role in catalysing change. The outcome is a Portfolio Blueprint, with a series of leverage points that can address barriers and opportunities through innovation.

In Portfolio, we build and manage a portfolio of connected innovations designed to address the leverage points identified in earlier stages.

In Intelligence, we generate actionable insights and intelligence to inform decision-makers, provide feedback loops and accelerate learning about how to achieve transformation at scale.

Contents

Summary

This Annex presents the findings on the Economic and Financial Assessment of Transformative Adaptation, supporting Glasgow City Region's Adaptation Strategy and Action Plan. The work has been undertaken under the Clyde Rebuilt project. The aim has been to undertake a high-level analysis of the economic and financial benefits of adaptation (in Glasgow City Region) at the portfolio and position scale. The activities and findings are summarised below.

Economic barriers

The project activities in this area commenced with a literature review on the economics of adaptation, assessing the potential economic barriers to adaptation, and investigating potential solutions. This highlighted two key challenges for adaptation. First, the uncertainty around future climate change, and thus the uncertainty for delivering adaptation benefits, which poses additional hurdles for the economic and financial case. Second, the timing of adaptation, which reduces the economic and financial attractiveness, because future adaptation benefits are low in present value terms, when compared to up-front adaptation costs. The review also identified the solution space to address these, which is centred on iterative adaptive management and identified early building blocks that build the economic case for interventions.

Economic costs of climate change, and costs and benefits of adaptation in Glasgow City Region

The analysis has assessed the economic costs of climate change in Glasgow City Region, building on the previous Glasgow City Region Climate Risk and Opportunity assessment.

This study has first assessed the potential macro-economic costs of climate change in the region. **The analysis indicates economic costs of approximately 0.3 to 0.4% of regional GDP in 2030, rising to approximately 1.0 to 1.3% of regional GDP by 2045, for a low and high warming scenario respectively (RCP2.6 and RCP6)**. These impacts are dominated by flooding (all sources). The economic costs of climate change rise significantly after mid-century, rising but stabilising at below 1.5% for a low warming scenario (RCP2.6), however, they rise very significantly (and continue rising over time) for higher warming scenarios, exceeding 2% of GDP (RCP4.5) and 3% for RCP6.0 by 2070. The study has then focused down on three of the largest impacts and undertaken further analysis of the economic cost of climate change for Glasgow City Region.

- **Coastal, river and surface floods.** The annual cost of flooding (expected) in Glasgow City Region is currently estimated at around £70 million, split broadly evenly between the three sources: coastal, river and surface floods. An analysis of future climate change estimates these costs will rise significantly with climate change, and with both climate and socio-economic change included, they could increase by around £100 million/year by the 2050s, over current levels, with much higher impacts in a warmer scenario in the late century. The project has also assessed the potential costs and benefits of adaptation. This shows the large benefits that adaptation can have, e.g. with potential benefits of £30 million/year even in the 2050s.

- **Heat related mortality and high temperature.** The current costs of heat extremes are currently low in Glasgow City Region, but expected to increase by 2050, when it is projected a heatwave could occur once every other year. The economic analysis here indicates this could have economic costs of around £100 million/year (including the non-market effects on health and well-being). The analysis has also assessed the potential costs and benefits of adaptation, and this finds that these future costs could be reduced by 40% at low cost through early warning and public health responses.

- **Benefits from reduced winter heating demand.** Winter heating demand dominates energy use in Glasgow City Region, primarily through gas use, and is a major household and business expenditure item. Future warming from climate change will generate a benefit by reducing future heating demand. This has been estimated at a potential economic benefit of around £100 million/year by 2050. However, the new commitment to net zero will mean that gas will be replaced by hydrogen or electric heating. There will still be economic benefits from reduced winter heating demand, but the exact estimates are more uncertain as the net zero pathway is unclear. There is also a need to consider the potential effects of household overheating (and thus climate resilient houses) under net zero commitments for building energy efficiency.

Economic costs and benefits of the Adaptation Strategy Interventions

The analysis has assessed the potential economic costs and benefits of the 11 Interventions in Glasgow City Region's Adaptation Strategy and Action Plan, which includes the Portfolio Blueprint. Whilst it has not been possible to create an overall cost-benefit ratio, the individual Interventions have been assessed to generate the economic case.

- **Interventions 1, 2 and 4** are focused on governance changes, information provision, and capacity building, across various actors (government, private and communities). While these are more difficult to assess in terms of their economic benefits, a review of the literature finds there is a strong economic and financial case for these actions. The analysis finds that these Interventions have economic benefits, as they generate downstream economic benefits from the use of information and improved decisions. These will far outweigh their costs, and these Interventions are considered low-regret. The review also finds that working through community organisations – as proposed– is a highly effective approach for adaptation. All of these governance and capacity building interventions will, however, require public finance for funding.

- **Intervention 3**, on increasing adaptation finance, is a cross-cutting Intervention, and will help scale-up the finance to deliver all the Interventions above and below. The availability of finance is an obvious and important constraint to adaptation. The nature of the adaptation investment – often with the characteristics of public goods and/or without fully commercial revenues – means that there is a need to create funding mechanisms to combine both private and public resources. The economic and financial case for such action is extremely strong, as a small public investment in this area could generate a large potential volume of finance, crowding in private and third sector finance. This is set out in the Resource Mobilisation Plan (Annex 3) and deliverable in Clyde Rebuilt (DEL 06).

- **Intervention 6** on adapting the Clyde Corridor has a strong economic case and there is a justification for the Government to intervene in supporting coastal and river flooding adaptation, especially using a planned iterative spatial approach. This will reduce losses and increase the efficiency of investment along the corridor. The economic benefits of flood adaptation far outweigh the costs, with the literature reviewed identifying a ratio of 6:1 (i.e. for every £ invested, there are £6 of economic benefits generated). The planned pathway approach has been tested in other regions, with positive economic appraisal results. Historically, flood protection has been funded by the public sector, recognising the public good characteristics. However, there is potential for increasing private sector finance, using a range of potential models, from direct funding through to blended public-private models, and insurance.

- **Intervention 7** on enhancing early warning has an extremely strong economic and financial case. A review of the literature finds economic benefit to cost ratios for these Interventions are typically around 10: 1. They are therefore no-regret options. The study has undertaken new analysis on a heat early warning (heat alert) system and finds this would have a high benefit to cost ratio in the Region. Early warning systems are typically funded by government, because of their public goods characteristics. This

Intervention also assessed household resilience and resistance measures. An analysis of the potential economic benefits of these measures find they are highest for new buildings, and this indicates a possible focus on new houses. There is a greater potential for private financing of these measures, though blended schemes may be needed if this is extended to retrofit properties. Finally, the Intervention considered new insurance models. Insurance is a valuable risk spreading mechanism, but without widespread adaptation, the current models face challenges because of increasing extreme events. Further development of these new models therefore has a strong potential for private financing.

- **Intervention 8,** making infrastructure and the built environment climate resilience also has a strong economic and financial case. The literature review has found that the benefit to cost ratios for these Interventions are typically around 4: 1, and even higher for critical infrastructure (e.g. electricity, water supply, key transport routes) because of the risks of cascading effects. The economic case for enhancing resilience to floods is very strong, especially given current impacts. The economic case for addressing future heat in buildings is usually good, especially for new buildings, but further analysis is needed at the local level to confirm this given the cool climate of the Region. While public/grant funding can create the enabling environment and regulatory framework for adaptation in this area, and clearly has a role for public infrastructure, this is a further area where there is a high opportunity to look for private sector finance.

- **Intervention 9** on nature-based solutions (blue-green) has a strong economic case. This arises from the adaptation benefits (flood reduction or heat reduction), but also their wider economic benefits from improved amenity and recreational value, health and mental well-being, social cohesion, air quality improvements and CO_2 sequestration. This also leads to good benefit to cost ratios, however, many of these benefits are non-market in nature. These solutions are most effective in reducing low levels of flooding (or modest reductions in heat), and thus may need to be complemented with other forms of adaptation, such as in grey-green portfolios. The fact that many benefits are non-market in nature means that the financial case for nature-based solutions is lower than the economic case, which makes them less attractive from a private investment viewpoint. However, there are some options to encourage other investors, with payment for ecosystem services, or the use of challenge funds or cross-subsidies.

- **Intervention 5, and Intervention 10** on monitoring evaluation and learning, and on establishing Glasgow City Region as a global research hub, both have a strong and linked economic case. The cycle of adaptive management, i.e. research, piloting, innovation, monitoring, evaluation and learning, has an economic value and generates economic benefits, because it leads to different actions, and generates higher benefits or lower costs as a result. Such activities can therefore be seen as a low-regret action. The development of Glasgow City Region as an innovation hub also offers potential economic benefits, from publicly funded research, from the positive spill-overs and multipliers this can generate (as captured in the literature on the green Entrepreneurial State). While public finance will be important, especially for the evaluation and learning components, there is a potential for crowding in private and third sector funding to the innovation space.

- **Intervention 11** focuses on the transition to a climate-resilient economy, particularly working with the private sector. Businesses and individuals will take action when the benefits of doing so are clear to them, and the benefits outweigh the costs. However, that is not always the case, and there is a role for the Government to play in removing barriers, e.g. lack of information, coordination problems. Such action is likely to be a low-regret option, and the economic case for such action is strong. These benefits are likely to be particularly important for SMEs, as they may not have the capacity or resources to invest. There is a further set of benefits from considering supply chains, as these involve inter-dependent and international risks, which may mean individual private sector actors will struggle to take the appropriate actions. Glasgow City Region could play a role in removing barriers to enable and encourage private sector adaptation, particularly through the provision of information and awareness raising.

PART 1 Introduction

Resilient Regions: Clyde Rebuilt is a project seeking to catalyse a transformational approach to addressing the impacts of climate change in Glasgow City Region (GCR). It is led by Climate Ready Clyde[1] (CRC), a regional climate initiative made up of stakeholders from the city region, with technical, cultural, economic and governance expertise from Sniffer which supports CRC. It also has cultural expertise and understanding of creative arts in sustainability from charity Creative Carbon Scotland, and specialist climate change and economic expertise from research consultancy Paul Watkiss Associates. The project is funded by CRC's 15 members and Europe's leading climate innovation initiative, EIT Climate-KIC.

The project recognises that current incremental adaptation is not delivering at the scale and pace needed to address the climate challenge. This requires a new urgency and there is a need to consider more fundamental shifts to new approaches and systems. The project has four key aims, to:

- Develop a Vision and Theory of Change for Adaptation in the City Region;
- Develop Glasgow City Region's Adaptation Strategy and a transformational adaptation portfolio blueprint;
- Develop an adaptation solutions portfolio using an iterative approach (with learning); and
- Develop a portfolio of bankable projects and look to scale-up with potential investors.

The project has been developed around addressing the barriers and constraints to adaptation, working across three domains: i) economic and financial, ii) policy institutional and governance, and iii) social, behavioural and cultural barriers to adaptation.

This report presents the findings of the Economic and Financial Assessment of Transformative Adaptation and is Deliverable 5 of the Clyde Rebuilt project (and also published as Annex 1 of the GCR Adaptation Strategy). The aim of this deliverable has been to undertake a high-level analysis of the economic and financial benefits (including co-benefits) of transformative adaptation (in Glasgow City Region) at the portfolio and position scale. The work has supported the development of Glasgow City Region's Adaptation Strategy and Action Plan and is published as an Annex to the Strategy.

1 Climate Ready Clyde (CRC) is a regional climate partnership, made up of stakeholders from the City Region. It includes eight local authorities, the Scottish Environment Protection Agency (SEPA), Strathclyde Partnership for Transport (SPT), Glasgow and Strathclyde Universities, Scottish Gas Networks (SGN), NatureScot and NHS Greater Glasgow and Clyde.

The Clyde Rebuilt Definition of Transformational Adaptation

The Intergovernmental Panel on Climate Change (IPCC, 2014), defines adaptation as 'the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects'.

It defines **transformational adaptation** as adaptation that changes the fundamental attributes of a system in response to climate and its effects, as compared to incremental adaptation, which are actions where the central aim is to maintain the essence and integrity of a system or process at a given scale.

Deliverable 10 of the project has undertaken a detailed literature review, and produced a synthesis, 'what is transformational adaptation?' This finds that there is no commonly agreed definition in practice, i.e. transformational adaptation means different things to different people and communities of practice.

For the Clyde Rebuilt project, the following working definition has been developed.

Transformational adaptation involves changing existing approaches, altering governance arrangements, and addressing underlying causes of climate risk or vulnerability. It may also involve re-thinking the future vision of the region, including the societal, cultural, institutional, ecological, and physical changes needed, as well as the region's political economy. Transformational approaches call for systems thinking and socio-institutional analysis, and offer the potential to deliver a larger, more sustainable, permanent, long-term change. Source Clyde Rebuilt (Watkiss and Cimato, 2020).

Objectives and Structure of the Deliverable

This report (Deliverable 5 of the Clyde Rebuilt project, Annex 1 of the GCR Adaptation Strategy) is focused on the ‘Economic and Financial Assessment of Transformative Adaptation’. The aim of the deliverable is to undertake a high-level analysis of the economic and financial benefits (including co-benefits) of transformative adaptation at the portfolio and position scale.

The project commenced with a literature review on the economics of adaptation, assessing the potential economic barriers to adaptation, and investigating potential solutions. However, immediately after the initial literature review, near the start of the project, the COVID-19 crisis occurred. In response, the study stream undertook early work to undertake an analysis and produce a scoping paper to influence the post COVID stimulus packages in Glasgow City Region. This was published as a separate paper (COVID analysis Delivering a Green Recovery/Green New Deal Post-COVID-19: Opportunities and priorities for a Glasgow City Region response).

Following this, work continued on the economic analysis, aligned to the Adaptation Strategy and Blueprint Portfolio.

The deliverable is set out as follows.

- The deliverable starts with the background context and literature review findings on the potential economic and financial barriers to adaptation.
- It then presents a high-level analysis of the potential economic costs of climate change in Glasgow City Region, and the potential costs and benefits of adaptation, building on previous economic analysis for Glasgow City Region.
- The analysis then focuses on GCR’s Adaptation Strategy – produced as part of Clyde Rebuilt, and assesses the potential costs and benefits of the eleven Interventions.

PART 2 Economic and Financial Barriers and Solutions to Adaptation

There is a recognition that there are barriers or constraints that make it difficult for individuals, businesses and governments to plan and implement adaptation actions (Cimato and Mullan, 2010: Moser et al., 2010: Klein et al., 2014), including in the urban context.

These various barriers can make it difficult to make decisions or take action, even when it is clear that action is needed (Cimato et al., 2017). They can, for example, constrain the means for adaptation, increase costs, and reduce incentives, including for urban adaptation (Oberlack and Eisenack, 2014). Addressing these challenges is therefore key for successful adaptation implementation and for the Clyde Rebuilt project.

These barriers can sometimes be so large as to limit or prevent adaptation, i.e. such that incremental adaptation options cannot be implemented over a given time horizon to achieve objectives, maintain values, or sustain current systems. In these cases, these barriers could act as a trigger for *transformational* adaptation, or to put it another way, only transformational adaptation can overcome these constraints (noting in extreme cases, even transformational options may come up against hard adaptation limits).

These barriers or constraints to adaptation include (Adger et al., 2007) physical and ecological limits, technological limits, financial barriers, information and cognitive barriers, and social and cultural barriers, though other typologies have been developed (e.g. Klein et al.., 2014). For the Clyde Rebuilt project, we have grouped barriers and constraints into four broad areas:

- Uncertainty;
- Economic and financial;
- Policy, institutional and governance; and
- Social, behavioural and cultural.

The second of these is the focus of this workstream, though it is stressed that all four need to be considered together to enable transformational adaptation.

While these barriers apply to all adaptation, some barriers are greater for transformational change, notably because of the greater resistance (including psychological) to transition shifts, as well as the challenge in visioning and delivering these transitions (and their benefits), the (typically) larger costs, and the greater level of change threatening existing power dynamics (Chung, 2015).

