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CLIMATE CHANGE ADAPTATION AND ECONOMICS AND INVESTMENT DECISION MAKING IN THE CITIES

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'How to guide' and case studies

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CONTENTS

1. INTRODUCTION

This document brings together the knowledge and experience from the previous tasks of this project, Climate change adaptation economics and investment decision making in EU cities, to provide guidance for supporting municipal and local authorities through the use of adaptation economics in an urban context.

Section 2 introduces the role of adaptation economics in investment decision-making and outlines when it can be used at different stages in the project development and appraisal process. Section 3 then describes the relevant decision tools and their features that can be used to undertake economic appraisal of adaptation options, including in decision making under uncertainty. Section 4 provides a toolkit for choosing which approach to use, based on a set of principles and considerations.

Section 5 presents a summary. It should be noted that this guidance document is intended as a general outline of the use of adaptation economics in an urban context. For detailed step by step advice on the practical application of the decision tools relevant to adaptation economics, section 6 includes a list of useful resources.

Sections 8 to11 then present a variety of use-cases to illustrate the use of decision-making tools in different urban contexts. These include a summary of the economic analysis of adaptation investments in three case study cities (Loulé, Turku and Genoa) undertaken for this project, as well as other examples taken from the relevant literature, in particular from the ECONADAPT database (see section 6). These examples provide insights into:

- Potential applications of adaptation economics for urban investment decision making, related to different types of investments in adaptation and different points in the adaptation policy cycle.
- Opportunities, challenges and lessons learned.

2. THE ROLE OF ADAPTATION ECONOMICS IN INVESTMENT DECISION MAKING

2.1. What is economic appraisal?

Economic appraisal is a fundamental part of public policy and decision-making. It aims to assess the costs and benefits, and the risks, of alternative ways to meet project or policy objectives (HM Treasury,2020). Municipalities, governments and publicly owned financial institutions (such as the EIB) routinely undertake economic appraisal as part of a project development cycle. Economic appraisal can inform decision-making for improving allocative efficiency, i.e. do the benefits of a project outweigh its costs? If so, the project is judged to be allocatively efficient i.e. the market is efficient, and all goods and services have been optimally distributed. Economic appraisal is carried out from the perspective of society, including the valuation of non-market costs and benefits such as those arising from public goods (for instance environmental resources such as air quality). It therefore differs from a financial appraisal, that looks at the incremental cash flows (revenues and costs) generated by a project to assess its financial viability (a private perspective). Economic appraisal assesses project benefits and costs, in present value terms, and presents these as calculation of the Economic Net Present Value (ENPV),[1] Economic Benefit to Cost Ratio (BCR)[2] and/or the Economic Internal Rate of Return (EIRR).[3]

2.2. Why include climate adaptation in economic appraisal?

The risks of climate change (from Sea Level Rise (SLR), flooding, heat and water stress, degradation of urban ecosystems, loss of biodiversity for example) threaten urban economic assets and people's livelihoods, but also the social networks that foster resilience and quality of life (Chu et al, 2019). There is therefore a need to

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[1] Total discounted economic benefits minus total discounted economic costs.

[2] The discounted economic benefits minus total discounted economic costs is sometimes presented as a ratio.

[3] The rate at which the NPV is zero. The IRR can also be used to rank different projects.

identify, and if appropriate, to manage, physical climate risks, with investment in climate change adaptation.

Previous studies have found that adaptation generally offers a good economic return. The Global Commission on Adaptation (GCA) uses the term 'the adaptation 'triple dividend''. The GCA reports economic benefit to cost ratios for investment in adaptation typically range from 2:1 to 10:1 as a result of avoided losses, environmental and social benefits and economic benefits (GCA, 2019). Yet an adaptation investment gap persists. Investors frequently highlight that a major barrier towards investing in adaptation projects is a lack of investment-ready, risk adjusted projects with a commercial rate of return (OECD, 2018). In addition, it is still difficult to identify and develop the business case for adaptation and quantify and value adaptation benefits due to, for example (IFC, 2013):

- **Awareness**: A lack of knowledge and information on the cost of physical climate risks and the benefits of adaptation.
- **Capacity**: Limited resources, skills and technical knowledge to appraise adaptation benefits.
- **Case studies**: Lack of best practice project examples.
- **Uncertainty** and **complexity** associated with determining the benefits of adaptation.

Information on the impact of physical climate risks (financial) and adaptation costs and benefits (economic) can help establish the business case for adaptation and the adaptation performance of the asset. This information can then be used to, for example:

- Raise awareness of the benefits of adaptation and gain political support.
- Support the shortlisting, selection and prioritisation of alternative adaptation options.

Bankable projects that robustly manage physical climate risk and generate a measurable adaptation benefit may also be attractive to investors seeking sustainable investment opportunities, driven by:

- Regulators and governments consolidating sustainability into investment decision making.
- Growing recognition of the materiality of physical climate risks and sustainable investment opportunities.
- Greater scrutiny of the sustainability impact of investments and concern over 'greenwashing'.

Use of economic appraisal in assessing adaptation actions can also aid acceptability by demonstrating value for money, justifying spending and illustrating equity impacts.

Capacity for appraising the economic costs and benefits of investment in climate change adaptation is however still developing. The ex-ante economic appraisal of adaptation investment decisions is also challenging, because (Watkiss & Cimato, 2018):

- The analysis of physical climate risk and adaptation costs and benefits are site and context specific.
- There are complex issues of timing, with the need to make investments now that have benefits over time that are changing (non-stationary).
- There is large uncertainty involved with future climate change, and thus also adaptation benefits, which makes it difficult to take decisions.
- Adaptation benefits primarily arise in the future and therefore are reduced in net present value terms when discounted, as compared to the up-front investment costs, which can make it challenging to have an acceptable economic appraisal.
- Economic analysis is undertaken from the perspective of society, as opposed to financial analysis, and requires valuation of social and environmental aspects, where additional monetary valuation is required. This is important as many adaptation interventions involve these social and environmental benefits, and without their inclusion, the case for investment is lower.

- More applied analysis and decision making under uncertainty can be used to overcome these challenges, but these are complex to apply, require detailed data and are time consuming and resource intensive.

2.3. Application of adaptation economic appraisal in an urban context

Building on a number of findings from e.g. the ECONADAPT European research project (see section 6), practical approaches are emerging to support policy makers and investors in the economic appraisal of adaptation, including for investments (ADB, 2015). While a range of adaptation decision-making frameworks for cities have been developed (see section 6) and research has assessed the costs of climate change in Europe[4], a knowledge gap remains in the specific application of adaptation economic appraisal in an urban context. Addressing this knowledge gap is important as urban investments can cover a range of inter-dependent economic sectors and be geographically spread. As a result, they can be exposed to a range of physical climate risks, adaptation challenges and benefits (both market and non-market). This can exacerbate the challenge of identifying and developing the business case for adaptation and quantifying adaptation benefits.

It is highlighted that there are a number of types of adaptation investment for which adaptation economics is relevant:

- Climate resilience of projects, i.e. the climate proofing of proposed investments, i.e. where adaptation is a secondary objective, such as building resilience into a planned road project.

- Adaptation projects, where addressing climate risks is the primary objective (e.g. coastal protection to manage rising sea levels). A variation of this is where a project has strong adaptation co-benefits, i.e. where there are multiple objectives, ones of which is adaptation.

[4] See: https://www.coacch.eu/coacch-objectives/

By way of illustration, we can first use the example of a new urban transport link, e.g. Cross-Rail in London. In this example, the primary objective of the project is to encourage local economic development, but it is important to ensure that the underground rail infrastructure is designed such that it minimizes the risk of overheating in the subway rail carriages as a result of higher and/or more frequent summer heatwaves, and reduces passengers' discomfort. Thus, the climate change risk is likely to be one of a number of factors (e.g. safety, speed) and the costs of a possible adaptation measure such as ventilation or air conditioning are unlikely to be dominant in overall project costs. In this case, the climate proofing should solely focus on the adaptation response - and the marginal costs and benefits of adaptation - to address potential climate risks or take advantage of opportunities. This climate proofing is important because a specific feature of urban environments is the widespread use of built infrastructure with long lifetimes. These lifetimes mean that infrastructure design and build in the short-term can lock-in vulnerability to climate change risks in the long-term, as the climate changes. Where climate risks are likely to be significant to the functioning of infrastructure, therefore, it is more important to take account of the changing nature and extent of these risks and their associated uncertainties during design, especially if it is costly or difficult to retrofit changes later.