Economic and Financial Barriers to Adaptation

In terms of the economic barriers to adaptation (HMG, 2013: LSE, 2016), there are a range of market failures that make adaptation challenging. These are grounded in welfare economic theory and its underlying principles. In this case, barriers to (efficient) adaptation broadly correspond to market failures (HMT, 2018), or those factors that prevent the private sector from delivering socially efficient adaptation, and therefore justify government intervention.

The presence of uncertainty translates through to imperfect information (a market failure) (HMT, 2018), and acts as a barrier to the adaptation of both public authorities and the private sector (individuals and firms): when public or private actors have inaccurate, incomplete or uncertain information they are therefore unable to make the most appropriate adaptation decisions, or in some cases, any decision at all. As well as a lack of information, there can also be asymmetric information (Cimato and Mullan, 2010).

A major economic barrier for adaptation is over public goods and externalities: many adaptation actions have public goods or non-market dimensions that the private sector is unlikely to invest in (e.g. large-scale flood defences, health protection). To put another way, by acting rationally in their own interest, individuals or organisations will base their adaptation decisions on private costs and benefits, not those that are best from a societal perspective, and will not seek to generate gains for others (and may even lead to maladaptation by transferring risks to others). These issues are important and act as a constraint to adaptation.

There is a difference between the economic versus the financial case for action, which leads to underinvestment by the private sector. For example, ecosystem-based adaptation is very attractive from a social welfare (public) perspective, because of the large environmental benefits, but these are non-market benefits and are therefore not as important from the financial (private investor) perspective (ECONADAPT, 2017). **It is the role of government – including local and regional government – to address externalities and deliver adaptation investment with the nature of public goods.**

There are also potential barriers around misaligned incentives, where the costs of adaptation fall on certain individuals, while the benefits accrue to others, e.g. between property owners and tenants in building adaptation measures (Cimato et al., 2017). The market structures in place, whether these are monopoly, oligopoly or perfect competition, shape the incentives and affect the investment decisions on climate change adaptation, and may incentivise adaptation, and/or lead to over- or under-adaptation due to distortions (Fankhauser et al., 1999).

In terms of longer-term (including transformational) adaptation, the nature of public economic appraisal acts as a further barrier, because the present value of future adaptation benefits is low due to discounting, and this makes it more difficult to justify short-term integration investment to deliver longer-term change (OECD, 2015).

The availability of finance is also an obvious and important constraint to adaptation. Globally, there has been a major uplift in climate finance flows for mitigation in recent years. Data from the Climate Policy Initiative (CPI, 2019) reports that global public finance flows for adaptation were US$30 billion/year in 2017/8. Almost all of this was from the public sector (although data on private adaptation finance flows are poor). However, this can be contrasted with the potential costs of adaptation and thus adaptation financing needs (UNEP, 2018), which are estimated at an order of magnitude higher even by 2030, i.e. hundreds of billions. What is also interesting is that adaptation finance flows are much lower than mitigation flows, indeed the latter are now huge (US$ 537 billion annually, CPI, 2019). The reasons for this relate to the issues above around economics, notably the financial return on adaptation and the challenges around the generation of revenue or income streams (as compared to mitigation), as well as the public good and non-market elements, imperfect information, etc. which constrain private investment. There are often additional opportunity or transaction costs associated with adaptation (ECONADAPT, 2017), and other factors can act to constrain the financing of adaptation (e.g. the need to work with many actors, as compared to large financing projects).

Surveys and reviews find that financial constraints are a big impediment to regional and local government adaptation, yet urban areas are likely to dominate adaptation investments, because of the concentration of people, assets and economic activity. Financial constraints are likely to be particularly important during times of falling budgets, or challenging budgetary choices or competing priorities. This is particularly relevant for COVID-19 but may also generate some opportunities through a green recovery: this has been considered in a separate Clyde Rebuilt policy brief (Clyde Rebuilt, 2020).

Possible Solutions and Enablers to Transformational Adaptation

The literature review provides some information on how to address the potential economic and financial barriers above.

In terms of uncertainty and information failures, it is possible to fund more science and studies, and raise awareness, to address knowledge gaps (and tackle the failure of imperfect information). However, this is unlikely to reduce uncertainty, and thus there is a need for more information and awareness on how to make decisions under uncertainty (Watkiss et al., 2014), and frameworks that help to identify and prioritise early adaptation (Warren et al., 2018). There is a literature on the benefits of building adaptive capacity, including organisational and structure capacity (Ballard, 2013), and on technical assistance, with some economic analysis of these areas (LSE, 2016). However, analysing climate information and making decisions is challenging, and there is an important role for boundary agents (also called knowledge brokers) (Hegger and Dieperink, 2014). There are a growing number of research institutions and intermediary boundary organisations (such as Sniffer), that have a stronger focus on climate change solutions rather than on generating knowledge directly. Cities and regions can themselves act as facilitators, to encourage innovation, link initiatives and more (Huang-Lachmann and Lovett, 2016). There is also a high potential for demonstration and pioneer projects, especially for more transformational change, to address perceptions and allow learning.

For economic and finance barriers, the focus is on addressing market failures. Many of the market failures associated with adaptation can be tackled by government intervention, noting this can take several forms. It can be done through direct provision and support or by introducing a regulatory framework that is conducive or creating the enabling environment for the private sector to deliver adaptation (Cimato et al., 2017). It can also be advanced through provision of guidance, information and awareness to help overcome problems relating to misaligned incentives and market distortions.

Financial incentives can be introduced by governments to encourage individuals or organisations to adopt certain behaviours, which includes a range of instruments that can be used to raise finance to support adaptation, e.g. taxes, fees or charges or to internalise the external costs of their actions. There are examples now of cities in Europe that have funded significant adaptation investment through local financing approaches, e.g. Copenhagen Cloudburst plan and its use of water charges (City of Copenhagen, 2012). There are also potential grants, loans and other forms of revenue transfers from national or regional (subnational) governments, as well as a new range of insurance and financial resilience products that could help raise finance (UNEP, 2018). Innovative instruments, such as challenge funds can be used to pilot activities, or to create markets where these don't exist, such as with payment for ecosystem services (Richards and Thompson, 2019). There is also a new focus on incentivising private sector finance into adaptation (EEA, 2017), sometime using public sources to unlock this, as well as new insurance models at city and individual level.

There is some literature that discusses ways to help overcome possible barriers to transformational adaptation. David-Tabara et al. (2018) identify focusing on solutions, not problems, and on opportunities rather than impacts and costs. Complementing this, they highlight better understanding of agency, to promote the institutionalisation of multiple networks working on systemic innovation and win-win solutions.

A Framework for Addressing the Economic and Financial Barriers

While the section above identifies several challenges and some solutions, two warrant particular attention. First, the uncertainty around future climate change, and thus the uncertainty for delivering adaptation benefits, which poses additional hurdles for the economic and financial case. These are particularly the case for transformational adaptation, as there may be additional uncertainty associated with delivering more systemic change. Second, the timing of adaptation, which reduces the economic and financial attractiveness, because future adaptation benefits are low in present value terms, when compared to up-front adaptation costs. Again, these are a greater barrier for transformational adaptation, because of the generally longer time-frames involved.

The review also identified the possible solution space to address these. There is a literature on decision making under uncertainty and its use in economics (Watkiss et al., 2014: Dittrich et al., 2016). This includes several techniques, but of most relevance, is the focus on iterative adaptive management (Jones et al., 2014), as this has high potential for working with transformational change. Adaptive management is an iterative cycle of monitoring, research, evaluation and learning, i.e. a process, that is used to improve future management strategies (also called iterative risk management).

The framework for the project economic analysis has therefore built on recent developments in this area and their application in the UK notably through the UK Climate Change Risk Assessment (Warren et al., 2016; Warren et at., 2018; Watkiss and Betts, 2021). This sets out focus areas for identifying early adaptation priorities, using a portfolio or 'building block' approach, that can still pass an 'economic test'. It centres on three areas:

- Address any current adaptation gap by implementing 'no-regret' or 'low-regret' actions[2] to reduce risks associated with current climate variability as well as building future climate resilience, or to enhance opportunities.
- Intervene to ensure that adaptation is considered in near-term decisions that have long lifetimes, such as major infrastructure developments, in order to avoid 'lock-in'. This can include the use of decision making

2 No-regret adaptation is defined as options that 'generate net social and/or economic benefits irrespective of whether or not anthropogenic climate change occurs' (IPCC, 2014b). A variation of no-regret options are win-win options, which are options that have positive co-benefits, which could include wider social, environmental or ancillary benefits. These are differentiated from low-regret options, which may have low costs or high benefits, or low levels of regret, or may be no-regret options that have opportunity or transaction costs in practice.

under uncertainty (DMUU) concepts (i.e. flexibility, robustness).
- Fast-track early adaptive management activities, especially for decisions that have long lead times or involve major future change, including planning, monitoring and research. This can enhance learning and allows the use of evidence in forthcoming future decisions, for either risks or opportunities.

These are shown below, along with the decision characteristics involved. It is stressed that at the regional level, all three of these adaptation priorities or building blocks (shown in the green boxes) are needed, and together these represent a portfolio of interventions. As such, these cover all the intervention areas in GCR's Adaptation Strategy and the Portfolio Blueprint.

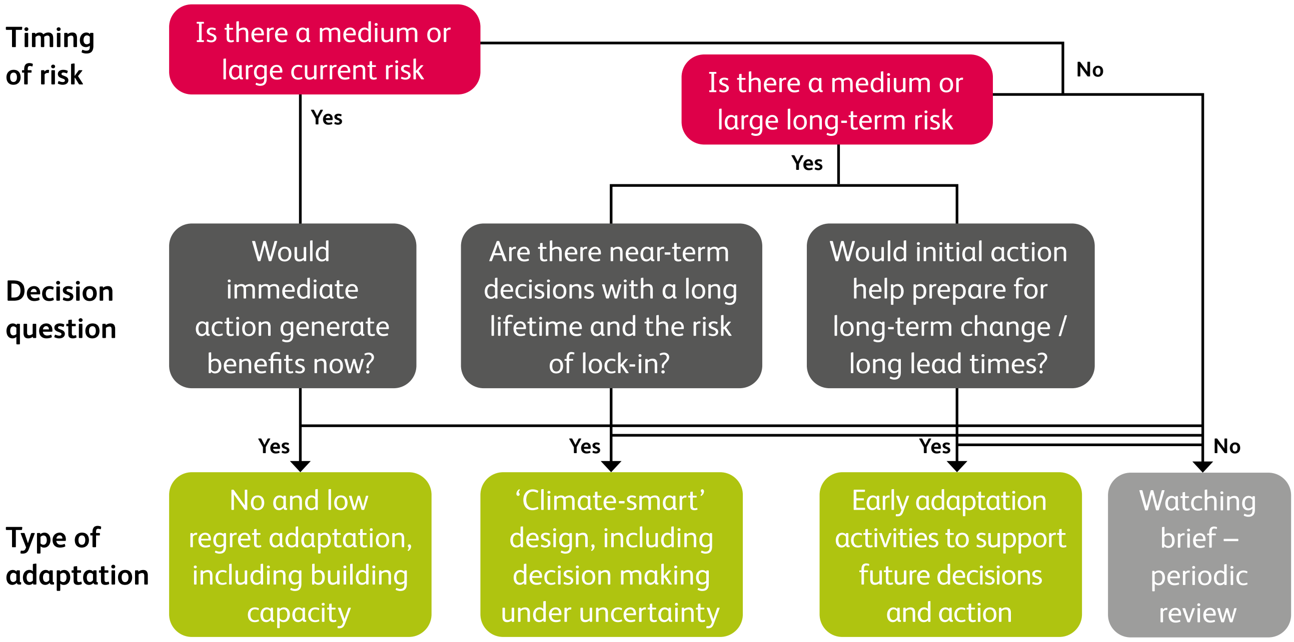

Figure 1. Early adaptation priority framework. Source: CCRA3 Method Chapter Authors updated from CCRA2 (Watkiss and Betts, 2021).

The differences between the three 'building blocks' of early adaptation in the figure are quite subtle, but important.

On the left, there are some current decisions or actions that can be taken now to address current climate risks. These lead to an immediate benefit. An example is to improve weather and climate services to reduce current weather-related impacts from heatwaves. These priorities are reflected in the Adaptation Strategy Intervention on Enhancing early warning and preparedness for floods and heatwaves.

Moving to the centre of the figure, there are some near-term decisions which also involve future climate change risks, and there is a one-off opportunity to adapt now. For example, to change the design of a major new infrastructure project (e.g. a major bridge or hydroelectric-power plant) to make them more resilient to future climate change, noting later major retrofits could be expensive or impossible. These also align to a category of the Adaptation Strategy, with the Intervention to Ensure our homes, offices, buildings and infrastructure are climate resilient.

Finally, on the right of the figure, there are some future decisions that may be needed to address major future climate change, where it makes sense to start planning now (especially if lead times are long). This includes longer-term transformative change, and aligns to the Clyde Rebuilt Portfolio Blueprint.

PART 3

The Economic Costs of Climate Change and Costs and Benefits of Adaptation in Glasgow City Region

Introduction

Previous work for Glasgow City Region and Climate Ready Clyde has undertaken some initial economic analysis of climate change. This built on Glasgow City Region's Climate Risk and Opportunity Assessment (GCRCROA) (CRC, 2018), which identified approximately 67 risks and opportunities in the region, split across six themes:

- Infrastructure;
- Built Environment;
- Society and Health;
- Natural Environment;
- Economy, Business and Industry;
- International, Cross Cutting and Adaptive Capacity.

An initial economic study (Watkiss et al, 2019a) undertook an indicative analysis of the economic costs and benefits of these risks and opportunities in terms of social welfare, which considers both market and non-market impacts. The results are brought together and presented in the figure below. The analysis has found that the future economic costs of climate change in GCR are likely to be dominated by a small number of risks:

- River, surface and coastal floods leading to property damage for residential houses;
- River, surface and coastal floods leading to property damage for business and industry;
- And to a lesser extent, flood related disruption to transport (road and rail), including damage to infrastructure and impacts on travel time.

These impacts will all lead to large financial as well as economic costs. It is stressed that many of these economic impacts will disproportionally affect socially deprived and vulnerable groups. There are also strong geographical patterns for the distribution of risks across different authorities in the region, reflecting differentiated flood risks. There are also potentially significant economic costs (non-market) from increasing heat extremes (health related mortality and morbidity) in the longer term.

The results also show that there will be large economic benefits for the City Region. Again, these are dominated by a small number of categories, notably:

- Large financial and economic benefits in terms of reduced winter energy use for heating, for both the residential sector and business/industry;
- Large economic benefits from reduced cold related health impacts;
- And to a lesser extent, financial and economic benefits from reduced cold weather-related expenditure and disruption for infrastructure and transport.

These benefits will also fall disproportionally to socially deprived and vulnerable groups, however, they are more evenly spread across all geographical areas of the City Region.

		CURRENT		2020s	2050s	2080s
	THEME 1 - INFRASTRUCTURE					
1	In1: Risks of cascading failures from interdependent infrastructure networks	Uncertain	*Maj Ext risk	Uncertain		
2	In2: Risks to infrastructure services from river, surface water and groundwater flooding	-M	*Maj Ext risk	-M	-M	-H
3	In3: Risks to infrastructure services from coastal flooding and erosion	-M	*Maj Ext risk	-M	-M	-M
4	In4: Risks of sewer flooding due to heavy rainfall	Uncertain	*Maj Ext risk	Uncertain but potentially high		
5	In5: Risks to bridges and pipelines from high river flows and bank erosion	-L	*min Ext risk	-L	-L	-L
6	In6: Risks to transport networks from slope and embankment failure	-L	*Maj Ext risk	-L	-L	-L
7	In7: Risks to subterranean and surface infrastructure from subsidence	Uncertain		-L	-L	-L
8	In8: Risks to energy, transport and ICT infrastructure from storms and high waves	-M	*Maj Ext risk	-M	-M	-M
9	In9: Risks to transport, digital and energy infrastructure from extreme heat		*min Ext risk		-L	-L
10	In10: Risks to infrastructure from increase in vegetation growth rates/changes in growing season	-M		-M	-M	-M
11	In11: Risks to infrastructure from wildfires				-L	-L
12	In12: Risks to water-based transport and trade infrastructure (ports, canals, harbours, etc.) from SLR	Uncertain				
13	In13: Potential benefits to water, transport, digital, energy infrastructure from reduced extreme cold	Uncertain				
	THEME 2 - BUILT ENVIRONMENT					
1	BE1. Risks to homes from flooding	-VH	*Maj Ext risk	-VH	-VH	-VH
2	BE2. Risks to building fabric from moisture, wind, storms and driving rain	-L	*Maj Ext risk	-L	-L	-L
3	BE3. Risks to significant heritage properties from landslides, flooding or coastal erosion	Uncertain				
4	BE4. Risks to traditional and historic buildings from moisture, wind and driving rain	Uncertain				
5	BE5. Increased maintenance of green space due to rising temperatures and severe weather	Uncertain				
6	BE6. Increased cooling demand in buildings as a result of rising temperatures	-L		-L	-L	-H
7	BE7. Risks to homes from sea level rise	captured in flooding above				
8	BE8. Risk of overheating of buildings from increased energy efficiency/insulation					
9	BE9. Potential for improved physical and mental health from increased use of parks and green space			+L	+L	+L
10	BE10. Opportunities for local food growing from warmer temperatures and increased growing season			+L	+L	+L
11	BE11. Reduced heating demand to buildings from rising temperatures	+VH		+VH	+VH	+VH
12	BE12. Increased viability of renewable electricity and heat from changing weather conditions			-L	-L	-L
	THEME 3 - COMMUNITIES AND HEALTH					
1	CH1: Risks to people and communities from flooding	-L		-L	-M	-M
2	CH2: Increase in summer temperatures and heatwaves leading to increased morbidity and mortality	-L	*Maj Ext risk	-M/VH	-M/VH	-M/VH
3	CH3: Risks to business continuity of health and social care from extreme weather	Uncertain		Uncertain but potentially high		
4	CH4: Increased patient demand on NHS services from high winds, snow and ice, floods, cold weather			-L	-L	-L
5	CH5: Risks to the viability of coastal communities from sea level rise	partly captured in flooding				
6	CH6: Risks to health from changes in air quality	-L		-L	-L	-L
	Risks to health from changes in air quality (aero-allergens)	Not quantified				
7	CH7: Risks to health from vector-borne pathogens	-L		Uncertain		
8	CH8: Risks to Sport and leisure activities from severe weather, higher temp and increased prec			-L	-L	-L
9	CH9: Potential benefits to health and wellbeing from reduced cold			+VH	+VH	+VH
	THEME 4 - NATURAL ENVIRONMENT					
1	NE1: Risks from changes in agricultural productivity and land suitability	Not quantified				
2	NE2: Risks to soils from increased seasonal aridity and wetness	Not quantified				
3	NE3: Risks from changes in forest productivity and land suitability	-L		-L	-L	-L
4	NE4: Risks to species and habitats due to inability to respond to changing climatic conditions	Not quantified				
5	NE5: Risks to natural carbon stores and carbon sequestration	Not quantified				
6	NE6: Risks to agriculture and wildlife from water scarcity and flooding	-L		-L	-L	-L
7	NE7: Risks to freshwater fish species from higher water temperature, phenology	Not quantified				
8	NE8: Risks of land management practices exacerbating flood risk	Not quantified				
9	NE9: Risks to agriculture, forestry, landscapes and wildlife from pests, pathogens and invasive sp	Not quantified				
10	NE10: Risks to agriculture, forestry, landscapes and heritage from changes in extremes and wildfire	Not quantified				
11	NE11: Risks to the natural environment from sea level rise	Not quantified				
12	NE12: Risks and opportunities for marine species, fisheries and heritage from ocean acidification	Not quantified				
13	NE13: Opportunities from changes in agricultural productivity and land suitability	Not quantified				
14	NE14: Opportunities from changes in forest productivity and land suitability	Not quantified				
15	NE15: Opportunities from new species colonisations	Not quantified				
	THEME 5 - BUSINESS AND INDUSTRY					
1	BI1: Risk to new and existing business sites from river, surface water and coastal flooding.	-VH	*Maj Ext risk	-VH	-VH	-VH
2	BI2: Risks to business operations from water scarcity	N		N	-L	-L
3	BI3: Risks to business from reduced employee productivity	-L		-L	-L	-L
4	BI4: Risks to business from disruption to supply chains and distribution networks	Uncertain		Uncertain but potentially high		
5	BI5: Opportunities for products and services to support adaptation to climate change	This will be covered in the K-Matrix report				
6	BI6: Increased tourism revenue from increased temperatures			+L	+L	+L

IMPACT			BENEFIT		
N	Negligble				
-L	Low	<£0.5 million/yr	+L	Low	<£0.5 million/yr
-M	Medium	£0.5 - 5 million/yr	+M	Medium	£0.5 - 5 million/yr
-H	High	£5 - 25 million/yr	+H	High	£5 - 25 million/yr
-VH	Very high	>£25 million/yr	+VH	Very high	>£25 million/yr

min Ext risk =	Extreme event with minor impacts
Maj Ext risk =	Extreme event with major (\$/HH) impacts

Figure 2 Total Economic Costs of Current Climate Extremes and Future Climate Change for Glasgow City Region

Macro-economic Impacts of Climate Change in GCR

For Clyde Rebuilt, we have built on these early initial economic results from the GCR-CROA. This has developed some new macro-economic analysis, and undertaken detailed deep-dives in the most important areas. This work has drawn on our collaborative work in the COACCH project. This has undertaken detailed sector by sector analysis (COACCH, 2019) of the potential economic costs of climate change in Europe. This includes analysis of energy demand and supply, labour productivity, agriculture, forestry, fisheries, transport, sea- level rise, and riverine floods.

These sector results have subsequently been fed into a macro-economic model, the ICES macroeconomic computable general equilibrium (CGE) model (COACCH, 2020). This framework allows the analysis of the higher order economic implications of climate change impacts, working with multi-country, multi-sector representation of the global economic system. It captures the linkages between sectors and includes trade flows of domestic and international goods and services. The modelling framework can thus show the effect of climate impacts on the economic performance of a country or region as a whole – including on GDP.

The COACCH project has also introduced a further innovation, as the ICES model results have been downscaled at a more local (dis-aggregated) level. This allows a localised analysis at the approximate level of Glasgow City Region. The COACCH project macro-economic assessment (2020) of climate change impacts is based on a subnational level analysis. This provides insights on impacts within countries. For this analysis, we have focused on the region of South Western Scotland.

The analysis has considered future global warming scenarios, captured by the Representative Concentration Pathways (RCPs), as well as future socio-economic scenarios, using the Shared Socioeconomic Pathways (SSPs). Furthermore, to account for uncertainty, each impact (e.g. floods) were considered for a medium (central) scenario, but also low and high sensitivity values.

The analysis has focused on three RCPs that provide a span from strong mitigation scenarios, consistent with the Paris Agreement (RCP2.6), through to higher warming scenario (RCP6.0). At the current time, current pledges for reducing emissions, as set out in the Nationally Determined Contributions, indicate warming of just above 3˚C this century (UNEP, 2019), i.e. close to RCP6.0. All three scenarios have been run for SSP2, which is a middle of the road socio-economic scenario.

	Near-term: 2031–2050		End-of-century: 2081–2100	
Scenario	**Mean (˚C)**	***likely* range (˚C)**	**Mean (˚C)**	***likely* range (˚C)**
RCP2.6	1.6	1.1 to 2.0	1.6	0.9 to 2.4
RCP4.5	1.7	1.3 to 2.2	2.5	1.7 to 3.3
RCP6.0	1.6	1.2 to 2.0	2.9	2.0 to 3.8
RCP8.5	2.0	1.5 to 2.4	4.3	3.2 to 5.4

Table 1 Projected global mean surface temperature change relative to 1850–1900 for two time periods under four RCPs. Source IPCC, 2019.

The total economic costs for the Region, as a percentage of regional GDP (in the relevant future year) are shown in Figure 3, for different time periods.

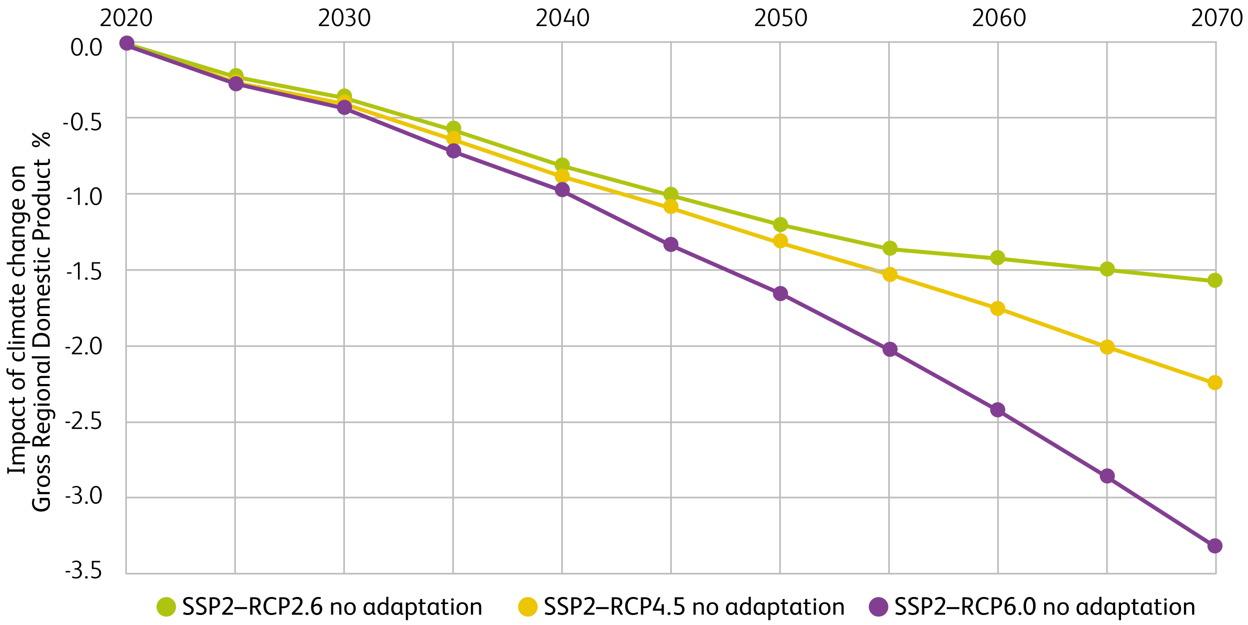

Figure 3 Economic Costs as a % of Regional GDP for South Western Scotland. Based on analysis using the COACCH policy explorer.

In the short-term, there are not very large differences between scenarios, because much of the climate change is already locked into the system. The analysis indicates economic costs of approximately 0.3 to 0.4% of regional GDP in 2030, rising to approximately 1.0 to 1.3% of regional GDP by 2045, for a low and high warming scenario respectively (RCP2.6 and RCP6). These impacts are dominated by flooding (coastal and river).

The economic costs of climate change rise significantly after mid-century, rising but stabilising at below 1.5% for a low warming scenario (RCP2.6), however, they rise very significantly (and continue rising over time) for higher warming scenarios, exceeding 2% of GDP (RCP4.5) and 3% for RCP6.0 by 2070. This shows that global mitigation will have large benefits in reducing impacts in Glasgow City Region.

The overall results, when all sectoral effects are considered, show potentially large economic losses in regional GDP for Glasgow City Region, especially if temperatures exceed 2°C of warming globally. The main drivers of these macroeconomic impacts – and GDP losses – are from floods.

It is noted that up to 2050, there is not a large difference between RCP-SSP scenarios, as the climate signal is not that different. **This means that there is a need for adaptation, whatever happens to global GHG emission levels.** In the late century, there will be an increasing need for adaptation, and this will be very large if global emissions are not reduced. It is also noted that there is uncertainty around the central values shown, in terms of the level of impacts. This is important in shaping the adaptation response.

It is important to stress that this analysis does not include important non-market impacts including on health and on biodiversity and ecosystem services. These would increase the impacts above further. It also does not include the potential impacts of climate or socio-economic tipping points.

However, these economic costs can be reduced significantly under an adaptation scenario. An indication of the potential benefits for adaptation are shown below, again using the COACCH Model.

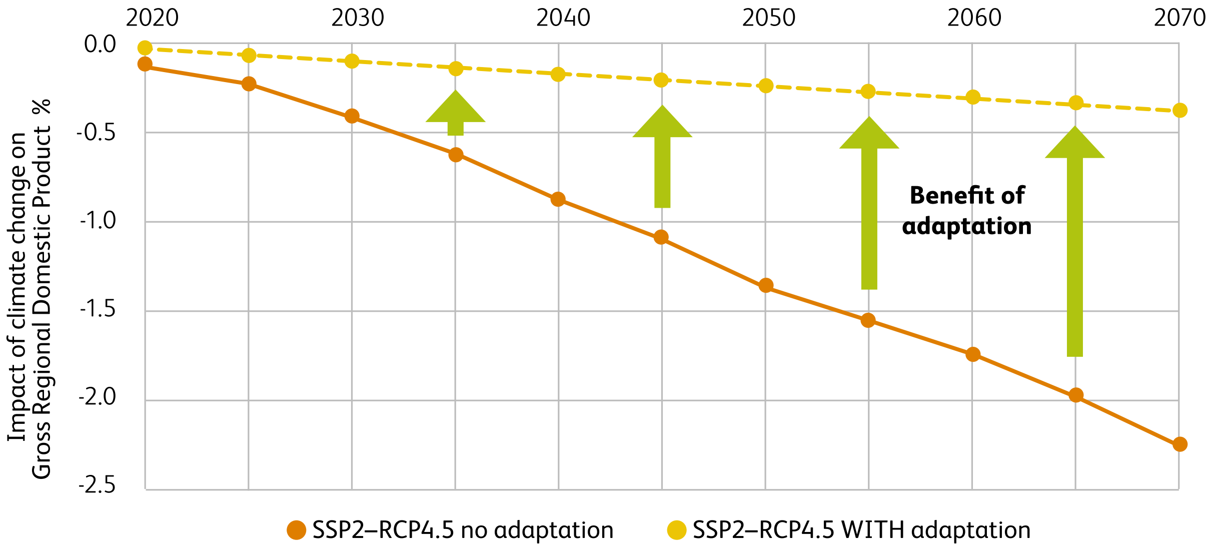

Figure 5 Economic Costs as a % of Regional GDP for South Western Scotland – with and without adaptation. Based on analysis using the COACCH policy explorer.

This indicates that adaptation can reduce the annual damage costs shown above significantly (by an order of magnitude). **Overall, the indication is that the economic costs of climate change in the near term could be reduced to very low levels with adaptation.**

Deep Dive 1: Economic Costs of River, Surface and Coastal Floods in GCR

The major impact of climate change in Glasgow City Region is from flooding. This can arise from multiple sources of floods – including coastal, river and surface flooding. The study has assessed the potential economic costs of these impacts, and the potential costs and benefits of adaptation.

The starting point is to assess the current economic costs in the region. The SEPA (2015) Flood Risk Management Strategy for Clyde & Loch Lomond Local Plan District estimated current risks, including the potential economic costs of flooding. This covers an area of around 4,800km² and has a population of approximately 1.9 million and a coastline of around 500km. The area contains the River Clyde and its many tributaries and is heavily urbanised. However outside of the urbanised areas the main land covers are agricultural grazing lands, coniferous and broadleaved woodland.

The 2015 FRM Strategy reports the annual average damages[3] as shown below, with a total of £65 million as an annualised cost. Note that this includes some areas that are outside Glasgow City Region, but the majority are within the Region. The damages include impacts for residential and non-residential buildings, as well as impacts on some infrastructure.

	Annual Average Damage
River flooding	
River Clyde catchment group	£22 million
River Leven catchment	£4.2 million
Coastal flooding	
Clyde and Loch Lomond coastal area	£19 million
Surface water flooding	
Clyde and Loch Lomond Local Plan District	£20 million
TOTAL	**£65 million**

Table 2 Summary of flood risk from various sources within the Flood Risk Management Clyde and Loch Lomond Local Plan District (Source: SEPA, 2015).