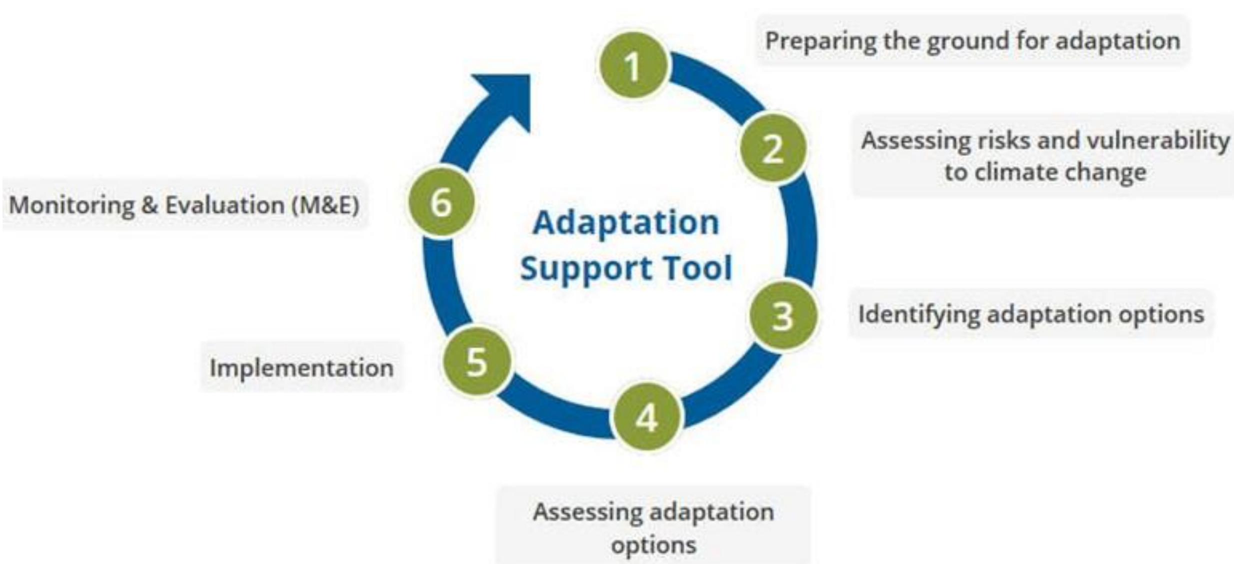
This is not the case, however, in the appraisal of an urban flood defence scheme such as that in Prague (see section 3.1.1), where the primary objective is reducing climate related risks, and in this case, factoring how to counteract higher but uncertain flood risks under climate change. In this case, adaptation is a primary objective of the project and will be critical in determining the overall project cost. In this instance, the adaptation is a targeted project and therefore detailed climate risk assessment combined with detailed economic appraisal that utilize decision-making under uncertainty will be much more valuable. These types of targeted adaptation projects are likely to become more important this decade, as city authorities seek to scale up adaptation.

Finally, for some projects, and notably urban projects, there may be planned investments which are delivering multiple objectives, one of which is adaptation. For example, one of the case studies (Genoa) is investing in a new park / green space, which will provide benefits in terms of recreation, non-motorised transport connectively, but also reduced flooding and potentially reduced urban heat extremes. In this case, positive adaptation action may be a secondary objective; the marginal benefits of adaptation are an extra economic benefit stream, that help increase the economic justification for the project, and can be assessed as part of the project cost-benefit analysis.

2.4. When should we apply economic appraisal in the project/policy cycle?

There is an existing framework for adaptation in general, as formalised by the European Environment Agency adaptation cycle (Figure 1). The application of adaptation economics can be undertaken at various points in this adaptation decision-making cycle. For example, economics can help in an initial appraisal of the potential significance of climate risks to a project (Step 2), the early prioritization of adaptation (Step 3), as well as the more detailed economic appraisal of adaptation options (Step 4).

Figure 1 - Decision making cycle



Source: https://climate-adapt.eea.europa.eu/knowledge/tools/adaptation-support-tool

Table 1 maps the possible role for adaptation economics at each stage of the adaptation decision-making cycle under the themes of: strategic adaptation planning; and ex-ante appraisal of project adaptation performance. From an investor perspective, the possible role for adaptation economics at each stage is similar.

These also align to the project development cycle that is often used by city authorities or financing institutions. Economic appraisal can help establish the rationale for investment in adaptation or adapted projects as part of project concept development. Then during project appraisal, the focus is on considering and prioritizing the alternative choices, and demonstrating the business case for investment and the adaptation performance of the asset.

Table 1 - The application of adaptation economics in adaptation decision-making

Stage in the adaptation decision-making cycle	Role for economic analysis	Approaches
Mainstreaming adaptation economics into strategic planning: • **Stage 1 – Preparing the ground for adaptation**	Setting out the economic rationale for adaptation, for example to justify the use of municipal funds. Identification of the adaptation objective. Identify key indicators of adaptation performance as part of monitoring processes and inform future decision-making.	Economic case (market failures, justification for intervention) Economic considerations in early concepts

Stage in the adaptation decision-making cycle	Role for economic analysis	Approaches
Ex-ante appraisal of adaptation: • **Stage 2 – Assessing risk and vulnerability to climate change** • **Stage 3 – Identifying adaptation options** • **Stage 4 – Assessing and prioritising adaptation options** • **Stage 5 – Implementation** • **Stage 6 – Monitoring and evaluation (including ex post analysis)**	Economic assessment of the extent of physical climate risks, and the costs and benefits of different adaptation responses, in order to demonstrate the business case for investment or the adaptation performance. This includes informing the shortlisting or selection of adaptation options. Screening of higher risk or adaptation focused projects (light touch economic appraisal) to, for example, determine whether detailed economic appraisal is possible. Determine the availability of data and associated uncertainties to inform the choice of an appropriate economic appraisal method(s). Identify (and evaluate) key indicators of adaptation performance as part of monitoring processes.	Traditional approaches to economic appraisal Decision-making under uncertainty Light touch approaches

2.5. Upstream steps in Adaptation Economics– Strategic adaptation planning

Adaptation economics has an important role to play in **preparing the ground for adaptation (Stage 1** of the adaptation cycle**)** by:

- Setting out the economic rationale for adaptation to raise awareness of the benefits of adaptation and gain political support.
- Outlining the early business case for adaptation, by identifying adaptation investment need and the associated benefits.
- Highlighting the opportunity for (and the role of) economic appraisal to support both the further development of an adaptation strategy and subsequent adaptation decision-making.

Where possible, adaptation economic appraisal should be **mainstreamed** into strategic planning to identify the costs and benefits of physical climate risks and support the development of a pipeline of adaptation projects[5] and adapted assets[6]. The development of an adaptation strategy is the foundation for effective and efficient adaptation by providing a framework for the scoping, and subsequent prioritisation of investment in adaptation. This also provides the opportunity to work with prospective financiers, as the basis for the development of an accompanying investment plan.

In support of a **monitoring and evaluation process (Stage 6)** adaptation economics also has a role in the identification and measurement of adaptation performance indicators (at a portfolio level). For example, Cost-Benefit Analysis can be used to assess an ex-post economic NPV or EIRR. This information can then inform both reporting requirements and identify the need for further investment (if necessary), including triggering additional project investment as part of an adaptation pathways approach.

2.6. Appraisal steps in Adaptation Economics

Once a specific investment, be it an adaption project, or climate proofing of a planned project, is identified, a detailed appraisal step can be undertaken.

[5] Defined as a substantial contribution to adaptation within the EU Sustainable Finance Taxonomy.
[6] In line with the principal of Do No Significant Harm (DNSH) to adaptation according to the EU Sustainable Finance Taxonomy.

Framing the economic aspects of adaptation projects and data needs

When moving to the actual appraisal of the project, the starting point is to frame the project in terms of the key economic parameters, i.e. what are the main benefit and cost streams. The principal categories for this are listed in the left-hand column of Table 2. These represent a disaggregation of the costs and benefits that need to be weighed against each other in any form of economic analysis.

For a targeted adaptation project, the costs and benefits will be primarily targeting a particular climate risk, i.e. the benefit stream will be climate benefits. In this case, there should be a detailed analysis of the climate risk the project is trying to address.

For an adapted asset or climate proofing project, the focus will be on looking at the incremental impacts of climate change, and then the additional costs and benefits of climate proofing that investment. This can often draw on existing climate risk assessment of the project. In such a case, the key issue is to identify how climate affects the cost and benefit categories, and which areas are most sensitive to climate risks and so require most attention.

Table 2 – Principal categories

Economic Parameter	Impact of Current Climate & Climate Change on Economic Parameter
Fixed Capital Costs	Targeted adaptation projects. Assess the economic benefit of adaptation. Climate proofing. Assess how current & projected future climate may impact on each individual parameter
Variable Costs (Operation & Maintenance)	
Revenue	
Non-Market Benefits	
Economic & Financial Performance indicator	Targeted adaptation. Costs and benefits of reducing climate risk through adaptation (e.g. NPV of overall project). Climate proofing. Assess the effect of climate on measure of financial &

	economic performance, and costs and benefits of incremental adaptation (e.g. NPV of marginal costs and benefit for adaptation only, not whole project)

Ex-ante project appraisal of adaptation performance

As shown in Table 1, during ex-ante project appraisal, economic analysis can inform the assessment of physical climate risk (Stage 2), identification of adaptation options (Stage 3) and assessment and prioritision of adaptation options (Stage 4). In support of project implementation (Stage 5) and monitoring and evaluation processes (Stage 6) economic appraisal also has a role in the ex-post evaluation of adaptation performance.

There are two potential levels of details in these appraisals.

Detailed economic appraisal

For any targeted project that is seeking to deliver adaptation, where adaptation is the primary objective, the detailed economic appraisal should consider physical climate risk and adaptation in detail. This can include detailed decision making under uncertainty methods.

For non-climate projects (climate proofing), where there are material economic or financial impacts associated with high physical climate risks or detailed economic appraisal (with the option of decision making under uncertainty) may be justified. This involves assessing the costs and benefits of the additional adaptation options/investment in detail. Thus, more detailed analysis can be undertaken in cases where climate change has a potentially material impact on the economic and financial performance of a project (i.e. if it changes the economic internal rate of return, or indeed, the direction of the investment decision). In such cases, if an adaptation decision involves a long life-time and it may be difficult or costly to change later, decision making under uncertainty methods could be considered (Watkiss & Cimato, 2018). These approaches are however complex to apply, require a complete data set that quantifies the majority or all cost and benefit components and are time consuming and resource intensive, thereby further constraining their use.