This information is in the process of being updated for the Flood Risk Management Strategies and Local Flood Risk Management Plans[4]. There is a draft Flood Risk Management Strategy 2021-2027 for Clyde and Loch Lomond (SEPA, 2020). Currently it is estimated there are around 170,000 people and 98,000 homes and businesses at risk from flooding. The expected annual cost of flooding is around £70 million, which is slightly higher than the previous 2015 estimate above.

3 Annual Average Damages are the theoretical average economic damages caused by flooding when considered over a very long period of time. High likelihood events, which occur more regularly, contribute proportionally more to Annual Average Damages than rarer events.

4 Information from these strategies and plans contribute to the delivery of the Flood Risk Management (Scotland) Act 2009 (FRM Act) and are updated every six years. The Flood Risk Management Strategies and Local Flood Risk Development Plans are in the process of being updated and will be published in December 2021 and June 2022 respectively.

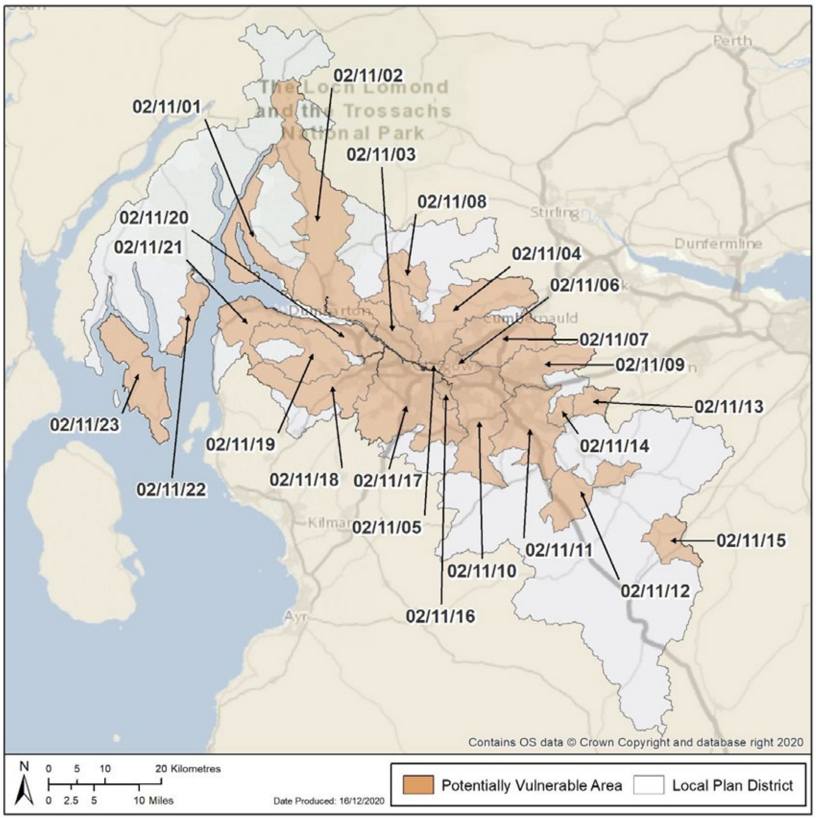

Figure 6 Potentially Vulnerable Areas in Clyde and Loch Lomond Local Plan District

The next step is to consider future climate change impacts on coastal, river and surface flooding. The analysis has updated recent national work to derive new estimates for the region.

Watkiss (2019a) estimated the impacts of climate change on flooding in GCR. The resulting impacts are shown below. The results indicate that the estimated annual average damage (AAD) increases from £65 million currently to £97 million by the 2080s for a high emission scenario. The values for residential flooding damage increase from £28 million to £44 million (an increase of £16 million) and the values for non-residential increase from £26 million to £42 million (an increase also of £16 million) for a high warming scenario (UKCP09 high).

Category	River Flooding £Million/yr		Coastal Flooding £Million/yr		Surface Flooding £Million/yr	
	Current AAD	2080s AAD (increase)	Current AAD	2080s AAD (increase)	Current AAD	2080s AAD (increase)
Residential prop.	13	20.0 (7.0)	5.2	10.8 (5.6)	9.4	13.0 (3.6)
Non-residential	6.4	10.3 (3.9)	11	20.3 (9.3)	8.8	11.9 (3.1)
Emergency services	1.1	1.7 (0.6)	1	2.0 (1.0)		
Vehicles	0.65	1.0 (0.4)	0.54	1.1 (0.5)	0.4	0.5 (0.1)
Roads	0.35	0.4 (0.1)	0.94	1.8 (0.9)	1.4	1.9 (0.5)
Agriculture	0.18	0.3 (0.1)	0.016	0.0 (0.0)		
Total	**22**	**33.7 (12.2)**	**18.7**	**36.0 (17.3)**	**20**	**27.3 (7.3)**

Table 3 Estimated current and indicative future AAD under climate change (2080s). Source current damage from FRM Strategy (Source: SEPA, 2015) plus future climate increase (Watkiss 2019a) for a high warming scenario, current prices, undiscounted.

However, these estimates do not take into account socio-economic change. The numbers will increase because of the rising population in the region, and the number of properties, but also more generally from economic growth and the higher value at risk. This means that even without climate change, there will be more incentive for Glasgow City Region to increase protection, as more people and assets become exposed. Watkiss et al (2019b) factored in population and economic growth (as captured by GDP/capita) to these numbers and this significantly increased the future economic costs, to hundreds of million/year, for a high warming scenario.

Scenario	Current	2030	2050	2080
Current	£60 million/yr			
Climate change (CC) only				£100 million/yr
Socio-economic (SE) change only		£94 million/yr	£135 million/yr	£195 million/yr
CC and SE together		£105 million/yr	£170 million/yr	£290 million/yr

Table 4 Annual average damage (£) from Flooding in Glasgow City Region – Effects of climate, socio-economic change for a high warming scenario, current prices, undiscounted. Source Watkiss, 2019b.

Current estimates and future CC only are based on the values from SEPA (2015). CC scenario is UKCP09 high. SE scenario = SSP2 = Middle of the Road scenario, based on the IIASA SSP data. Samir et al 2017., Cuaresma, 2017. This takes UK data and scales for Glasgow City Region.

It is highlighted that SEPA has developed a national visualisation tool for floods, that includes the potential to look at climate change, (**https://www.sepa.org.uk/data-visualisation/nfra2018/**) but this does not produce data.

For the Clyde Rebuilt project, we have developed a new set of data on the potential economic costs of flooding in GCR (expected annual damage, EAD), based on the latest national flood risk assessments (Sayers et al, 2020), which include Scotland and the Clyde as part of the third UK Climate Change Risk Assessment. The main advantages of this data set are that it has different future climate scenarios and time periods, with a 2°C and 4°C, as well as population growth projections (low, high and no growth), and it also considers the potential benefits of adaptation in reducing risks. These data are available as an online set of data but have needed considerable work to downscale to the region (**https://www.ukclimaterisk.org/ccra-research/**), and these have been used and reanalysed here. The numbers are available for the Clyde and Loch Lomond area, which is smaller than the entire GCR.

The CCRA3 analysis includes three scenarios, which allow the analysis of different levels of adaptation:

- **No additional action.** This is a counterfactual scenario with low levels of adaptation, assuming that existing flood protection is maintained, but there is no future additional adaptation, i.e. investment in conventional defences fails to keep pace with climate change.
- **Current objectives and current adaptation (CLA).** This assumes flood risk management policies continue to be implemented as in the recent past whilst taking on board anticipated changes that are likely to result from recent changes in policy. While current policies are in line with this scenario, they imply high levels of future costs.
- **Enhanced whole system adaptation (EWS).** This goes beyond the current implementation of policy (and recently introduced policy) with implementation in-line with a higher level of ambition.

The three scenarios are presented below, first for residential, then for non-residential. The Sayers study has analysis for low and high population growth. We assume the average of the two. Note that these results include population growth, but no other socio-economic change, and importantly, they do not take account of economic growth. It is highlighted that these CCRA3 estimates have slightly different estimates to the SEPA baseline flood costs. They show a slightly lower level of current damages (£45 million/year rather than £70 million/year, and have a greater economic damage for non-residential properties). This is due to the geographical coverage, as a smaller area of coast is included, though there are also differences because of the models used and the assumptions.

The residential analysis shows an increase in floods risks over time, and with higher warming scenarios. It also shows the large benefits that adaptation can have (See Table 7). An advanced level of adaptation, as projected under the Adaptation Strategy, could reduce coastal and river flooding to below current levels (though it would have less impact on surface flooding).

Residential Analysis- static socio-economic assumptions

No additional action

		2050s		2080s	
	Present day	2°C	4°C	2°C	4°C
Fluvial	10,427,003	12,808,984	14,436,	13,886,874	18,322,277
	% increase	23%	38%	33%	76%
Surface	6,790,306	13,596,582	15,434,816	15,652,068	19,849,909
	% increase	100%	127%	131%	192%
Coastal	2,145,728	2,163,704	2,281,404	2,153,567	2,399,376
	% increase	1%	6%	0%	12%
Total	**19,363,037**	**28,569,270**	**32,152,523**	**31,692,508**	**40,571,562**
	% increase	**48%**	**66%**	**64%**	**110%**

Table 5 Annual average damage (£) for residential properties from Flooding in Clyde and Loch Lomond. Effects of climate, including population growth. Source Sayers et al., 2020.

Current levels of adaptation

		2050s		2080s	
	Present day	2°C	4°C	2°C	4°C
Fluvial	10,427,003	11,614,793	13,082,984	12,116,133	15,968,245
	% increase	11%	25%	16%	53%
Surface	6,790,306	13,056,191	14,815,904	13,496,889	17,031,300
	% increase	92%	118%	99%	151%
Coastal	2,145,728	1,968,756	2,031,698	1,891,629	1,969,413
	% increase	-8%	-5%	-12%	-8%
Total	**19,363,037**	**26,639,739**	**29,930,586**	**27,504,651**	**34,968,958**
	% increase	**38%**	**55%**	**42%**	**81%**

Table 6 Annual average damage (£) for residential properties from Flooding in Clyde and Loch Lomond. Effects of climate, including population growth (central). Source Sayers et al., 2020.

Enhanced whole system adaptation

		2050s		2080s	
	Present day	2°C	4°C	2°C	4°C
Fluvial	10,427,003	5,620,922	6,313,847	5,461,066	7,153,467
	% increase	-46%	-39%	-48%	-31%
Surface	6,790,306	10,917,122	12,559,740	11,623,966	14,532,255
	% increase	61%	85%	71%	114%
Coastal	2,145,728	1,015,089	1,085,379	940,019	1,017,055
	% increase	-53%	-49%	-56%	-53%
Total	**19,363,037**	**17,553,133**	**19,958,966**	**18,025,051**	**22,702,777**
	% increase	**-9%**	**3%**	**-7%**	**17%**

Table 7 Annual average damage (£) for residential properties from Flooding in Clyde and Loch Lomond. Effects of climate, including population growth (central). Source Sayers et al., 2020.

Overall, adaptation can reduce total flood impacts to slightly below current levels under a 2˚C world, and even under a 4˚C world, it would limit the increase in flood related costs to below a 20% increase. This would have large economic benefits (as seen in the comparison between tables).

However, these values assume static socio-economic assumptions with respect to growth, i.e. today's economy. We have therefore increased these values to take account of other socio-economic change, to reflect the planned economic growth in the Region. This significantly increases the values, even in the mid-century, and especially in late century, because floods would have larger impacts due to the higher value at risk. Adaptation also has benefits in reducing damages in this case, and the absolute level of adaptation benefit (£) is greater, but so is the residual damage after adaptation.

Residential analysis – with socio-economic change

No adaptation

		2050s		2080s	
	Present day	2°C	4°C	2°C	4°C
Fluvial	10,427,003	23,661,112	26,667,305	47,583,972	62,783,316
		127%	156%	356%	502%
Surface	6,790,306	25,076,698	28,466,685	53,370,597	67,653,054
		269%	319%	686%	896%
Coastal	2,145,728	3,996,539	4,213,847	7,378,047	8,219,324
		86%	96%	244%	283%
Total	**19,363,037**	**52,734,348**	**59,347,837**	**124,174,523**	**138,655,694**
		172%	**207%**	**541%**	**616%**

Table 8 Annual average damage (£) for residential properties from Flooding in Clyde and Loch Lomond. Effects of climate, including population AND economic growth. Source authors, based on Sayers et al., 2020.

Current Level of Adaptation

		2050s		2080s	
	Present day	2°C	4°C	2°C	4°C
Fluvial	10,427,003	21,493,765	24,210,876	41,814,072	55,107,779
		106%	132%	301%	429%
Surface	6,790,306	24,095,931	27,343,331	46,151,103	58,209,797
		255%	303%	580%	757%
Coastal	2,145,728	3,641,807	3,758,054	6,516,488	6,782,947
		70%	75%	204%	216%
Total	**19,363,037**	**49,231,502**	**55,312,261**	**107,766,067**	**120,100,523**
		154%	**186%**	**457%**	**520%**

Table 9 Annual average damage (£) for residential properties from Flooding in Clyde and Loch Lomond. Effects of climate, and including population AND economic growth. Source authors, based on Sayers et al., 2020.

Enhanced whole-system adaptation

		2050s		2080s	
	Present day	2°C	4°C	2°C	4°C
Fluvial	10,427,003	10,404,818	11,687,446	18,862,687	24,705,219
		0%	12%	81%	137%
Surface	6,790,306	20,169,976	23,202,817	39,951,700	49,924,344
		197%	242%	488%	635%
Coastal	2,145,728	1,876,886	2,006,703	3,228,480	3,492,115
		-13%	-6%	50%	63%
Total	**19,363,037**	**32,451,680**	**36,896,967**	**70,624,016**	**78,121,678**
		68%	**91%**	**265%**	**303%**

Table 10 Annual average damage (£) for residential properties from Flooding in Clyde and Loch Lomond. Effects of climate and including population AND economic growth. Source authors, based on Sayers et al., 2020.

The overall annual benefits of adaptation are shown below, for the two sets of figures.

Benefit/year	2050s		2080s	
	2°C	4°C	2°C	4°C
Population change only				
CLA – No adaptation	1,929,531	2,221,937	4,187,857	5,602,603
EWS-CLA	9,086,606	9,971,620	9,479,599	12,266,181
Population and socio-economic change				
CLA – No adaptation	3,502,847	4,035,576	16,408,456	18,555,171
EWS-CLA	16,779,821	18,415,294	37,142,051	41,978,845

Table 11 Benefits of adaptation (£/year) for total flooding residential properties, based on Sayers et al., 2020. Top Population only. Bottom Population and Economic growth.

The same analysis has been undertaken for non-residential buildings. The baseline set assume no socio-economic change. Interestingly, the Sayers EAD numbers are higher for non-residential than residential numbers, with estimated current levels of £25 million/year. These rise in future years. Again, adaptation can significantly reduce these impacts and could actually reduce the hazard component to below current levels.

Non-residential analysis – static socio-economic assumptions

No adaptation

		2050s		2080s	
	Present day	2°C	4°C	2°C	4°C
Fluvial	13,802,634	12,153,965	13,326,920	12,733,016	16,325,959
		-12%	-3%	-8%	18%
Surface	3,531,580	5,813,943	6,533,526	6,407,548	7,648,254
		65%	85%	81%	117%
Coastal	8,323,261	6,811,606	7,233,148	7,021,927	7,946,665
		-18%	-13%	-16%	-5%
Total	**25,657,474**	**24,779,514**	**27,093,594**	**26,162,491**	**31,920,878**
		-3%	**6%**	**2%**	**24%**

Table 12 Annual average damage (£) for non-residential properties from Flooding in Clyde and Loch Lomond. Effects of climate, no socio-economic change. Source Sayers et al., 2020.

Current levels of adaptation

		2050s		2080s	
	Present day	2°C	4°C	2°C	4°C
Fluvial	13,802,634	9,876,253	10,776,060	10,330,916	13,192,686
		-28%	-22%	-25%	-4%
Surface	3,531,580	5,772,467	6,482,836	5,864,185	7,089,361
		63%	84%	66%	101%
Coastal	8,323,261	5,551,612	5,818,408	5,710,879	6,095,683
		-33%	-30%	-31%	-27%
Total	**25,657,474**	**21,200,332**	**23,077,304**	**21,905,980**	**26,377,730**
		-17%	**-10%**	**-15%**	**3%**

Table 13 Annual average damage (£) for non-residential properties from Flooding in Clyde and Loch Lomond. Effects of climate, no socio-economic change. Source Sayers et al., 2020.

Enhanced whole-system adaptation

		2050s		2080s	
	Present day	2°C	4°C	2°C	4°C
Fluvial	13,802,634	5,945,183	6,555,143	6,260,889	7,875,672
		-57%	-53%	-55%	-43%
Surface	3,531,580	5,141,525	5,909,318	5,441,876	6,600,988
		46%	67%	54%	87%
Coastal	8,323,261	3,892,040	4,154,038	4,046,954	4,381,381
		-53%	-50%	-51%	-47%
Total	**25,657,474**	**14,978,748**	**16,618,498**	**15,749,718**	**18,858,040**
		-42%	**-35%**	**-39%**	**-27%**

Table 14 Annual average damage (£) for non-residential properties from Flooding in Clyde and Loch Lomond. Effects of climate, no socio-economic change. Source Sayers et al., 2020.

Non-residential analysis – with socio-economic change

The same scenarios are considered below, with socio-economic change included. Again, this increases the baseline damages from flooding very significantly. In this case, adaptation has large benefits, but it is not sufficient to reduce all damages.

No adaptation

		2050s		2080s	
	Present day	2°C	4°C	2°C	4°C
Fluvial	13,802,634	22,535,400	24,710,247	44,359,566	56,876,741
		63%	79%	221%	312%
Surface	3,531,580	10,783,270	12,116,786	22,341,629	26,650,975
		205%	243%	533%	655%
Coastal	8,323,261	12,629,810	13,411,416	24,463,146	27,684,767
		52%	61%	194%	233%
Total	**25,657,474**	**45,948,479**	**50,238,449**	**91,164,341**	**111,212,483**
		79%	**96%**	**255%**	**333%**

Table 15 Annual average damage (£) for non-residential properties from Flooding in Clyde and Loch Lomond. Effects of climate, including economic growth. Source authors, based on Sayers et al., 2020.

Current levels of adaptation

		2050s		2080s	
	Present day	2°C	4°C	2°C	4°C
Fluvial	13,802,634	18,312,157	19,980,543	35,991,076	45,960,974
		33%	45%	161%	233%
Surface	3,531,580	10,706,282	12,022,748	20,451,884	24,707,430
		203%	240%	479%	600%
Coastal	8,323,261	10,293,579	10,788,261	19,895,686	21,236,277
		24%	30%	139%	155%
Total	**25,657,474**	**39,312,018**	**42,791,553**	**76,338,646**	**91,904,681**
		53%	**67%**	**198%**	**258%**

Table 16 Annual average damage (£) for non-residential properties from Flooding in Clyde and Loch Lomond. Effects of climate, including economic growth. Source authors, based on Sayers et al., 2020.

Enhanced whole-system adaptation

		2050s		2080s	
	Present day	2°C	4°C	2°C	4°C
Fluvial	13,802,634	11,023,322	12,154,286	21,811,823	27,437,440
		-20%	-12%	58%	99%
Surface	3,531,580	9,536,690	10,959,762	18,983,010	23,006,615
		170%	210%	438%	551%
Coastal	8,323,261	7,216,467	7,702,252	14,098,867	15,263,951
		-13%	-7%	69%	83%
Total	**25,657,474**	**27,776,478**	**30,816,300**	**54,893,700**	**65,708,007**
		8%	**20%**	**114%**	**156%**

Table 17 Annual average damage (£) for non-residential properties from Flooding in Clyde and Loch Lomond. Effects of climate, including economic growth. Source authors, based on Sayers et al., 2020.

The benefits of adaptation are shown below. Again, this shows high annual benefits, from the reduction in flooding (all cause).

Benefit/year	2050s		2080s	
	2°C	4°C	2°C	4°C
Population change only				
CLA – No adaptation	3,579,182	4,016,290	4,256,511	5,543,148
EWS-CLA	6,221,584	6,458,806	6,156,261	7,519,690
Population & socio-economic change				
CLA – No adaptation	6,636,461	7,446,897	14,825,695	19,307,801
EWS-CLA	11,535,540	11,975,252	21,444,946	26,196,674

Table 18 Benefits of adaptation (£/year) for total flooding non-residential properties, based on Sayers et al., 2020. Top Population only. Bottom Population and Economic growth.

When the combined benefits of flood risks to residential and non-residential properties are added together, they are very significant. For example, benefits could be £15 million/year (climate only) or £30 million/year (climate and socio-economics) in the 2050s, irrespective of the whether 2 or 4˚C of warming has occurred. The benefits in late century (2080s) are much larger.

Benefit/year	2050s		2080s	
	2°C	4°C	2°C	4°C
Impacts				
Population change only				
No adaptation	53,348,784	59,246,117	57,854,998	72,492,439
CLA	47,840,071	53,007,890	49,410,630	61,346,688
EWS	32,531,881	36,577,464	33,774,770	41,560,817
Population change & socio-economic change				
No adaptation	98,682,828	109,586,286	215,338,864	249,868,177
CLA	88,543,520	98,103,814	184,104,713	212,005,204
EWS	60,228,158	67,713,267	125,517,716	143,829,686
Adaptation benefits				
Population change only				
CLA – No adaptation	5,508,713	6,238,227	8,444,368	11,145,751
EWS-CLA	15,308,190	16,430,426	15,635,860	19,785,871
Population change & socio-economic change				
CLA – No adaptation	10,139,308	11,482,473	31,234,151	37,862,972
EWS-CLA	28,315,361	30,390,546	58,586,997	68,175,519

Table 19 Total impacts, and total benefits of adaptation (£/year) for total flooding residential and non-residential properties, based on Sayers et al., 2020. Top Population only. Bottom Population and Economic growth.

Deep Dive 2: Economic Costs of Health and Heat

The main health risk of higher summer temperatures and heatwaves is associated with premature (excess) deaths (mortality). Numerous studies show that daily mortality increases above a temperature threshold, though the threshold and rate of increase varying between regions. Several studies have quantified these impacts in the UK and for the Devolved Administrations including Scotland (Hames and Vardoulakis, 2012). The CCRA1 estimates were updated in a later study (Hajat et al, 2014). This reported that climate change in Scotland could potentially result in a 520% increase in heat related deaths by the 2080s under a medium emissions scenario – though this is relatively small in real terms (rising from 0.7 per 100,000 population to 4.4 per 100,000 population). For the 2050s, this equates to an additional 30 to 110 deaths per year for Glasgow City Region, for low and high warming scenarios, and a central value of an additional 60 deaths per year from heat.

The additional premature fatalities – specifically the change in the risk of a fatality – can be valued in monetary terms. This is more difficult to value than many other sectors, because there are no observed market prices. However, it is possible to derive monetary values by considering the total effect of the impact on society's welfare. This requires analysis of three components which each capture different parts of the total effect (Hunt et al., 2016):

- The resource costs i.e. medical treatment costs;
- The opportunity costs, in terms of lost productivity; and
- Dis-utility i.e. pain or suffering, concern and inconvenience to family and others.

The first two components can be captured relatively easily. Techniques are also available to capture the third component, by assessing the 'willingness to pay' or the 'willingness to accept compensation' for a particular health outcome. For this outcome, the key metric is the valuation of the change in risk of a fatality. The valuation of the change in the risk of fatalities is routinely included in Government appraisal, in the road transport sector with respect to accidents. Clyde Rebuilt has undertaken such an analysis, updating previous values from Watkiss et al., 2019a. The analysis uses the current values from DfT (2020) for the average value of prevention of a fatality. This is approximately £2 million (2020 prices), which comprises the total from lost output, human costs and medical costs.

However, there is an important question of whether these values should be transferred to the heat context, as heat predominantly affects those who are old and/or have exiting health conditions. Previous studies have therefore used an alternative approach as a sensitivity, based on the Value of a Life Year (VOLY) Lost (which is derived from the full Value of Statistical Life, i.e. the VPF) mirroring the approach used in air pollution valuation by Defra. This adjusts down the economic costs based on the estimated period of life lost. The VOLY numbers are based on Interdepartmental Group on Costs and Benefits (Defra, 2007), with values updated to 2020 prices, and assuming 12 months of life is lost on average for each fatality.

This shows that the choice of valuation metric makes a very large difference to the results. Indeed, with a full Value of a Prevented Fatality, the impacts become as important in economic terms as flooding.

Valuation £million/year) Value of prevented fatality			
	2020s	2050s	2080s
Low	24.8	55.5	90.2
Central	57.8	118.2	195.9
High	104.4	225.1	385.9
Valuation £million/year) Value of Value of Life Year Lost			
	2020s	2050s	2080s
Low	0.7	1.6	2.6
Central	1.7	3.4	5.6
High	3.0	6.5	11.1

Table 20 Monetary valuation of heat related mortality – Glasgow City Region, £M/year. 2020 prices, undiscounted. Two different valuation approaches are used, the VPF and VOLY.

These results may not fully include the effects of heat waves and urban heat island effects. However, they also do not include natural acclimatisation (to changing temperatures over time), which would significantly reduce the values.

In addition to these fatalities, heat (and extreme heat) is linked with a range of other health impacts (morbidity). Previous studies (e.g. CCRA, HRW, 2012/ Hames and Vardoulakis, 2011) have estimated these additional morbidity impacts by correlating with heat related mortality, reporting that there are approximately 100 morbidity cases for each fatality. This leads to a larger number of cases than mortality, but the valuation of each individual case is much less. For the 2050s, this equates to an additional 2,700 to 11,000 cases per year, for low and high warming scenarios, and a central value of an additional 5,800 hospital cases per year from heat.

These can be valued, using estimates based on human cost, lost productivity and medical care. An upper value can be derived, based on the willingness to pay (WTP) values (£8,500) for respiratory hospital admission / cardiovascular admission, as applied in the air pollution context (Defra, 2019). A lower value is based on unit value of £700 per case, as used in the first UK Climate Change Risk Assessment (Hames and Vardoulakis, 2012), updated to 2020 prices. The resulting estimates are below. These significantly increases the overall impacts.

Valuation £million/year) High Respiratory hospital admissions			
	2020s	2050s	2080s
Low	10.3	23.1	37.5
Central	24.0	49.1	81.5
High	43.4	93.6	160.5
Valuation £million/year) Low Patient day			
	2020s	2050s	2080s
Low	0.9	1.9	3.1
Central	2.0	4.0	6.7
High	3.6	7.7	13.2

Table 21 Monetary valuation of heat related morbidity – Glasgow City Region, £M/year. 2020 prices, undiscounted. Two different valuation approaches are used.

There is also a link between heat, health and wellbeing. Above certain thresholds, heat can reduce comfort levels in buildings. This is partially covered by the potential increase in cooling (as an autonomous adaptation) but given the low levels of cooling degree days in Scotland, this is more likely to be represented as periods of hotter weather with higher internal building temperatures.

It is possible to consider the adaptation benefits in addressing these heat, health and well-being impacts. There are a large number of potential adaptation options to address these heat related risks, but they generally fall under two main themes:

- Health related interventions, including awareness and behavioural change; and
- Building and spatial planning related interventions.

The first of these has been a focus in the Adaptation Strategy, under the Intervention on early warning.

The main option is to introduce a heat alert system. Currently, unlike England and Wales, Scotland is not currently part of the heat health watch system (HHW), although it is covered by the broader National Severe Weather Warnings (NSWWS). There is evidence from previous studies on the cost and benefits of heat alert schemes, with analysis of the benefits and costs of heat alert systems across the world. A review of such schemes by Toloo et al. (2013) on the effectiveness of heat warning systems reports high effectiveness (reductions in heat wave related fatalities) but quite large variations between schemes. Whilst the average effectiveness was 40%, reviews of some systems indicated much higher benefits, as much as 80%. Several studies have also looked at the potential additional benefits of heatwave alert systems in reducing future heat related mortality under future climate change (Hunt et al., 2016; Bouwer et al., 2018; Chiabai et al., 2018). For example, the estimated benefits on setup of a warning system, real-time surveillance of health data, and emergency plans for vulnerable people with visits and care offer, were estimated to be 65% effective and have high benefit to cost ratios (Chiabai et al., 2018).

These studies indicate the economic costs in the Tables above could be reduced significantly – at least for heat-wave related fatalities (noting the tables include all heat related mortality which is higher). This would lead to large health benefits – and thus economic benefits. The economic benefits are indicatively estimated at 40% of the values in the tables above, this indicates annual benefits (assuming central values from the low and high sensitivities) could be £25 million/year by the 2050s for a medium warming scenario.

These can be compared to the potential costs of such a scheme. This has been estimated by Watkiss et al., (2019b). This estimates the costs of the early warning information for Scotland is very low (a few hundred thousand/year), however, it would have higher costs locally in Glasgow City Region from the triggering of the scheme, because of the resource costs of health professionals. The costs of running the scheme therefore increase over time, as it is triggered more frequently as the climate changes. In the 2020s, the costs would be very low. However, by the 2050s, because the scheme would be triggered every other year (due to the increase in heat extremes), these resources costs are significant. The total annual operating costs, including resource costs, is estimated at £6 million/year by the 2050s. However, this still means that the scheme has a very high benefit to cost ratio, because of the large benefits in reduced mortality and morbidity (i.e. 40% reductions in damage costs as shown in the tables above).

Deep Dive 3: Temperature-related Economic Opportunities

Temperature is one of the major drivers of energy demand in Scotland, affecting winter heating for both the residential and service/business sectors. More than half (51%) of the energy Scotland consumes in homes and businesses is used for heating, the majority of which is supplied by natural gas (Scottish Government, 2017).

Climate change will therefore have positive effects on future energy demand by reducing winter heating. These responses are largely autonomous and can be considered as an impact or an adaptation. These future changes are quite complex to assess, especially as they need to be seen in the context of other drivers (e.g. changing housing stock, insulation levels, income, prices) and because they are influenced by future net zero policy (both in terms of energy efficiency levels, but also energy source and energy prices).

Residential benefits

Information on current energy demand is available from the Scottish Energy Statistics (2018). These show that heating is predominantly supplied by gas (79%) and also show that Scotland has higher consumption of gas, per household, when compared to the UK average. This reflects the colder climate in Scotland.

The influence of temperature on energy demand can be assessed with the indicator of heating degree days (Jenkins et al, 2008), which is a metric to account for the effect of weather on energy consumption[5] and by implication, the amount of heating needed. The number of heating degree days in the UK – and for Scotland – have been falling (as captured in the UKCP09 observation trend reports, Hendon et al., 2019), and are now around 10% lower than the period of the 1961-1990 (Kendon et al., 2020). This is shown in the table below. However, other factors are also important in looking at changes in actual energy demand, and average energy consumption in Scotland is falling as a result of greater energy efficiency uptake.

Area	1961–1990 average	1981–2010 average	2010–2019 average
UK	2736	2570	2474
Scotland	3142	2994	2919

Table 22 Heating degree days for UK and Scotland, 1960–2019, expressed as anomalies relative to the 1981–2010 average. Source Kendon et al., 2020.

Heating degree days are projected to fall with future climate change, due to warming. The CCRA3 has estimates based on UKCP18, which indicate continued HDD falls in future years. Even for a 2°C scenario, there would be a large reduction in heating degree days – probably twice that observed to date. For higher warming scenarios, the reductions would be even larger. The CCRA3 estimates are shown below.

5 Heating degree days are an annual measure of the extent to which daily temperatures suggest that buildings may require some form of space heating, based on the daily temperature being below a threshold of 15.5°C. There are two ways of calculate HDD – a simple summation of the number of degrees Celsius the mean temperature is below 15.5°C for each day and a weighted summation.