However, many climate proofing projects may only require a **'light-touch' economic appraisal** to introduce an economic rationale for adaptation and support the analysis of adaptation options. Light-touch approaches to economic appraisal of adaptation are a form of rapid assessment, either using existing information from previous projects or using simple models or functions to help identify options or provide indicative costs and benefits. These approaches aim to capture the conceptual aspects of detailed approaches (while maintaining a degree of economic rigour) to allow for qualitative or quantitative analysis. Light-touch economic appraisal may also have a role in screening high physical climate risk projects or projects where adaptation is not a primary objective.

2.7. Adaptation finance and the EU Taxonomy

The issues above are becoming more important with greater focus on physical climate risks, e.g. in the Task Force on Climate Related Financial Disclosures (TCFD), and with the EU Sustainable Finance Taxonomy ('EU Taxonomy')[7]. The latter provides a common language and a clear definition of sustainable economic activities. Demonstrating alignment with EU Taxonomy would provide confidence that a project is considered environmentally sustainable, as well as potentially improving the cost of and access to capital.

The EU Taxonomy recognises that adaptation can be:

- Focused on the economic activity itself, by strengthening an asset or economic activity to withstand identified physical climate risks over its lifetime – **adapted activity** (i.e. green infrastructure); and/or

[7] See EU Sustainable Finance Taxonomy: https://ec.europa.eu/info/business-economy-euro/banking-and-finance/sustainable-finance/eu-taxonomy-sustainable-activities_en

- Systemic, aiming to actively reduce vulnerability and build resilience of a wider system or systems – **enabling adaptation** (the development of an early warning system for flood risk).

In terms of impact, as a minimum, an economic activity must **Do No Significant Harm (DNSH) to adaptation**[8]. An economic activity may however have a high potential to **substantially contribute to adaptation**, which may justify more detailed economic appraisal. Table 3 sets out adaptation activities in terms of their nature and impact.

[8] As well as doing no significant harm to other environmental objectives.

Table 3 – The nature of adaptation and adaptation impact

	Do no significant harm: adaptation	Substantial contribution to adaptation
Adapted activity	The economic activity must reduce all material physical climate risks to the activity to the extent possible (to the extent economically rationale) and on a best effort basis. For example, incorporating sustainable drainage systems in urban areas.	The economic activity includes adaptation solutions that either: • Substantially reduce the risk of adverse impact; or, • Substantially reduces the adverse impact of the current and expected future climate on that economic activity itself. For example, an urban flood risk management programme.
Enabling adaptation	The economic activity and its adaptation measures do not increase the risks of an adverse climate impact on other people, nature and assets or hamper adaptation elsewhere. For example, incorporating green infrastructure into urban spaces.	The economic activity provides adaptation solutions that: • Contribute substantially to preventing or reducing the risk of adverse impact; or, • Substantially reduces the adverse impact of the current and expected future climate on other people, nature or assets. For example, investment in the development of an Earth observation satellite.

Source: Adapted from the EU Technical Expert Group on Sustainable Finance (2020) Taxonomy Report: Technical Annex.

3. KEY DECISION SUPPORT TOOLS & THEIR FEATURES

This section gives a brief outline of key decision support tools for economic appraisal for adaptation. These are presented here in order to provide the available methods that can be used to appraise adaptation projects and policies. The fundamental difference between adaptation economic appraisal and typical economic appraisal is a greater emphasis on managing uncertainty and risk, and on accounting for the temporal difference between current and future costs and/or benefits.

A wide range of decision-support methods have been developed to estimate and analyse the costs and benefits of adaptation, each with strengths and weaknesses that vary with application (Tröltzsch et al, 2016). There is no 'one-size-fits-all' approach to adaptation economic appraisal and it is important to carefully select the most appropriate approach for the investment decision-making and adaptation context. An important trade-off to be made is whether using a more novel, but resource-intensive, method that better handles uncertainties is worthwhile instead of a more familiar, traditional, method. The following provides an outline of the use of economic approaches highlighting the opportunities and challenges associated with their application in an urban adaptation context.

3.1. Traditional approaches to economic appraisal

Table 4 summarizes key traditional approaches to economic appraisal, giving their strengths and weaknesses. In particular:

- **Cost-Benefit Analysis (CBA)**, which helps assess the socio-economic desirability - the economic efficiency criterion referred to, earlier - of the project (EIB,2013). It is designed to produce a measure of project returns corrected for various distortions and constraints to markets (such as undefined property rights, lack of competition and distorted prices) that cause externalities with no price assigned for them. When making investment decisions, firms tend to consider only those costs (expenditures) and benefits (revenues) that accrue directly to them. Conversely, social CBA considers the costs and benefits to the society as a whole with the purpose of informing public decision-making and increasing the social value or improving allocative efficiency. Technical limitations may make it difficult or impracticable to quantify and monetize all relevant impacts as costs and benefits (Boardman et al, 2018). There is rarely enough economic data early in the project development and appraisal processes to undertake a full cost-benefit analysis for adaptation (Watkiss & Cimato 2018).

- **Cost-Effectiveness Analysis (CEA)** is a widely used decision support tool. It allows comparison of the costs of alternative options for achieving a common output (or objectives). In this regard it is a relative measure, providing comparative information between choices. A metric can be constructed for the quantitative (but not monetized) benefit (in defined units) and compared to the cost of delivering one unit (e.g. the cost per tonne of pollution abated). This can then be used for the ranking of alternatives Boardman et al (2018). While this method has become the dominant approach for mitigation, its application to adaptation is more limited, because adaptation usually needs to consider multiple objectives and criteria.
- **Multi-Criteria Analysis (MCA)** is an approach that assesses options by scoring them using different criteria and applying weightings to each criteria in order to arrive to a single score to compare alternative projects. As long as sufficient data is available it can be a useful alternative to CBA or can incorporate results of CBAs.

It is important to note that the economic efficiency criterion – i.e. whether aggregate benefits outweigh aggregate costs or not – is at the centre of economic appraisal of projects and policies and so needs to be incorporated in more sophisticated assessments of e.g. uncertainty. It is highlighted that traditional approaches for economic appraisal work particularly well for low-regret and no-regret options[9].

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[9] 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, 2014). A variation of no-regret options are win-win options, which are options that

These tend to generate short-term benefits, and therefore are more amenable to decisions approaches that match this time-scale. It is also highlighted that traditional approaches can sometimes be extended to consider future climate uncertainty, albeit in simplistic approaches. The most obvious example is to use sensitivity testing for CBA, to examine if an adaptation intervention passes a CBA test under different scenarios. Such analysis may allow some rapid analysis to highlight the influence of climate and can be a trigger for more detailed decision making under uncertainty.

Examples of the application of traditional approaches to economic appraisal in an urban context are given in the following sections.

Table 4 – Approaches to adaptation economics: Traditional approaches to economic appraisal

Approach	Strengths	Weaknesses
Cost-Benefit Analysis (CBA) focuses on determining economic efficiency of adaptation options. The net benefit is calculated by comparing the costs associated with planning, preparing and implementing adaptation against its benefits (avoided damage costs or the accrued benefits following adoption and implementation). CBAs are carried out in a quantitative and monetized framing, where costs and benefits are expressed in explicit economic terms highlighting trade-offs. The	Attractive methodology for its relative simplicity. Provides a systematic outlining of monetised costs and benefits, ultimately offering a simple economic value. Increased transparency of decision-making	Can be difficult to monetise all benefit streams, in particular in urban development context where investments target public urban infrastructure and social services. Does not explicitly deal with uncertainties. Optimises the selection of options

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.

goal is to systematically identify options which maximise social welfare against clearly identified sets of climate change impacts. CBA is most easily applied in assessment of low and no regret options in market sectors and when probabilities of climate risks are known. It is best used in combination with decision support tools, which consider qualitative factors (e.g. multi-criteria analysis) or those that frame adaptation in a broader iterative risk framework.	through systematic approach. Use of single matrix facilitates comparability between options. Can be extended with sensitivity analysis to test influence of future climate.	against single, pre-defined future scenarios of climate change. Choice of time horizon and scales can dramatically change results. Limited application for questions of natural resource preservation, irreversibility and intrinsic values. Does not automatically incorporate distributional or equity issues. Choice of discount rate is a matter of on-going contention and debate.
Cost-Effectiveness Analysis (CEA) aims to provide a comparison and ranking of the relative cost-effectiveness of various options to achieve pre-determined targets, i.e. what can be achieved at a given cost. The cost-effectiveness of a list of options is calculated by dividing the lifetime cost by the lifetime benefit of each option.	In contrast to CBA, CEA allows for non-monetary valuation of benefits, opting for quantification in physical terms instead. Increases applicability to non-market sectors. Provides easily understandable	Optimises to a single metric, which can be difficult to choose. Focus on a single metric may omit important risks and may not capture all costs and benefits for option appraisal.

CEA can be used to analyse both project-oriented work and policy approaches. At the technical or project level, CEA is useful in comparing and ranking alternative options by assessing options in terms of the cost per unit of benefit delivered. At the policy or programme level, where combinations of measures are needed, CEA is useful in determining the most cost-effective order of implementation and identifying the least-cost path. CEA is most appropriate for near-term assessment, particularly for identifying low and no regret options, in areas where monetary valuation of benefits is difficult. It is most applicable where there is a clear target and where climate uncertainty is low. It is also considered good practice to undertake CEA within an iterative plan, to capture enabling steps, portfolios and inter-linkages, rather than using the outputs as a simple technical prioritisation.	rankings of measures. Frequently used for mitigation, and thus approach known by policy makers. Can look at the cost implications of more ambitious policies.	Less applicable for cross-sectoral or complex risks. May give lower priority to non-technical measures such as capacity building and other soft measures. CEA does not explicitly deal with uncertainty and aims to optimise the selection of adaptation interventions against a single objective usually under one climate scenario.
Multi-Criteria Analysis (MCA) is a methodology used to assess and score adaptation options against a set of pre-defined and weighted decision-making criteria. Unlike CBA, MCA allows the consideration of both quantitative and	Can consider a wide set of criteria, even where quantification is challenging or limited. For example, MCA is	Subjectivity can be high. Giving consistent scores can be difficult.

qualitative data in the ranking of options. Therefore, MCA can effectively incorporate important dimensions in adaptation such as economic efficiency, urgency, co-benefits, no-regret and robustness characteristics. MCA can support the consideration of uncertainty in the prioritisation of adaptation options. However, the analysis of uncertainty will usually remain subjective and qualitative. MCA provides a structured framework for combining expert judgement and stakeholder preferences and is well suited for encouraging stakeholder participation in adaptation decision-making. MCA can be used for cross-sectoral analyses which are highly relevant for the assessment of adaptation strategies or action plans which have a broad range of adaptation objectives.	able to consider elements like feasibility, equity and acceptability, which can often be hard to quantify. Relatively simple and transparent and can be done at relatively low cost and within a limited time. Provides a structured framework for combining expert judgement and stakeholder preferences.	Analysis of uncertainty often highly qualitative

Source: Adapted from ECONADAPT (2016) Toolbox: Methods https://econadapt-toolbox.eu/methods

3.1.1.Example for CBA, Flood protection measures – Prague[10]

Outline of context:

- **Geographical**: Prague, Czech Rep.
- **Climate risk**: Flood risk on Vltava and Berounka rivers.

[10] See: Sainz de Murieta, E. et al (2016)

Adaptation action:

- **Overall project**: Prague flood protection measures that have been carried out in the period 1999 to 2014, totaling to €256 M. The complex flood protection project consists of several types of measures: (i) line measures (i.e., fixed anti-flood earth dikes, reinforced concrete walls, mobile barriers etc.) and (ii) barriers in the waste-water system (i.e., backflow preventors etc.). These projects were assessed in terms of their future potential under climate change, similar to a standard adaptation appraisal.
- **Contribution to adaptation**: Protection of the city from flood risks.

Decision tool

- **Decision tool used**: Cost Benefit Analysis (CBA) to understand the relationship between flood damage-reducing measures and economic efficiency. The model allowed comparison of investments under different climate projections since it uses a common metric, i.e. monetary value. However, the model only assessed direct tangible damages to buildings and infrastructure and loss of agricultural production. Non-market effects such as those on human health were excluded.
- **Stage in adaptation decision-making cycle**: Step 4 (appraisal).
- **Data & data sources**: There was a significant amount of data available (climate data, hydrological modelling, damage costs, etc.).

Methods and Results

- **Method**: Climate and infrastructure data used to produce several models, including a hydrological model (that predicts the likelihood of flood and their intensity) and a damage and risk model (that predicts the cost of flood on infrastructure and agriculture land). This was then used to:
    - Calculate the monetary value of the Expected Annual Damage (EAD) that is avoided by the adaptation measures. The monetary EAD acts as a common metric that can be compared against the status quo, to determine whether adaptation measures have a positive socioeconomic benefit.

- Compare the EAD with investment costs, as measured by the Present Value (PV) of investments. If avoided damages (as measured by the EAD) are higher than the cost of interventions, then the intervention is beneficial.
- Apply sensitivity analysis to investigate the influence of different values of single inputs.

- **Results**: Showed that the EAD was superior to the PV costs, i.e. that the adaptation project promotes efficiency in the scenarios of changing future climate.

Opportunities, Challenges and Lesson learned

The appraisal of flood protection measures in Prague highlights both the opportunity and limitations of CBA. On the one hand, CBA allowed for the incorporation of different input data, reflecting the various sources of uncertainty, therefore yielding results regarding the economic efficiency of the investment under the contemplated range of conditions. On the other hand, the choice of CBA meant other decision criteria may not be considered. The study did not take account of uncertainty (future growth, urbanization, etc.), which could affect the validity of results in the long-term.

3.1.2. Example for Cost-effectiveness analysis, Adaptation options for public water supply - River Thames[11]

Outline of context:

- **Geographical**: River Thames, UK.
- **Climate risk**: Vulnerability of water supply to changes in climate, land use and population.

Adaptation action: Range of mitigation and adaptation strategies to reduce the level of phosphorus in water and soil.

[11] See: Whitehead et al (2013).

Decision tool: Cost-effectiveness analysis (CEA) used to compare various adaptation strategies in achieving a reduction the level of phosphorus in water and soil.

Methods and Results: An integrated catchment model (INCA) for phosphorus had previously been developed. Using this model, seven scenarios were considered for CEA, each describing different changes in climate, land use, and water management (construction of a reservoir). Using pre-existing models as input, this allowed estimation of the effectiveness of those changes on phosphorus concentration.

The costs of measures were based on those that occur to agents directly affected by the mitigation or adaptation measures, as well as public investment costs on water infrastructure. Using estimates from existing literature, the cost of reducing fertilizers was assessed for the entire river basin, taking account of current and future land use. The cost of new infrastructure (the reservoir) was also estimated. Cost-effectiveness was then calculated by dividing the costs by the percentage reduction in phosphorus from the baseline.

Opportunities, Challenges and Lesson learned

The River Thames case study underlines the potential that CEA provides in comparing several intervention strategies without calculating their monetary value, which can be difficult. Here, the common outcome (reduced phosphorous concentration in water) of all the potential interventions was used as the common metric to assess their cost-effectiveness. However, while this was appropriate in this case, CEA would not have worked to compare interventions that have different outcomes, and another common metric (such as monetized benefits) would have had to be used.

3.1.3. Example for MCA, Inventory of climate adaptation options and ranking of alternatives, Netherlands[12]

Outline of context:

- **Geographical**: The Netherlands

[12] See: de Bruin et al (2009).

- **Climate risk**: Range of risks included in national adaptation strategy.
- **Policy context**: The study seeks to contribute to the development of a national adaptation strategy in the Netherlands that could include a wide set of policy instruments including infrastructural solutions, financial instruments or institutional approaches etc.

Decision tool:

- **Decision tool used**: Multi-criteria analysis (MCA) with CBA element that is both quantitative and qualitative.
- **Stage in adaptation decision-making cycle**: Stage 3 – identifying adaptation options.

Methods and Results:

- **Method**: Development of an inventory and ranking of adaptation options based on stakeholder analysis and expert judgement and presentation of estimates of incremental costs and benefits. The assessment does not deal with uncertainties but works on the basis of one climate change scenario for the period up to 2050. The assessment included the following steps:
    - Identification of adaptation options in the Netherlands, based on literature study and consultation of stakeholders;
    - Qualitative assessment of the characteristics of the options;
    - Definition of criteria used to make a ranking of the options, based on expert judgements;
    - Determination of the scores of the options on the various criteria;
    - Determination of the weights to be used in the MCA for ranking of the options;
    - Actual ranking and an interpretation of results.
- **Results**: Ranked adaptation options with indication of the costs and benefits of option.

Opportunities, Challenges and Lesson learned

This study shows the advantages of using qualitative analysis when data availability is limited:

- It allows for softer elements to be included into the assessment that are difficult to quantify, such as cultural practices and norms.
- It is a useful tool for high level planning as it identifies a number of adaptation options across different sectors that can be used for further discussions
- The method is useful in communication with the stakeholders and in raising awareness about the challenges of adaptation and the various options to do so.
- The method is relatively straightforward and has low research costs.

However, the CBA element of the study was weak in terms of available data, and therefore incomplete, and does not provide the level of robustness and precision that more detailed CBA and CEA can bring about.

3.2. Decision-making under uncertainty

As a result of the challenges associated with adaptation economics, more recent approaches have been developed for adaptation decision making under uncertainty. These methods aim to incorporate uncertainties that arise from future climate modelling and other socio-economic sources by focusing on one or more of the following principles:

- Learning (e.g. scientific knowledge about climate increases over time, resulting in a reduction in climate uncertainties);
- Flexibility (e.g. in responding as new knowledge about climate becomes available);
- Robustness (e.g. adaptation responses designed to be effective under a range of alternative potential climate futures)
- Hedging (risk spreading against alternative potential climate futures)

- Minimizing regrets (e.g. undertaking low-risk adaptation that has low costs under any potential climate futures).

This principles-based approach also provides the opportunity for the application of light-touch approaches to economic appraisal (discussed further below).