HDD (degree days) compared to 1981–2000 mean					
Warming	**1.5°C**	**2°C**	**2.5°C**	**3°C**	**4°C**
Scotland	-334	-528	-642	-766	-1011

Table 23 Future Heating degree days for Scotland. Central estimates compared to 1981-2000 Source CCRA3.

There are different methods for assessing the future impact of climate change on heating demand – using econometric analysis, or impact functions based on heating degree days. For the analysis here, we use the latter. We use data from UK CCRA3 above to investigate the potential scale of benefits. There are considerable uncertainties with these projections, because they depend on the assumed population growth and household density, housing stock, the technology and efficiency of heating, insulation level, the fuel mix for heating, income and prices.

The analysis has first considered a business-as-usual scenario, with continued gas use rather than the move to net zero. Average annual domestic gas bills are currently an important part of household expenditure, averaging around £680/year in South Scotland (in 2019) (BEIS, 2020, assuming 15000 kWH/year). The reductions in heating could therefore generate the following level of benefits in the table below. These would translate into regional benefits of £100 million/year for 2°C rising to just under £200 million/year for a 4°C scenario. These do not consider socio-economic change (e.g. population, economic growth).

Warming	1.5°C	2°C	2.5°C	3°C	4°C
HDD reduction	334	528	642	766	1011
% reduction	11	18	21	26	34
Household saving/yr	76	120	145	173	229
GCR benefitsMillion/year	62.4	98.6	119.9	143.1	188.8

Table 24 Indicative reductions (economic benefits) in average household expenditure for business as usual, with current assumptions and current gas heating, current average heating bills (and no socio-economic change)

A number of caveats are noted with these estimates:

- The numbers above only include gas heating. In Scotland, around 20% of homes use electricity for heating. The benefits to these households are likely to be larger/household, due to the higher cost of delivering heating through electric power;
- The values assume constant (current) retail prices. It is stressed that the use of the long-run variable cost of energy supply values would lead to lower values, as these are around 40% of the retail costs (and such values would be used in government economic appraisal);
- The benefits of reduced gas use would have additional GHG mitigation and air quality benefits. These economic benefits can be valued using carbon values and air quality valuation estimates and would increase the economic costs above.
- However, there is an issue of potential rebound effects, as climate change reduces energy use and therefore energy bills, which will increase consumers' disposable income, in turn leading to greater consumption of energy (or other products and services).
- The benefits of reduced winter heating will also have positive distributional effects, as it will benefit those on low incomes the most (in relative terms). It will also help reduce fuel poverty. As low-income households spend a higher proportion of incomes on fuel (10%), these groups will experience largest relative benefits.

Benefits to business and industry

There are also winter heating related benefits for the non-residential sector (business and industry). These are potentially large, as industrial and commercial gas consumption makes up approximately 40% of all gas consumed in Scotland. For the analysis here, we have taken current commercial and industrial gas use in Scotland (BEIS, 2020b) and non-residential gas prices, and downscaled to Glasgow City Region. This indicates the additional benefits from reduction winter heating to business and industry in GCR are large, at an additional £11 to £32 million/year, depending on the future climate scenario.

Net Zero

These future benefits will vary due to population and economic growth, as well as changes in houses, insulation levels etc., i.e. with socio-economic change. The projected increase in new homes will increase the benefits, as the population and number of households in the region is set to increase.

However, the bigger impact is from the move to net zero. In 2019, the Scottish Government[6] committed to a target of net-zero emissions of all greenhouse gases by 2045. The Scottish Government has also set out that it will adopt an ambitious new target to reduce emissions by 75% by 2030, and has an ambitious Climate Change Adaptation Programme. Glasgow has announced a goal to be the UK's first carbon neutral city by 2030 following a decision of the Council's City Administration Committee[7]. This includes a large number (61) of actions[8].

This would mean that forms of zero energy are used for heating, rather than gas, and there is likely to be a much greater focus on energy efficiency to reduce energy use in homes. There would still be benefits from reduced winter heating, but they will be different.

There are still no clear policy commitments in Scotland, or indeed in the UK, on how to deliver net zero for the heating sector. The Committee on Climate Change (CCC) developed techno-economic scenarios of their Net Zero report (CCC, 2019). These scenarios illustrate ways in which extensive decarbonisation of the UK economy could occur by 2050 (to demonstrate that a Net Zero emissions target by 2050 is plausible). This was further updated in the 6th Carbon budget (CCC, 2020). This sets out that different pathways are possible, either with zero carbon electricity, e.g. powering heat pumps, or from switching from natural gas to hydrogen for heating. This is accompanied by energy efficiency measures.

6 The Scottish Government has amended the Climate Change (Emissions Reduction Targets) (Scotland) Bill such that GHG emissions in Scotland must reach net-zero by 2045 (**https://www.gov.scot/news/scotland-to-become-a-net-zero-society/**).

7 **https://www.glasgow.gov.uk/article/25066/Council-Sets-Target-Of-Carbon-Neutral-Glasgow-by-2030**

8 **http://www.glasgow.gov.uk/councillorsandcommittees/submissiondocuments.asp?submissionid=94826**

The CCC report outlines the following key messages:

- In residential buildings, the parts of the stock which are generally easier and/or less costly to decarbonise include new homes, homes off the gas grid, homes suitable for district heating, and homes on the gas grid with relatively low barriers.
- For non-residential buildings, a combination of energy efficiency, heat networks and heat pumps lead to near complete decarbonisation.
- The 'Further Ambition' scenario additionally deploys low-carbon heating and energy efficiency measures for homes which are considered more costly and/or difficult to decarbonise. This includes homes on the gas grid with space constraints, and homes with heritage value. This scenario also includes the conversion of residual gas demand to hydrogen.
- In non-residential buildings, the 'Further Ambition' scenario abates all residual CO_2 emissions. Gas used for peak heating demand in heat networks is decarbonised by shifting to hydrogen.
- The analysis confirmed that reaching net-zero emissions in buildings is achievable but that it remains costly, with a total annual cost compared to a theoretical counterfactual without any action on emissions estimated to be in the region of £15 billion in 2050 (UK).
- Delivering this will require a clear trajectory of standards. This includes delivering commitments announced under the Future Homes Standard, alongside ambitious standards for new non-residential buildings, delivering commitments on energy efficiency standards across the stock, and a long-term regulatory approach for delivering low-carbon heat.

In summary, the net zero target will have a major influence on these benefits of reduced winter heating costs, because it will affect energy technology and fuel choice, household energy efficiency (e.g. building standards) and thus potential demand, as well as energy prices. The exact influence is very complex and depends on how the net zero target is met.

A lower level of winter heating demand – due to climate change – will have benefits in reducing household costs for space heating, perhaps offsetting some of the cost increases from the transition to net zero. Note that while energy efficiency measures would reduce baseline energy heating demand, and thus reduce the benefits above, delivery of electric or hydrogen powered heating is more expensive than gas, per kWh, thus there would still be very large economic benefits from warmer temperatures. However, climate change could also make net zero slightly harder to achieve in GCR, because it involves more complex consideration of designing household energy systems for a changing climate. It is much easier to design a new net zero energy system for a static climate than one that is changing, especially because the measures taken to improve energy efficiency have a direct influence on household overheating potential, and because if there is an increase in cooling demand, then it changes the potential option choice for homes (i.e. from heating only to duel heating and cooling).

Further work in this area is recommended as the Adaptation Strategy is delivered, to ensure an integrated analysis of net zero and climate resilience objectives.

PART 4

Economic Analysis of Glasgow City Region's Adaptation Strategy

Introduction

The Clyde Rebuilt project has supported Glasgow City Region in developing an Adaptation Strategy. The Strategy sets out the vision for the Region, and provides a strategic framework for adaptation in and by Glasgow City Region, that fits alongside and supports key plans, policies, and activities. It also sets out the governance and enabling environment to take adaptation forward.

The Strategy is built around a series of Interventions. Some of these Interventions take a proactive but incremental approach to adaptation. In such cases, the aim is to improve the climate resilience of existing systems and actions, e.g. by mainstreaming climate change into policies, programmes, and plans. In other areas, however, this incremental approach will not be sufficient to address the scale of future risks. In such cases, a different form of adaptation is needed, involving more transformational adaptation.

The Strategy sets out 11 Interventions, presented in the figure below. This maps the Interventions into incremental versus transformational adaptation (y axis) but also the boundaries between adaptation, adaptation and mitigation, or sustainable development (x axis).

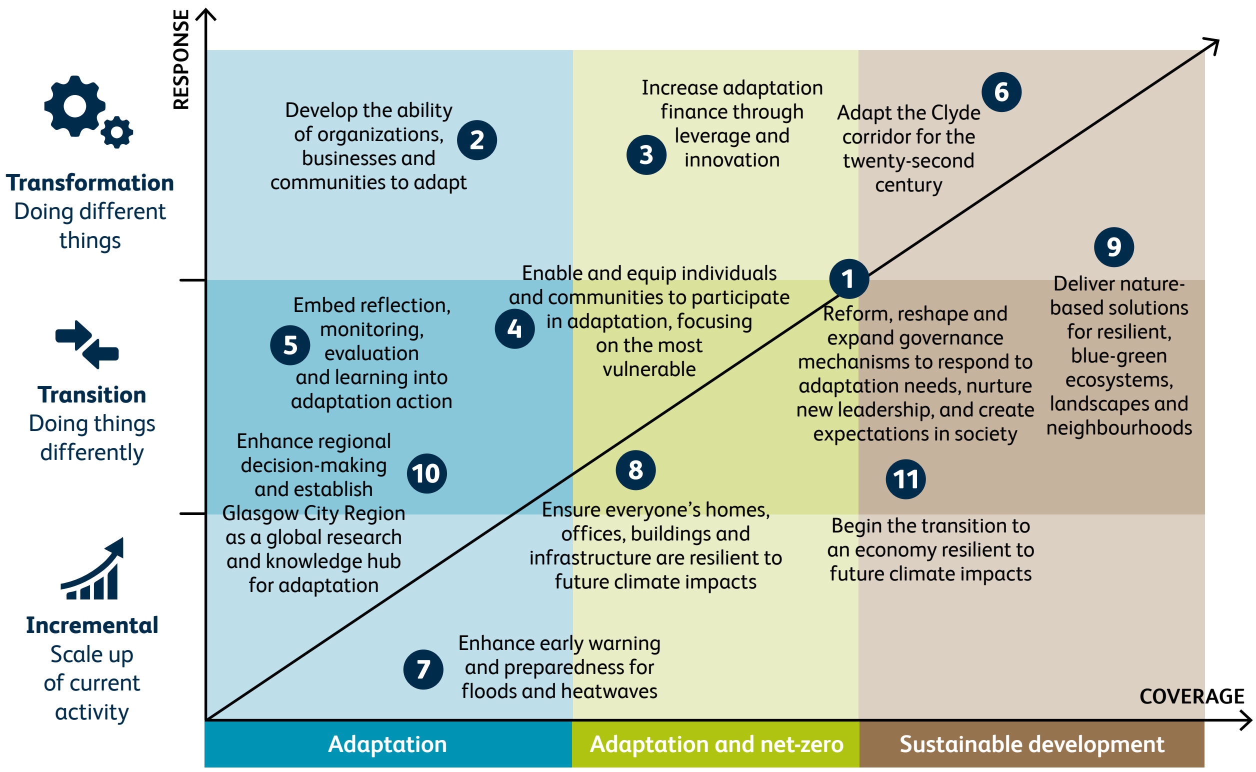

Figure 7 Regional Adaptation Strategy Interventions by coverage and type of response.

This component of the project has assessed the indicative economic costs and benefits for each of these 11 Interventions. These are presented in turn below. In each case, we review the economic rationale for the intervention, then look at the economic case, including the potential costs and benefits.

Economic Analysis of Adaptation Strategy Interventions

Intervention 1

Reform, reshape and expand governance mechanisms to respond to adaptation needs, nurture new leadership, and create expectations in society

This Intervention aims to create societal expectations for transformative adaptation, and to ensure that GCR has new governance mechanisms, institutional structures and leadership to enable the City Region to adapt effectively. It includes four actions:

- A detailed review of a new institutional landscape needed for adaptation – which identifies ways of enhancing governance for adaptation and how institutions work together, explores the changing civic space and the shifting role of the Region and technological advances.
- A broader coalition of actors mobilised to deliver the Strategy – with new public, private and third sector actors engaged, guided by a focus on those who are most influential for change or likely to be most affected.
- Adaptation leadership that is nurtured and developed – where all those involved (public sector, trade and professional networks, and community leaders) better understand the specific challenges associated with adaptation activity.
- News, arts, media and cultural organisations telling stories about the climate crisis and opportunities to adapt.

Economic Rationale:

Governance barriers and behavioural inertia hinder adaptation decision-making and action, and are amongst the hardest to remove. They include coordination problems between different institutions and across different jurisdictions, lack of clarity on the roles and responsibilities of different stakeholders, and lack of strong leadership. In regions, these institutional aspects may be compounded by the problem of competing priorities, and the need to address short-term priorities (rather than long-term climate risks), inherent in political and indeed medium-term (5 year) planning cycles. There is therefore a strong economic rationale for public action to address these barriers, and create the governance mechanisms for effective adaptation.

Economic case:

The benefits of governance change are difficult to quantify and estimate in monetary terms. However, strengthening the governance landscape is generally reported as a low-regret intervention (ECONADAPT, 2017) and it will benefit the regional decision-making processes at a low-cost, overcoming barriers where they exist. The extension of governance frameworks to consider new actors, is also seen as highly beneficial in the literature. The use of local participatory forums and disaster planning was found to have very high economic benefits (Cartwright et al., 2013) across all options, and while it is in the international context, building resilience through grassroots organisations working with government officials has been found to be among the most effective approaches (Satterthwaite et al., 2020). This indicates that encouraging participatory and inclusive approaches and developing a skilled and motivated leadership are key to supporting adaptation action.

A literature review has identified further support in this area:

- Hurlbert and Diaz (2013) report that collaborative arrangements contribute to securing political agreement around the climate change agenda, but also channel the participation of civil society.
- Plummer (2013) emphasises how adaptive co-management favours collaboration among heterogeneous actors with diverse interests, and by doing so, this brings together public and private actors to address an environmental or resource problem.
- Lorenzoni et al. (2016) looked at the Regional Flood and Coastal Committees (RFCC) established in the UK by the Environment Agency under the Flood and Water Management Act 2010, and found that these contributed to a more collaborative-type flood management processes at the regional scale.
- Gram et al. (2016) found that, for the adaptation plan for the City of Kalounberg, enabling access to information and openly discussing controversial topics with citizens and stakeholders supported the municipality to address sensitive issues and plan for unpopular measures.
- Stanley (2016) describes the lack of leadership and guidance from national and state levels as one of the main barriers for local climate adaptation activities in coastal towns in Australia.
- Sharma-Wallace et al. (2018) conducted a systematic literature review on adaptive governance good practices and found that leaders can help identify or reframe environmental problems, build networks across stakeholders and scales, coordinate financial and organisational support for governance activities, design and implement innovative management interventions, and galvanise communities to action. They also found that ongoing capacity building is needed to ensure that when leaders leave others are willing, prepared, and equipped to continue their work in ways that resonate with the community and existing governance support networks.

Financial case:

This is one area where funding will be predominantly public, related to enhancing current government arrangements and developing new ones, though there is some potential to bring in funding from the third sector (e.g. from non-government organisations or foundations). There will not be a strong financial case for changes in governance on its own (and thus there is not a commercial financial case), but these activities will enable other actors and other forms of adaptation to get involved and help subsequent cases.

Intervention 2

Develop the ability of organisations, businesses and communities to adapt

This Intervention aims to enhance the contribution from businesses and communities to increasingly contribute to making adaptation happen. It includes the following actions:

- An enhanced programme to increase awareness of the potential impacts of climate change on organisations and communities and opportunities to adapt.
- Establishment of a City Region working group/forum and mentoring programme. Partnering public, private and third sector organisations together with those that broker knowledge to support greater integration of climate change into their strategic decision-making, supported by tools and techniques to make it happen.
- Targeted community capacity building for adaptation. In addition to capacity building of organisations and communities most exposed or vulnerable to impacts should be given opportunities to build their adaptive capacity and resilience.