Decision making under uncertainty approaches concentrate on the appraisal of adaptation options in projects. The quantification of the economic costs of climate change and the costs and benefits of adaptation guides the selection of one of the following strategic responses:

- Adapt now.
- Adapt now taking uncertainty into account (e.g. robust decisions, minimise regret).
- Prepare now for future adaptation (e.g. build in flexibility).
- Wait, collect information and data and adapt later.
- Do nothing

Decision-making under uncertainty methods are however data, time and resource intensive and require a high degree of expert knowledge. These issues often limit their application in some investment decision-making contexts, especially where climate change is not a principal factor in the overall costs and benefits. Careful consideration should therefore be taken for their application, reflecting on (ADB, 2020):

- The lifetime of the project - is it long (multiple decades) and therefore susceptible to changing climate risks.
- The irreversibility and lock-in involved of investment in substantial physical capital.
- Whether there are major regrets or high risks (e.g. high costs, critical infrastructure, portfolio concentration, loss of private assets, social costs, loss of life).

Table 5 highlights a range of approaches to decision-making against economic criteria, incorporating uncertainty, including Real Options Analysis (ROA), Robust

Decision Making (RDM), Portfolio analysis[13] and Adaptive management. No one method is applicable to all adaptation problems or investment contexts and each has strengths and weakness. The review of these approaches to decision-making under uncertainty by Dittrich et al (2016) to assess which are the most promising in providing a compromise between meaningful analysis and simple implementation.

Examples of the application of approaches to decision-making under uncertainty in an urban context are given in section 3.2.1.

Table 5 – Approaches to adaptation economics: Decision-making under uncertainty

Approach	Strengths	Weaknesses
Real Options Analysis (ROA) is used to prioritise adaptation interventions while considering the possibility to adjust them in the future to respond to new climate risk information. ROA uses dynamic programming which is an extension of decision-tree analysis, where each branch of the tree is associated with a possible outcome of a "risk events" that could occur in the future. Alternative designs of an option are specified and confronted with different climate scenarios with assigned probabilities. ROA allows for the assessment of the cost and benefits of varying developments in the design of the adaptation options under each scenario.	Can guide the timing of adaptation interventions. Allows for quantitative economic analysis of the value of flexibility and learning. Provides a structured way to conceptualise and visualise the concept of adaptive management. Can be applied more qualitatively when probabilistic data on impacts are limited.	Requirement for quantitative and monetised information on costs and benefits under multiple possible climate futures. Can be data and resource intensive, especially regarding probabilistic climate information and quantitative impact data. Less applicable to situation of deep uncertainties. A complex method which may require

[13] Note that methods such s decision-scaling or rule-based decision support criteria are excluded since they do not utilise economic efficiency as a primary criterion.

This approach allows to change the "fate" of projects which may have passed or failed deterministic economic analysis by demonstrating that it may be better to wait until more information is available or, alternatively, to make an initial adaptation investment immediately but incorporating some degree of flexibility in the design of the intervention. ROA is suited for informing decisions with a high risk of maladaptation such as public infrastructure projects that are large-scale, long-lived and costly. ROA has a complex methodology, which typically requires high volumes of data and resources. A more qualitative approach combined with the use of decision trees can be taken, which is of benefit when data is unavailable.		expert input and significant resources. Identification of decision points complex for (dynamic) aspects of climate change, and need to match these decision points to equivalent climate data.
Robust Decision Making (RDM) aims to identify adaptation options or strategies which can perform well over a wider range of possible futures. The focus of RDM is on 'robustness' rather than 'optimality' favouring minimising regret over optimising utility and thus presents an alternative to more traditional economic assessment methods like CBA or CEA, that solely use economic efficiency criteria.	Provides a structured approach to testing adaptation options or strategies against many possible futures. Applicable under situations of high uncertainty, e.g. climate change, where probabilistic	Formal application using probabilistic modelling requires large amount of quantitative information, computing power, and a high degree of expert knowledge. More informal approaches can make the

Applied with quantitative computer-based probabilistic modelling, RDM may rely on high volumes of data. Significant resources and expert knowledge may be needed for its application. More informal applications are possible but may suffer from subjective data inputs and stakeholders' perceptions. RDM is most useful under conditions involving high uncertainty. It can be particularly useful in near-term assessment for strategies that could enhance long-term resilience, and to identify low/no regret options.	information is low or missing. Can work with physical or economic metrics, enhancing potential for application across non-market sectors such as biodiversity or health.	assessment of adaptation activities more subjective, influenced by stakeholders' perceptions.
Portfolio Analysis (PA) can be used to compare multiple portfolios of adaptation options against the uncertainties of future socio-economic and climate change scenarios. Portfolio analysis examines the complementarity of adaptation options, to design and evaluate adaptation portfolios. The aim is then to identify portfolios that either (depending on preference) have the: • Highest expected return for a given risk; or, • Lowest degree of risk for a given rate of return. Options are selected which are effective over a range of possible future scenarios (socio-economic	Provides an effective way of visualising results and the risk-return trade-off. Deals explicitly with uncertainty, providing a structured way of quantifying portfolios of options to address uncertainty. Allows for benefits to be assessed using different metrics, including physical effectiveness (non-monetary benefit) or	Resource intensive. Requires a high degree of expert knowledge. Relies on the availability of quantitative data. Requires probabilistic information.

and climate change), emphasising the trade-offs that can be expected between the risks and benefits of various strategies. Portfolio analysis is therefore most applicable where adaptation options are potentially complementary and requires good economic and climate information and data.	economic efficiency (monetary benefit). Therefore, portfolio analysis has broad applicability in market and non-market sectors (such as ecosystem-based adaptation).	
Adaptive Management (AM), or Iterative Risk Management (IRM), is based on the idea that current decisions are constrained by imperfect knowledge and cognitive bias. IRM/AM advocates for cycles of monitoring, evaluation and learning to improve the performance of adaptation strategies and actions over time. IRM/AM does not follow a formal methodology and can be complex when multiple risks are considered or when suitable risk threshold must be identified to trigger future responses. IRM/AM can be seen as a general decision-making framework, which accommodates well other methods such as CBA, CEA or MCA.	Helps develop a flexible, dynamic approach to adaptation where decisions are adjusted over time to reduce the risk of maladaptation. Can be applied where uncertainty is high, e.g. where probabilistic information is low or missing. At scoping stage, relatively simple approach to apply and provides easily understandable ranking and outputs.	The identification of suitable risk thresholds can be difficult. Does not offer an effective approach to reduce complexity of treating multiple risks acting together

Source: Adapted from ECONADAPT (2016) Toolbox: Methods https://econadapt-toolbox.eu/methods

Decision-Scaling, also known as Climate Informed Decision Analysis (CIDA), is a method of incorporating climate change information into a decision-making process, by first identifying which sets of climate variables would affect the project and then determining the likelihood of those sets (Hallegatte et al. (2012)).

CIDA does not attempt to reduce uncertainties or make predictions, but rather determine which decision options are robust to a variety of plausible futures. It has three major phases:

1. Determination of key performance indicators for the project, based on stakeholders concerns, mapping to observable indicators, assignment of tolerance to groups of indicators.

2. Determine relationship of climate to indicators, the quantified climate sensitivity of each plan. Climate sensitivity is determined by assessing each plan to a wide range of possible climate changes. The climate conditions that are problematic to each plan are identified, as well as opportunities associated with future climates. A decision map (contingency matrix) can be produced, identifying each decision's performance under different climate possibilities, as well as the best decision for a given future climate. A map of which decision options are optimal under which groups of climate conditions can be constructed.

3. Using GCMs (and possibly downscaling), stochastic modeling, or expert judgment, determine plausibility (subjectively derived probability) of relevant groups of climate conditions identified in (2). The plausibilities are seen as the best possible use of the uncertain climate projections. The decision option is then based on application of decision-to-climate performance to relative climate plausibilities.

The primary applicability is for decisions regarding long-term investments which may have climate vulnerabilities. While standard decision-analysis requires well-characterized uncertainties, CIDA was developed to handle poorly-characterized climate change uncertainties and to make the best use of available climate information. It can be used as a framework for climate risk analysis of a planned project, or to help decide among multiple project options.

Decision criteria

Various decision-support techniques have been developed which do not require knowledge of, for example, the likelihood of an event/state occurring, in which case the determination of an expected value would not be possible (UKCIP, 2004). These so-called 'non probabilistic' criteria simply involve the application of predefined rules to possible outcome arrays, e.g. of net present values. Two main rules that we describe are:

- the maximin criterion;
- the minimax regret criterion;

The MAXIMIN criterion

The first step with this criterion is for the decision-maker to identify the "lowest" outcome (NPV) resulting from each adaptation option. If we do this for the outcome array in Table 6 we obtain:

Table 6 - MAXIMIN - lowest outcome NPV

Option	Minimum outcome
A_1	€150
A_2	€0
A_3	-€150

The decision rule under this criterion is to select the largest of these "lowest" outcomes, i.e. **max**imise the **min**imum NPV. Accordingly, the decision-maker should select adaptation option A1.

This criterion is inherently "conservative" or "pessimistic" as it focuses on the minimum possible outcome associated with each option - that is, the decision-maker simply attempts to avoid the worst possible consequence. Indeed, it is the most risk-averse criterion. Since the criterion fails to consider the magnitude of each outcome, it could lead to the selection of one option, despite very large benefits being associated with alternative options. For example, the criterion completely disregards the fact that by selecting A_2 the decision-maker could possibly accrue €600.

The MINIMAX (regret) criterion

With this criterion the decision-maker is concerned with the "loss" experienced if one state-of-nature occurred, but instead of selecting the option with the maximum NPV associated with this state, an alternative option is chosen. Consequently, the "loss" experienced by the decision-maker is defined as the difference between the maximum NPV and the actual NPV. Performing this calculation for each outcome produces a so-called "**regret matrix**", like the one shown in Table 7 below (UKCIP, 2004).

Table 7 – Regret matrix

		State of nature		
		S_1	S_2	S_3
Options	A_1	€200-€200=£0	€300-€175=€125	€600-€150=€450
	A_2	€200-€0=€200	€300-€300=€0	€600-€600=€0
	A_3	€200-(-€150)=€350	€300-€150=€150	€600-€450=€150

The aim of the criterion is to **min**imise the **max**imum ("loss") regret. The maximum regret for each of the three options is given by:

Table 8 – MINIMAX – maximum regret

Option	Maximum Regret
A_1	€450
A_2	€200
A_3	€350

Therefore, as the decision-maker wishes to minimise the maximum regret, the "best" option is to select action A_2. As the criterion strives to avoid the greatest foregone outcome it can also be regarded as “pessimistic”. This criterion should be used with caution, since it can be inconsistent in selecting the “best” option from a group of alternative options. It is possible to hypothesise situations where, for example, in the presence of three options (A_1, A_2 and A_3), A_3 represents the “best” option, yet if A_1 is removed as an alternative, A_2 might turn out to be the “best” option, even though A_3 is still among the alternatives.

Adaptive Management

As investment in adaptation is increasingly being seen as a dynamic process, which needs to prepare for future climatic and socio-economic conditions. More iterative risk management and learning processes are being considered to inform projects which allow for robust and flexible adaptation. Within this progressive approach there is also greater recognition of the role of adaptation economic appraisal, in strengthening capacity to envision and plan strategically and support the identification of robust adaptation solutions in the face of high uncertainty. Tröltzsch et al, (2016) suggest that adaptation economic appraisal could ideally:

- Provide clarity on the trade-offs associated with different pathways in the short, medium and long term.
- Provide an indication of the net value of different options under different possible futures.
- Highlight the value of future benefits, ultimately enhancing the consideration of sustainability principles in decision-making.

Error! Reference source not found. The AM/IRM approach does not use economic c riteria itself but provides a framework within which these criteria can be utilised. Examples of the application of decision-making frameworks under uncertainty are the Water Resources Management Plan for England and South Wales (Southern Water, 2019) and London Thames Estuary 2100 project (Environment Agency, 2012) (see section 3.2.2).

3.2.1. Example for Real Option Analysis, Flood risk protection in Bilbao[14]

Outline of context

- **Geographical**: Peninsula of Zorrotzaurre, in Bilbao, Basque Country, Spain.
- **Climate risk**: Flood risk
- **Policy context**: In 2012 a new urban development was approved in an old industrial site on Zorrotzaurre and it was envisaged to open a canal that would turn Zorrotzaurre into an island and significantly reduce the risk of flooding upstream.

Adaptation action

- **Overall project**: Opening a canal that would turn Zorrotzaurre into an island.
- **Contribution to adaptation**: Significantly reduce the risk of flooding upstream.

Decision tool

- **Decision tool used**: Real-Option Analysis (ROA) was chosen as there were major uncertainties regarding the risks and benefits of the investment over time. ROA was used to determine the value of the option to postpone the investment or to invest now.
- **Stage in adaptation decision-making cycle**: Assessing and prioritising adaptation options (Stage 4).

Methods and Results

- **Method**: The approach used a stochastic damage model that enables the calculation of flooding damages for any given time, depending on the difference between the increase of damages due to climate change and economic growth, and the discount rate. By using the monetary values found in previous studies, the stochastic damage function can estimate the

[14] See: Skourtos et al (2016)

damages related to flood at different points in time, but also estimate the benefits of adaptation, in terms of avoided impacts.

- **Results**: The results showed that both the expected damage and the risks decrease significantly due to intended flood resilience measure.
- **Conclusions**: The benefits of waiting do not exceed the costs (the foregone benefits), so the economic advice was to execute the project immediately.

Opportunities, Challenges and Lesson learned

ROA was chosen because; on the one hand, postponing an adaptation investment may help resolve uncertainty about future climate change and avoid choosing the wrong adaptation investment, but on the other hand, there is a potential cost in terms of flood risk associated with postponing and the loss of early benefits. However, uncertainty was attached to future damage values due to key assumptions that the intensity of extreme events does not change.

3.2.2. Example for Iterative Management Framework, London Thames Estuary 2100[15]

Outline of context:

- **Geographical**: The Thames Estuary, London, UK
- **Climate risk**: Tidal flood risk (mean SLR and storm surge)
- **Policy context**: The Thames Estuary 2100 Plan is a strategy for tidal flood risk management in the Thames Estuary to the year 2100.

Adaptation action:

- **Overall project**: The Plan sets out a framework to determine investment decisions over the long term, thus allowing for flexibility and adaptiveness to manage the uncertainty in future effects. The framework considers several different climate scenarios that would justify different interventions and can be triggered or re-assessed as more data becomes available.

[15] See Annex A in DEFRA (2020).

- **Contribution to adaptation**: Interventions address the effect of future climate change scenarios on flood risk in the Thames Estuary.

Decision tool:

- **Decision tool used**: Iterative risk management as the central framework, but incorporating Cost-Benefit Analysis (CBA) and Multi-Criteria Analysis (MCA) elements to capture both quantitative and qualitative considerations.
- **Stage in adaptation decision-making cycle**: Identifying adaptation options (Stage 3) and Assessing and prioritising adaptation options (Stage 4)

Methods and Result:

- **Method**: The approach followed four stages:
  - Assessing climate change: To understand the effect of future climate change on flood risk in Thames Estuary, different climate change scenarios were developed and were used to quantify climate risks under these alternative scenarios.
  - Designing adaptation options: the full range of available individual responses to increasing flood risk were assessed and bundled into four high-level options (HLOs) each designed to respond to a certain level of water level rise.
  - Appraising options to address the most likely view of risk: using a CBA and MCA.
  - Appraising options under other scenarios: CBA was then repeat using differing baselines and impact estimates suggested by the different climate scenarios. This enabled a view of how the options perform under different scenarios, and shows potential weaknesses.
- **Results**: The option with the highest cost-benefit ratio given current knowledge was recommended. Each option includes a series of individual interventions that will have to be triggered at different points through time.

Opportunities, Challenges and Lesson learned

The key purpose of adopting a framework approach was to ensure that adaptation decisions are triggered at the right time, based on continuous data collection, so that the project can keep a benefit-cost relationship close to those envisaged at initial appraisal. Routine monitoring takes place by updating a set of pre-determined indicators, and a formal review of the indicator trends takes place every 5 years. At least every 10 years the strategy is re-assessed.

3.3. Light-touch approaches

As described previously, detailed approaches to economic appraisal, and especially decision making under uncertainty, are complex to apply, require a large volume of data and are time consuming and resource intensive. Light-touch approaches to economic appraisal are a form of rapid assessment, either using existing information from previous projects or using simple models or functions to help identify options or provide indicative costs and benefits.

Some projects, and especially climate proofing projects, may only require a 'light-touch' economic appraisal to introduce an economic rationale for adaptation. Light-touch economic appraisal may also have a role in an initial screening of high physical climate risk projects and/or projects where adaptation is a primary objective. For example:

- Traditional approaches to economic appraisal - Technical and logistical limitations may make it difficult or impracticable to quantify and then monetise all relevant impacts as costs and benefits. It then may be desirable to undertake a semi-qualitative CBA where as many of the impacts as possible are monetised and then qualitative estimates of the relative importance of the remaining costs and benefits are made. For example, the order of magnitude of benefits may be estimated or drawn from secondary sources[16] and an expert judgement made as to the likely balance of benefits and costs.

[16] Boardman et al (2018) Cost-Benefit Analysis.

- Decision making frameworks under uncertainty – It is possible to capture the conceptual aspects of approaches to decision making under uncertainty (while maintaining a degree of economic rigour) to allow for a qualitative or semi-quantitative analysis. This can include the:[17]
    - Use of decision tree structures from ROA.
    - Principles of robustness testing from RDM
    - Adoption of risk-spreading portfolios of options from PA
    - Focus on evaluation and learning from Iterative Risk Management (IRM) for long-term strategies.

[17] Tröltzsch et al (2016).

4. TOOLKIT FOR CHOICE OF APPROACH

4.1. Introduction

As identified above, a wide range of methods are available to estimate the costs and benefits of adaptation and undertake appraisal. While there is no 'one-size-fits-all', and each approach has strengths and weaknesses, a number of principles for the selection of an approach to the economic appraisal of the benefits and costs of adaptation are identified. Figure 2 and Figure 3 provides a decision-tree to guide the selection of an appropriate approach in specific adaptation decision-making contexts. The selection of an approach can be broken down into traditional approaches vs decision-making under uncertainty (Table 9) and the depth of appraisal (Figure 4 and Figure 5). In addition, Figure 4 highlights the contexts where different economic appraisal methods may be more applicable.

4.2. Traditional approaches vs decision-making under uncertainty

For projects where adaptation is the primary objective, or where there are material economic or financial impacts associated with high physical climate risks, detailed economic appraisal may be justified. However, these approaches are complex to apply, require detailed data and time consuming and resource intensive. Capacity and methods for appraising physical climate risk to assets and the cost and benefits of adaptation responses are also still in their infancy. Many projects may only require a 'light-touch' economic appraisal to introduce an economic rationale for adaptation. Light-touch economic appraisal may also have a role in either screening high physical climate risk projects or projects where adaptation is a primary objective.