Economic Rationale:

The lack of information (a market failure), and lack of capacity to act, are important barriers to adaptation. These issues are particularly important for the private sector (and thus businesses) as well as local communities, and leads to inertia. The Treasury Green Book (HMT, 2019) identifies a key market failure is around imperfect information, as information is needed for markets to operate efficiently. There is therefore a strong economic case for investing in information and tools (as a public good) and to build capacity for these actors. Climate mainstreaming is also considered an effective way to support adaptation by favouring integration into plans, strategies, and processes, and promoting coherence and consistency across key sectors (Watkiss and Cimato, 2016: WRI, 2018).

Economic case:

There is a strong economic case for capacity building, from the improved outcomes it generates, and associated economic benefits. However, the economic appraisal of these investments is challenging. Improved information (and tools) have benefits from the value of information they generate, i.e. the improvement in decisions that arise from their use. Capacity building and training in climate sensitive sectors has been found to have very high benefit to cost ratios (>10:1) (Mullan et al., 2015). Institutional strengthening and capacity building to support implementation of climate adaptation options have also been found to have large benefits, because they increase efficiency of implementation (Watkiss and Cimato, 2016). They are generally rated as low-regret activities, because of the low cost, but high benefits (i.e. a small improvement in efficiency of delivery more than offsets the costs of capacity building).

Financial case:

The investment in information, tools and capacity building are also an area where funding will be predominantly public, because it is investing in public goods. These are therefore activities that would be expected to be funded by government and there is not a commercial financial case. However, the information and capacity provided will lead to financial benefits for businesses and communities as they apply these in adaptation decisions, and thus will improve the financial case for subsequent adaptation. It is also highlighted that the private sector will need to invest time and resources itself, e.g. to engage in working groups/forums and take action to integrate (mainstream) climate change into their plans, strategies and processes, and thus there may be in-kind financing.

Intervention 3

Increase adaptation finance through leverage and innovation

The aim of this Intervention is to mobilise and scale the resources needed across the City Region to implement the Interventions in the Adaptation Strategy. It includes the following actions:

- Strategic use of public sector funds to attract private sector investment – with public institutions taking a more commercial approach to spending, to lever in private sector investment.
- A regional adaptation finance strategy and action plan that sets out how to mobilise the required finance to deliver the Adaptation Strategy.
- Mapping and measurement of regional adaptation finance flows –to build understanding of the Region's finance requirements for adaptation.
- Piloting of new approaches to transformative adaptation finance.

Economic Rationale:

The availability of finance is an obvious and important constraint to adaptation. Even the best adaptation plans will not be implemented if they lack the necessary financial resources. The availability of finance is therefore a key enabler for the delivery of the overall Adaptation Strategy. This is expanded further in a separate deliverable in Clyde Rebuilt, Deliverable 6, the Resource Mobilisation Plan.

Economic case:

The benefits of raising finance for adaptation are obvious. However, the nature of the investment required – often with the characteristics of public goods and/or without commercial revenues – means that there is a need to create funding mechanisms able to combine both private and public resources. Creating the incentives for the private sector to invest when these are not clear or visible to private actors will be key to attracting capital. The economic case is therefore strong for investing time and resources to develop financing plans (including new financial instruments), because of the leveraging potential that this will generate. In effect, a small investment (cost) in this area will generate a large potential volume of finance flow, and this justifies the expenditure in this area.

Financial case:

This Intervention will create a financial platform and a framework for multiple funding sources to meet and co-fund a regional plan for adaptation. Public resources will be needed to create the platform and to do the initial work on the development of new financing models and instruments. The focus will be to generate approaches that crowd-in private finance, and thus there is a strong financial case for this investment, through the leveraging potential and scale-up of finance. This is set out in the separate deliverable in Clyde Rebuilt, Deliverable 6, the Resource Mobilisation Plan.

Intervention 4

Enable and equip individuals and communities to participate in adaptation, focusing on the most vulnerable

This Intervention aims to increase the role for individuals and communities to shape their places so they are climate ready, and increase the resources for equipping them to do so, to increase the pace and scale of community and local level action on adaptation. It includes the following actions:

- A shared understanding of how current community engagement is structured for adaptation.
- Increased community involvement in the Region's adaptation governance, decision-making, planning and delivery, with new decision-making processes that support implementation and delivery of adaptation that is more democratic and inclusive.
- Resources, training and education for communities and young people to shape their places, with new/enhanced toolkits and resources to support communities.
- Collaborations between organisations, communities, artists and cultural practitioners to stimulate creative and relevant adaptation responses.

Economic Rationale:

As with Intervention 2, the lack of information (a market failure), and lack of capacity to act, are important barriers to adaptation. There is therefore a strong economic case for investing in information and tools (as a public good) and to build capacity for these actors. These issues are particularly acute for the most vulnerable, who have low access to information and resources, and generally less decision-making power. Raising the adaptive capacity of communities and favouring their integration in the decision-making process will help find and deliver local solutions to address local problems, and favour greater ownership.

Economic case:

As highlighted above, building resilience through grassroots organisations working with government officials has been found to be among the most effective approaches (Satterthwaite et al., 2020). There is also some additional evidence in the literature that engaging communities in the adaptation decision-making process can lead to important benefits.

- Community engagement is a key component of governance and aligns to the principle of subsidiarity: that policy decisions are best made at the most decentralised or most local level at which effective action can be taken (Rawsthorne and Christian, 2004).

- McKinney and Harmon (2007) find that benefits include broadening and deepening local input, securing and sustaining local ownership and support, improving effective communication of key policy issues and directions. This heightens the trust, transparency and credibility of decision-making processes and improving social networks and connectedness.

- The New South Wales Department of Environment and Conservation (2006) in Australia conducted a meta-analysis review and found the following five key reasons for investing in community engagement strategies to improve environmental planning and decision making:
  - More effective projects. Participants become owners of the outcomes.
  - Trust and credibility. Builds relationships and allows the community to understand the constraints.
  - Cost savings. High-engagement projects mobilise volunteer energy.
  - Technical competence. Knowledge is captured through engagement; people bring depth, historical knowledge and new ideas to projects.
  - Better management of environmental, social and political risks. Increase the perception of openness and fairness, and reduce risks of conflict.

- Plante et al. (2016) found that participatory action research (PAR) can be an effective tool for enhancing governance capacity of communities to develop and implement adaptation strategies, as compared to a top-down approach, where information remains static and restrictive in terms of knowledge acquisition by the local actors and often leads to disengagement of the community.

- The Environment Agency (2019) reports on the effectiveness of some practices in building the understanding of climate challenges amongst communities, developing capacity for decision-making around adaptation options, and enabling exploration of how people understand and value the places they live in.

It is also highlighted that there is a strong economic case for helping the most vulnerable to adapt, when distributional effects are considered. This means that this intervention is likely to have very high distributional benefits.

Financial case:

The financing of activities associated with changes in decision making, and training and education, are likely to be predominantly public. However, there is some potential to bring in funding (and resources) from the third sector (e.g. non-government organisations or foundations or impact investors) for some of these activities, and also especially for local, community implementation of actions.

Intervention 5

Embed reflection, monitoring, evaluation, and learning into adaptation action

This Intervention aims to foster a learning culture within the City Region to increase the impact of all 11 Interventions, and to enable citizens to hold organisations to account through a process of monitoring and evaluation. In addition, it will build networks that further develop relationships with comparably vulnerable cities and regions around the world to exchange knowledge and learning. It includes the following actions:

- Learning by doing – building in active reflection and learning process with Climate Ready Clyde encouraging all those involved in delivery of the Adaptation Strategy to draw on local and cultural knowledge.
- Encourage large organisations to sign up to relevant international reporting initiatives, to share learning and collaborate on effectiveness and increase the Region's visibility of our work.
- Alignment of planning assumptions between domestic adaptation planning and the emerging TCFD/ investor regimes.
- Learning and knowledge exchange with other cities and regions, working through the international climate networks to develop new partnership and relationships to learn from progress and support further efforts in adaptation.

Economic Rationale:

Climate change involves inherent uncertainty, and this makes decision making difficult, often leading to inertia. There is a strong economic case for using an adaptive management approach, which includes a cycle of pilots, demonstration, monitoring, evaluation and learning, to improve future management strategies or decisions (Watkiss et al., 2014). There is also a high potential for demonstration and pioneer projects, especially for more transformational change, to address risk perceptions and allow learning.

Economic case:

There is a growing number of studies that apply the concepts of decision making under uncertainty, and iterative learning cycles, to help adaptation, which include economic analysis (ECONADAPT, 2017). These shows that these iterative approaches lead to higher benefit to cost ratios, when compared to more linear predict-and-optimise decisions. There is also a case for the value of information generated by learning. Learning has a value, as it leads to different actions, and allows higher benefits or lower costs as a result. Learning activities, can therefore be seen as a low regret action.

Financial case:

The financing of learning activities is likely to be predominantly from public sources, to set up the monitoring, evaluation and learning system. However, this will generate information for sharing and dissemination that has a value. This will benefit multiple actors, including public, private and third sector.

Intervention 6

Adapt the Clyde Corridor for the twenty-second Century

This Intervention aims to develop a long-term, iterative strategic pathway to match investment planning with the changing climate risks, including new investment and development on the Clyde Corridor. It includes the following actions:

- Work through Clyde Mission to govern climate risks for the entire river corridor – to manage the entire of the Clyde Corridor's changing climate risks over time.
- Develop an iterative adaptation pathway for the Clyde as a new, iterative, flexible approach to balancing development and climate risk in the river corridor over time. This will include long term management of coastal, river and surface water risks, and prioritise 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 and National Planning Framework.

Economic Rationale:

Adaptation to coastal and river flooding along the Clyde Corridor has the characteristics of public goods, and can generate positive externalities, though it is likely to involve significant costs. There is a strong case for the Government to intervene in supporting coastal and river flooding adaptation, and this intervention will help build the approach and governance arrangements, an iterative adaptation pathway, and embed it into national plans.

Economic case:

Coastal and river flood planning has benefits as it takes account of a range of public good characteristics. For example, flooding may be prevented by investment in flood defence systems. However, these would be under-supplied by private investors who have little incentive in investing in defence systems that would benefit others as well (indeed, they have an incentive to wait for others to make the investment and free-ride). Coastal and river spatial planning by a public agency may also be able to account for non-market external costs and so improve the economic efficiency of decision-making. Spatial planning generates economic benefits through the value of information, notably from avoided damages and losses.

As highlighted in the previous section (See Table 18), flooding already leads to annual expected costs of £70 million/year, and these are projected to increase very significantly with climate and socio-economic change, potentially doubling by mid-century without adaptation, and much more than this by later century under high warming scenarios. As also shown above, adaptation to coastal and river flooding in the Region will have high economic benefits, reducing down the damage costs from future climate change (avoided losses) by potentially tens of £millions/yr (also Table 18).

Economic analysis of flood infrastructure has also found high benefit to cost ratios (averaging approximately 5:1) (Mechler, 2016). A recent European review (ECONADPT, 2016) containing 110 observations on flood projects from 32 studies and databases in 16 European countries found a mean BCR of 6. Studies (Brown et al., 2011: Hinkel et al., 2014; Brown et al., 2015) find that adaptation to floods is an extremely cost-effective response, particularly reducing coastal flooding costs down to very low levels at low cost. These studies also show it is most economically robust to invest in protection where population densities are high, i.e. urban areas such as the Clyde Corridor. The use of green infrastructure can deliver similar economic benefits, and has additional benefits from avoided GHG emissions and wider socio-economic benefits.

The use of an iterative approach and the use of adaptation pathways for major coastal corridors have high (ex ante) benefit to cost ratios, as shown in the economic appraisal for the London Thames Estuary 2100 project (EA, 2011), as well as in the Netherlands as part of the Delta programme with dynamic cost-benefit analysis (Kind, 2014: Eijgenraam et al., 2014). Early work on adaptation pathways for the Clyde Corridor (Watkiss et al, 2019b) suggests high benefits for a similar adaptation pathway approach, although the options will vary (e.g. a large barrier for the Clyde is unlikely to be cost-effective).

Financial case:

Historically, flood protection has been funded by the public sector, recognising the public good nature of defences. However, there is an interest in getting greater private sector finance in flood funding, using a range of potential models, from direct funding, through to blended public-private models, insurance and others: these are set out in the finance Resource Mobilisation Plan (Deliverable 6).

Intervention 7

Enhance early warning and preparedness for floods and heatwaves

This Intervention aims to reduce the numbers of people impacted by flood risk and overheating by investing in early warning and preparedness, with a focus on the most vulnerable to the impacts of climate change. It includes the following actions:

- Extension of the flood warning scheme in Glasgow City Region.
- Implementation of an integrated climate alert warning system for Glasgow City Region covering the full range of hazards, such as drought, heat, wildfires and landslips.
- Continued delivery of strategic Flood Risk Management activities.
- A regional property flood resilience and resistance installation programme to support the cost of installing property resilience and resistance measures, to accelerate roll out of property level protection across Glasgow City Region, with priority going to the most socially vulnerable.
- Exploration of new insurance models to cover potential risks to the existing insurance models and new insurance models or instruments to ensure a viable long-term market.

Economic Rationale:

This intervention directly addresses some of the key barriers of climate change adaptation, notably the lack of information on climate risks and adaptation measures, and the need for a coordinated response by those affected by climate-related events. These can be achieved through enhancing early warning.

Economic case:

There is a very strong economic case for investing in early warning systems. These are generally considered to be no-regret options, because of the reduction in damages. We have considered the economic case for Flood Warning, Heat Warning, Resilience and Resistance measures, and insurance separately given their differences.

Flood warning – Early warning systems (EWS) for coastal and river flooding. The international literature identifies very high benefit to cost ratios for EWS, at around 10:1 (ECONDAPT, 2016: GCA, 2019) even for existing schemes. These benefits increase under future climate change, in line with the increase in severity and frequency of flood events. Note, however, that early warnings are generally not sufficient to reduce all damages, so should be part of wider package of interventions. There is existing flood risk warning in Glasgow City Region, but there is a strong economic case for strengthening this, including to cover surface water. Benefits can be improved by investing along whole weather value chain (i.e. improved accuracy and timeliness, greater communication and reach, and by working with users to help uptake and effective use of information) not just meteorological infrastructure and warnings.

Heat alerts – There are also similarly high benefits from early warning systems for heat, notably for heat alert systems. The international literature finds these have high benefits in reducing fatalities (Toloo et al. 2013) and they have high benefit to cost ratios as found in several economic assessments (Hunt et al., 2016; Bouwer et al., 2018; Chiabai et al., 2018). The analysis for Glasgow City Region context is presented in the previous chapter, but identifies high economic benefits and low costs, with according a high benefit to cost ratio.

Resilience measures – These are measures that are undertaken inside a property to reduce damage caused by floodwaters. Flood resilience, or wet proofing, accepts that floodwater will enter the building and allows for this situation through careful internal design such as raising electrical sockets and fitting tiled floors so that the building can quickly be returned to use after the flood. The costs of these include survey costs (EA, 2015), installation costs (EA, 2015; Wood Plc, 2019) and maintenance costs (EA, 2015). Generally, the literature reports that these measures are more expensive if retrofitted rather than installed in new builds.

Resistance measures – Flood resistance, or dry proofing, techniques prevent floodwater from entering a building. This approach includes, for example, using flood barriers across doorways, airbricks and raised floor levels, to prevent floodwaters from entering a building structure. The applicability of these measures depends on the type of flooding (recurrence and depth), as this alters the relative cost-effectiveness (and benefit to cost ratio).

Recent work for ASC (Wood Plc 2019) found that a number of flood resilience and resistance measures are no-regret adaptation measures (i.e. a benefit to cost ratio of greater than one in cases where there is a greater than 1% chance of Annual Exceedance Probability (AEP)).