Table 9 – Traditional approaches vs decision-making under uncertainty

Question	Answer	Pathway	Comment
Is climate uncertainty likely to have a major effect on the economic	Yes	Decision-making under uncertainty	Traditional economic appraisal approaches fail to fully account for

Question	Answer	Pathway	Comment
criterion outcome/is the lifetime long?	No	Traditional approaches	climate uncertainty. Also, long lifetimes are associated with urban planning. If climate uncertainty likely to have a major effect on the result or the lifetime of the project is long, then a decision-making under uncertainty approach should be considered
Are adaptation decisions likely to result in lock-in?	Yes	Decision-making under uncertainty	Urban planning often has a high risk of lock-in and potential irreversibility. Where feasible, decision-making under uncertainty methods should be considered.
	No	Traditional approaches	
Traditional approaches			
Are impacts measurable in monetary terms?	Yes	CBA	Where is it possible to quantify and then

Question	Answer	Pathway	Comment
	No	CEA or MCA	monetise all relevant impacts as costs and benefits, CBA should be used. This may not be the case early in the project development and appraisal processes. Where it is difficult or impracticable to monetise costs and benefits CEA or MCA could be considered.
Are adaptation responses working towards a single objective e.g. efficiency of water reduction options	Yes	CEA	CEA can be used to compare different measures for achieving the same adaptation objective. MCA allows for the comparison of alternative packages of measures for achieving a common goal.
	No	MCA	
Decision making under uncertainty			
Is there an opportunity for flexibility in, or	Yes	Dynamic adaptation pathways or ROA	ROA, for example, can be used to prioritise adaptation

Question	Answer	Pathway	Comment
learning from, the adaptation response?	No	See below	interventions while considering the possibility of the need to adjust them in the future.
Are adaptation responses complementary in dealing with the range of uncertain outcomes?	Yes	Portfolio analysis	Portfolio analysis can allow for the comparison of multiple portfolios of adaptation options to examine their complementarity.
	No	See below	
Is there good availability of climate and economic data?	Yes	RDM	RDM aims to identify adaptation options or strategies which can perform well over a wider range of possible futures. This method however requires a large amount of quantitative information, computing power to undertake Monte Carlo simulations, and a high degree of expert knowledge.

Question	Answer	Pathway	Comment
	No	Decision scaling, rule-based decision support criteria or scenario-based CBA	Such methods require the decision-maker to make explicit their attitudes to risk and beliefs in likelihood of alternative climate scenarios. More is therefore asked of the decision-maker when less data is available.

Figure 2 - Adaptation economic appraisal selection decision-tree

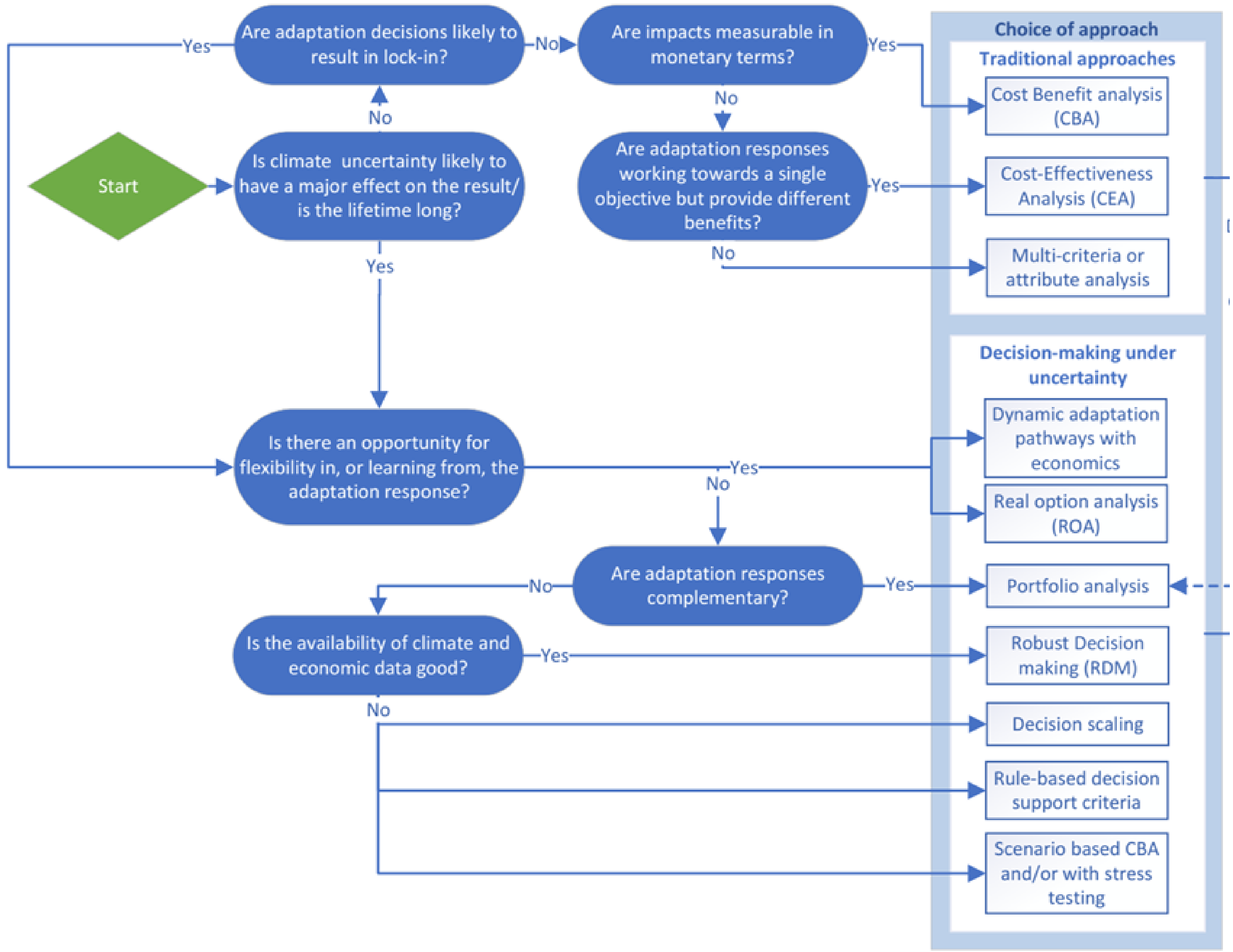
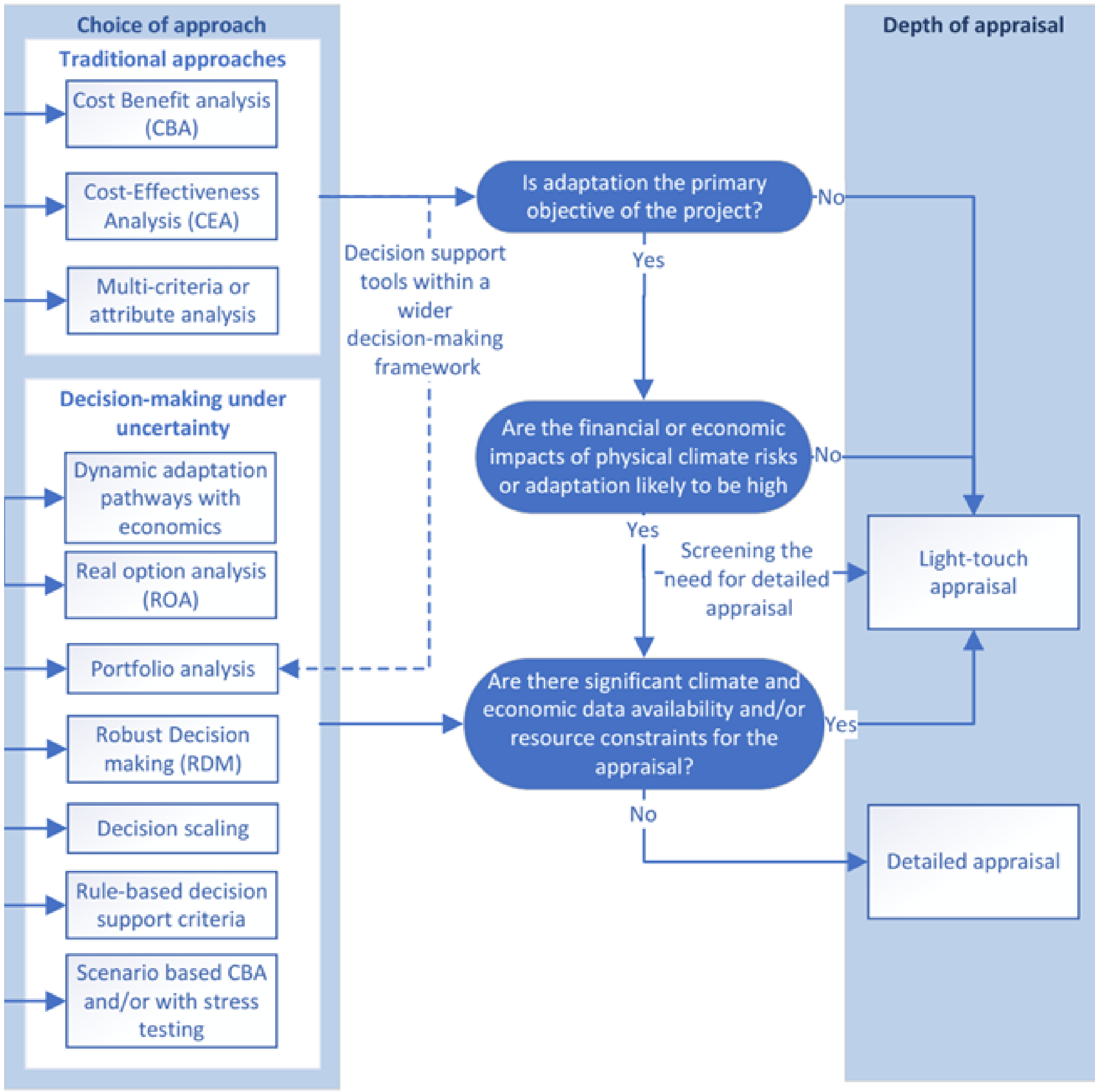
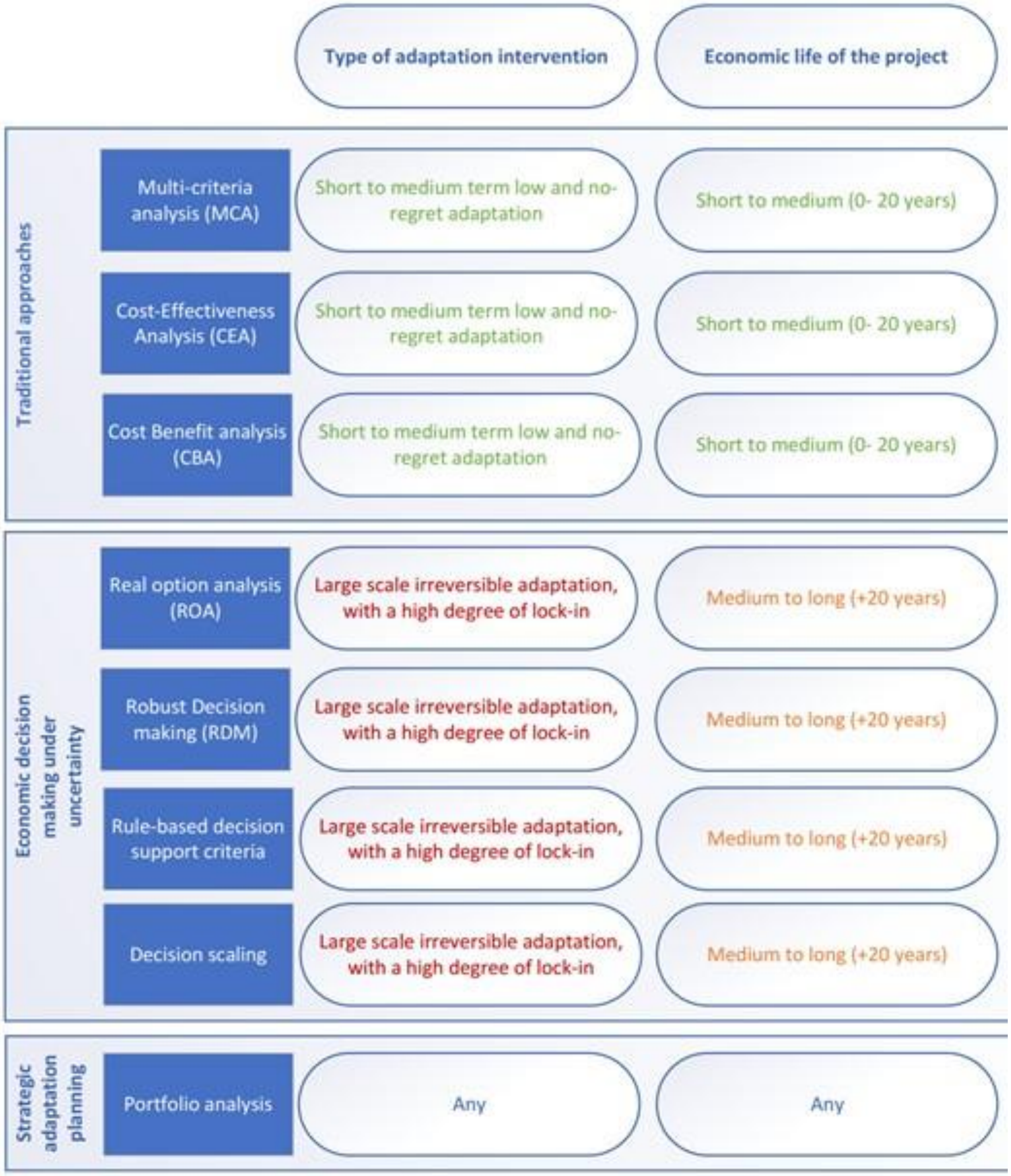