An indicative CBA analysis of household resilience and resistance – based on the CCC analysis (Watkiss et al., 2019) – indicated that there are some very low-cost resilience measures which are effective in reducing damage from flooding. These could be considered as no-regret for all new houses built in areas at risk. This means more should be done to help the industry promote and 'sell' such measures to developers and architects. However, a 'complete' package of all resilience measures is expensive, even when built in new houses, and may not pass a CBA test for low risk areas (but could be viable for high risk areas > 2% annual flooding risk). Resistance measures for new houses have a reasonable cost per property (below £1500) and the analysis found that they are able to deliver high BCRs under all future climate scenarios.

Insurance models. Insurance is a risk spreading mechanism, and has been previously assessed as a low-regret option (IPCC, 2014). However, in the absence of adaptation, the increase in flood events and damages could undermine the current model, and therefore new approaches are needed.

Financial case:

Public/grant funding will be necessary to fund early warning schemes (floods and heat), and this is justified based on the public good characteristics. Individuals and the private sectors are likely to fund measures to increase the resilience/resistance of private properties, though there is the potential for subsidies to help the most vulnerable and low-income households, though information campaigns and the regulatory framework can help to create the enabling environment for (private) adaptation. Insurance is funded currently by households, through the market, though there will need to be investment into research and development of new mechanisms for risk-spreading.

Intervention 8

Ensure our homes, offices, buildings and infrastructure are climate resilient

This Intervention aims to introduce set of activities to ensure climate resilience for new investments, existing homes, offices, and infrastructure, and which will begin planning new infrastructure required for resilience. It includes the following actions:

- Adaptation embedded in Glasgow City Region's net-zero transition ensuring the pathway to net-zero is resilient to the changes ahead.
- Creation of an adaptation forum for Glasgow City Region infrastructure working through the infrastructure portfolio of GCR City Deal to improve knowledge and understanding of risks.
- Adaptation of existing infrastructure, with policies and regulation to require all new investment to be climate resilient.
- Strengthening of adaptation requirements in the planning system supported by Scottish Government, Clydeplan and Local Planning Authorities through the National Planning Framework 4, the Regional Spatial Strategy and Local Development Plans and building standards.
- Creation of a regional retrofit framework for climate resilience, for use by the Region's building owners to assess climate resilience needs of building stock, and to underpin development of a retrofit programme which ensures stock is fit for the future, aligned with the net zero target.
- Creation of a framework for adapting cultural heritage assets.
- Lobby UK and Scottish Governments to reform infrastructure investment frameworks with Core Cities, and the Scottish Cities Alliance making for reforms to drive more investment into adaptation.
- Evaluation of future adaptation infrastructure needs with a strategic review for the City Region to identify and evaluate new infrastructure that may be required for future adaptation, with a view to developing an investment pipeline.

Economic Rationale:

This Intervention is primarily focussed on ensuring regional infrastructure and the built environment is resilient to climate change. Infrastructure and built assets are long-lived (typically 30+ years), so the infrastructure that we build today will be influenced by future climate risks, but may also lock-in development areas to future exposure and vulnerability. The impact of climate change on infrastructure can also lead to cascading and converging risks (Koks et al., 2019; Pant et al, 2020), e.g. transport disruption, loss of power, that can affect the regional economy (and can double direct risks for major events). There is therefore a case for public investment to help provide the information and incentives to climate smart public and private infrastructure provision, including the built environment. This is extremely important for new infrastructure, given the opportunities during design, but may also include incentives to retrofit the existing infrastructure and building stock, if the benefits of doing so outweigh the costs. Given the challenges embedded in decision-making in the presence of uncertainty, information gaps, and misaligned incentives, and the public nature of the goods and services provided by the infrastructure network, there is strong case for the government to intervene to create an enabling environment for adaptation. This also involves strong linkages to the new net zero ambitions (for Scotland and particularly Glasgow) and the need to create the enabling environment and incentives to ensure synergistic options are taken forward.

Economic case:

The analysis of flood related damages by Sayers et al (2020) identifies increases in flood risks for infrastructure in GCR, including Category A (including water treatment, energy and communication infrastructure sites) and Category B (including railway stations, landfill sites, hospitals and blue light service stations, care homes, GP surgeries, and schools). As the tables in the previous chapter also highlight, there are a large number of residential and non-residential properties at risks of flooding, now and increasing with climate change in the future. There is therefore a strong case for adaptation.

The Global Commission on Adaptation (2019) and the World Bank Lifelines report (Hallegatte et al. 2019) both show that making existing and new infrastructure more resilient to the shocks and stresses of the changing climate, makes sound economic sense, with a high benefit to cost ratio: on average, the benefits outweigh costs by a ratio of 4:1.

The economic case for enhancing the climate resilience to flood risks is very high. This can be seen by the case for the residential and non-residential buildings in the previous section, and the general findings in the literature, which indicate benefit to cost ratios of 6:1.

In terms of building overheating, there are lower risks in Scotland than in most of the UK, because of the colder current climate, but the increase in heat extremes is projected to increase, and these could be particularly important for Glasgow city, because of the heat island effect. There is a reasonably extensive literature on the benefits and costs of addressing overheating in buildings. This includes analysis of alternatives to mechanical cooling (passive cooling) in new houses and retrofits (Davis Langdon (2011): Frontier et al., (2013); ASC (2014); Li et al., 2019: Wood Plc (2019); CCC (2019)). These generally report positive benefit to cost ratios or high cost-effectiveness (£/% reduction in temperature), but these may be lower for Glasgow City Region (because of the cooler climate). This indicates the potential for low-regret options but also that there is a need (and opportunity) to address further risks in climate smart design to address lock-in risks. Further work is needed to undertake local cost-benefit analysis to see if these options may make economic sense.

It is also highlighted that addressing these risks require collaboration across regional government (and linkages with national government), and capacity building and investing in improved governance are likely to be needed, though these are considered no-regret activities.

Financial case:

While public/grant funding can create the enabling environment and regulatory framework for adaptation, and can invest in public infrastructure, this is one area where there is a high opportunity to look for private sector finance. This is explored in the Resource Mobilisation Plan (Deliverable 6) but could include blended finance.

Intervention 9

Deliver nature-based solutions for resilient, blue-green landscapes and neighbourhoods

This Intervention aims to accelerate the rollout of green and blue solutions, through a regional strategic network, targeted local interventions. It includes the following actions:

- Identify regional priorities for nature-based solutions (NBS).
- Delivery of the regional Strategic Green Network an emphasis on maximising the contribution of the network to adaptation.
- Creation of the Clyde Climate Forest.
- Increase investment in targeted habitat restoration for natural flood management, including in peatland, wetlands and transitional habitats.
- Roll out of large-scale blue and green infrastructure projects to demonstrate benefits to communities – either through new green infrastructure or removal of hard landscaping or public realm.
- Support for new local infill or expansion of existing nature-based solutions to strengthen the regional network.
- Develop and accelerate blue and green infrastructure financing.

Economic Rationale:

Nature-based solutions, including ecosystem-based adaptation and (resilient) green infrastructure, can provide economic benefits from avoided losses, but also lead to other co-benefits, including mitigation (carbon storage), recreational and health benefits. Together, these multiple benefits make a strong case for support (McVittie et al., 2017). However, the public nature of this type of adaptation, and the fact that many benefits are non-market in nature, makes it difficult for the private sector alone to invest. This therefore calls for the government to either provide these goods directly or create mechanisms to involve the private sector in their delivery.

Economic case:

There is a growing literature on the economic benefits of nature-based solutions for adaptation. NBS provide 'ecosystem services', i.e. provisioning, regulating, cultural and supporting services. These include wider economic benefits from amenity and recreational value; improved physical health and mental well-being; social cohesion; air quality improvements; and CO_2 sequestration, as well as adaptation benefits from reducing water runoff/managing flood risks and/or reducing urban heat island (UHI) effects (Demuzere et al., 2014; Matthews, 2015). In general, the literature reports good benefit to cost ratios for these interventions, when these wider benefits are taken into account. However, because many of these benefits are non-market in nature, NBS have higher economic benefits than financial benefits.

There are also a number of natural flood management options, although many of these focus on coastal options. Seddon et al. (2020) report that across 52 coastal defence projects in the USA, nature-based solutions were estimated to be two to five times more cost-effective at lower wave heights and at increased water depths compared to engineered structures. However, they have limits for more major events. In the urban context, green SuDS are one targeted option. There are studies that identify an effective role for these interventions in urban natural flood management. The benefit to cost ratios of SuDS have been studied (Ossa-Moreno et al. 2017) and finds these are generally positive, and there is guidance existing for estimation (Benefit of SuDS Tool (BeST) (UKCIRIA)), although the financial case alone does not appear to incentivise adaptation. These options tend to be quite site and context specific, and SuDS alone may be limited for coping with more major flood events (Dadson, 2017).

For cooling, there are a range of green options that move in scale from small-scale urban planting through to major urban green spaces. The literature reports that cooling benefits from green space options could reduce local temperature by 1- 2°C (Tapper, 2019: Kingsborough et al. 2017), although some studies report higher values at the localised scale (Thom et al., 2016), or if very large areas of urban land are converted to green. The benefit to cost ratio of green urban spaces shows a large range, which are very site and context specific, however, studies report that recreational benefits dominate the current benefits (Holzinger et al., 2014: Dennis and James, 2016) and cooling benefits are relatively low in economic terms. Nonetheless, the analysis of the costs and benefits of green space as an adaptation option (Liu et al. 2016; Mendizabal and Peña, 2016, Loibl et al, 2015) do show positive benefit to cost ratios (BCRs) for small urban schemes, when the multiple benefits (including recreation) are included.

The development of new green space often has lower benefit to cost ratios, due to the high opportunity costs associated with land-use (and land-use values) in major urban centres. This means that it can be more difficult for schemes to be economically justifiable based on adaptation benefits alone. However, wider benefits, and potential improvements in property values around a scheme can alter this. Smaller schemes can address some of the cost barriers, but have much lower / or more localised flood reduction or cooling effect.

As a result of the issues above, many schemes blend grey and green infrastructure together. This was adopted in the City of Copenhagen (2012) Cloudburst Management scheme, and this combined approach reduce the costs of grey infrastructure alone. Similarly, New York is developing schemes that blend green and grey together in portfolios (Aerts et al, 2013). Nature-based approaches often create (additional) recreation opportunities for locals and tourists and can therefore contribute to long-term gains in employment and income. Nauman et al. (2014) report that NBS along the River Elbe and its tributaries have a total economic benefit of €1.2 billion and a benefit to cost ratio of 3:1.

One option that is sometimes included is green roofs. These can provide multiple benefits, including reduced heating or cooling demand. However, the economic analysis of these shows they have low adaptation potential, and may not pass a cost-benefit test (Nurmi et al., 2013: Meyers et al., 2015; Mahdiyar et al., 2016). Further, many of these benefits are non-market in nature, and thus their private financial attractiveness is low.

When the full range of benefits are included – particularly the more intangible but real non-market values such as health, amenity, recreational, cultural and environmental regulatory benefits – NBS have positive benefit to cost ratios. This points to the need for GI to be advanced as options that address multiple objectives (rather than as exclusively adaptation options).

Financial case:

As highlighted above, the financial case for NBS is lower than the economic case, and these options often take time to establish: this makes them less attractive from a private investment viewpoint. Many schemes have therefore been public in nature. However, there are options for leveraging private sector finance to deliver and maintain green infrastructure. Examples include payment for ecosystem services, which create markets and payment schemes for environmental services (PES), e.g. for upstream flood management, or green space along river-ways to provide storm buffering and flood protection services. It is also possible to use challenge funds to promote the design and implementation of innovative solutions with the nature of public goods (e.g. as with the Biodiversity Challenge Fund of Scotland, Scottish Government 2019). There is also a further opportunity through the carbon markets.

Intervention 10

Enhance regional decision-making and establish Glasgow City Region as a global research and knowledge hub for adaptation

This Intervention aims to establish Glasgow City Region as a living lab for research and innovation. It includes the following actions:

- Enhanced adaptation research through open invitation to collaborate on publicly available research priorities – with Glasgow City Region promoted as a place for research and experimentation on climate change adaptation.
- Glasgow City Region established as a living lab for climate adaptation with the City Region providing a platform for academics to conduct research into climate resilience and adaptation.
- Convene an Expert Advisory Committee on Adaptation to provide actionable advice to actors in Glasgow City Region to ensure better evidenced decision-making.

Economic Rationale:

This intervention is to increase research and innovation, and thus directly contribute to supporting information and learning for climate change adaptation. There is a strong case for this through the value of information generated, which will allow improved decisions, and greater effectiveness and efficiency of implementation. It is likely to be particularly important for upscaling of transformational adaptation, to find out what works (Fazey et al., 2018).

Economic case:

There is work on the economic benefits of publicly funded research. Some studies (Martin et al,. 2007) have highlighted the technical innovation and socio-economic benefits that arise, and these has been advanced more recently in work by Mariana Mazzucato on the role of government in innovation (The Entrepreneurial State). Her work finds strong evidence for a similar value in green technologies (and the green Entrepreneurial State), i.e. that globally, the countries or regions that are leading in green transformations are those where the State is playing an active role, which has included research (R&D contracts and funding for discovery and development of innovations, and so on).

This Intervention would seek to deliver a similar transition for adaptation. Making Glasgow City Region a global research and knowledge hub would lead to significant benefits including attracting the adaptation research community which would in turn contribute to creating partnerships and collaborations between international researchers and practitioners. It would also support the development of a value chain for the adaptation economy overall, supporting existing evidence of a growing adaptation economy in the City Region (K-Matrix, 2019).

A unique feature is that the work will be in the partnership with ‘users’ such as public sector bodies, communities or businesses, and will seek to create similar research for use in adaptation planning in wider Scotland.

Financial case:

The investment in research and innovation will be led by the public sector, but there is a strong potential for crowding in private and third sector funding to this innovation space.

Intervention 11

Begin the transition to a climate-resilient economy

This Intervention aims to shift the City Region's economy to be climate ready, as well as take advantage of the opportunities of climate change, and seeks to address the macro-economic issues of productivity, skills, employment and supply chains as well as direct support to SMEs and large corporations. It includes the following actions:

- Adopt a climate smart regional economic development approach – with a strategic approach that improves the resilience of the City Region's economy (revised Regional Economy Strategy).
- Delivery of a just, climate resilient transition which nurtures adaptation skills – by identifying and supporting sectors, business locations and workers.
- Climate-resilient supply chains, as part of a net zero, circular economy.
- An SME support plan – with a package to support SMEs to both become resilient to the impacts of climate change across all aspects of their operations.

Economic Rationale:

The focus of this intervention is primarily to support the private sector to deliver adaptation. Businesses and individuals will take action when the benefits of doing so are evident and clear to them, and outweigh the costs. However, that is not always the case, and there is a role for the government to play in removing barriers such as uncertainty and lack of information, coordination problems, financial constraints, and the risk of maladaptation.

Economic case:

In general terms, there are good economic benefits from increasing private sector adaptation, and the investments in this intervention are low-regret, as they creating the enabling environment for such action, i.e. providing information and support, as well as reducing down the risks for the private sector (i.e. addressing risk perceptions, that might otherwise hold back adaptation). These benefits are likely to be particularly important for SMEs, as they will not often have the capacity or resources to invest in adaptation information or implementation.

There is a further set of benefits from considering supply chains, as these involve inter-dependent and international risks, which may mean individual private sector actors will struggle to take the appropriate actions. There are range of adaptation options that might be effective in reducing these risks, which may involve public and private actors, within the region, but also nationally. Glasgow City Region could play a role in removing some of the barriers to enable and encourage private sector adaptation as well as ensuring a higher level of resilience along supply chains: this could be through the provision of information and awareness raising initially.

Financial case:

There is a role for some public funding to help provide information and create the enabling environment, but the main financial case will be for private sector funding.

Summary

A summary of the economic case, and some of the information on potential benefit to cost ratios, are shown in the Table below.

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**

Table 25 Indicative economic analysis of the Adaptation Strategy Interventions.

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