Start
Is climate uncertainty likely to have a major effect on the result/ is the lifetime long?
No
Yes
Are adaptation decisions likely to result in lock-in?
Yes
No
Are impacts measurable in monetary terms?
Yes
No
Are adaptation responses working towards a single objective but provide different benefits?
Yes
No
Is there an opportunity for flexibility in, or learning from, the adaptation response?
Yes
No
Are adaptation responses complementary?
No
Yes
Is the availability of climate and economic data good?
Yes
No
Choice of approach
Traditional approaches
Cost Benefit analysis (CBA)
Cost-Effectiveness Analysis (CEA)
Multi-criteria or attribute analysis
Decision-making under uncertainty
Dynamic adaptation pathways with economics
Real option analysis (ROA)
Portfolio analysis
Robust Decision making (RDM)
Decision scaling
Rule-based decision support criteria
Scenario based CBA and/or with stress testing

Figure 3 - Adaptation economic appraisal selection decision-tree



Choice of approach
Traditional approaches
Cost Benefit analysis (CBA)
Cost-Effectiveness Analysis (CEA)
Multi-criteria or attribute analysis
Decision-making under uncertainty
Dynamic adaptation pathways with economics
Real option analysis (ROA)
Portfolio analysis
Robust Decision making (RDM)
Decision scaling
Rule-based decision support criteria
Scenario based CBA and/or with stress testing
Decision support tools within a wider decision-making framework
Is adaptation the primary objective of the project?
No
Yes
Are the financial or economic impacts of physical climate risks or adaptation likely to be high
No
Yes
Screening the need for detailed appraisal
Are there significant climate and economic data availability and/or resource constraints for the appraisal?
Yes
No
Depth of appraisal
Light-touch appraisal
Detailed appraisal

Figure 4 – Contexts where different economic appraisal methods may be applied



		Type of adaptation intervention	Economic life of the project
Traditional approaches	Multi-criteria analysis (MCA)	Short to medium term low and no-regret adaptation	Short to medium (0- 20 years)
	Cost-Effectiveness Analysis (CEA)	Short to medium term low and no-regret adaptation	Short to medium (0- 20 years)
	Cost Benefit analysis (CBA)	Short to medium term low and no-regret adaptation	Short to medium (0- 20 years)
Economic decision making under uncertainty	Real option analysis (ROA)	Large scale irreversible adaptation, with a high degree of lock-in	Medium to long (+20 years)
	Robust Decision making (RDM)	Large scale irreversible adaptation, with a high degree of lock-in	Medium to long (+20 years)
	Rule-based decision support criteria	Large scale irreversible adaptation, with a high degree of lock-in	Medium to long (+20 years)
	Decision scaling	Large scale irreversible adaptation, with a high degree of lock-in	Medium to long (+20 years)
Strategic adaptation planning	Portfolio analysis	Any	Any

Figure 5 – Contexts where different economic appraisal methods may be applied

		Understand of physical climate risks and the adaptation response	Management of uncertainty	Resource/capacity requirements
Traditional approaches	Multi-criteria analysis (MCA)	Physical climate risks and the adaptation response are known	Does not explicitly deal with uncertainty	Low
	Cost-Effectiveness Analysis (CEA)	Physical climate risks and the adaptation response are known	Does not explicitly deal with uncertainty	Moderate
	Cost Benefit analysis (CBA)	Physical climate risks and the adaptation response are known	Does not explicitly deal with uncertainty	Moderate
Economic decision making under uncertainty	Real option analysis (ROA)	High degree of risk and uncertainty	Explicitly deals with uncertainty	High
	Robust Decision making (RDM)	High degree of risk and uncertainty	Explicitly deals with uncertainty	High
	Rule-based decision support criteria	High degree of risk and uncertainty	Explicitly deals with uncertainty	Moderate
	Decision scaling	High degree of risk and uncertainty	Explicitly deals with uncertainty	Moderate
Strategic adaptation planning	Portfolio analysis	Physical climate risks and the adaptation response are known	Explicitly deals with uncertainty	Moderate

Table 10 – Depth of appraisal

Question	Answer	Pathway
Type of project		
Is adaptation the primary objective of the project (adaptation project)?	Yes	Detailed appraisal
	No	See below
Is adaptation a secondary objective of the project (adaptation is a co-benefit of the project)?	Yes	Light touch appraisal may be appropriate
	No	See below
Are the financial or economic impacts of climate change or adaptation likely to be high relative to the overall project benefits (climate proofing project)?	Yes	Detailed appraisal
	No	Light-touch appraisal
For detailed appraisal		
Are there significant climate and economic data availability constraints and/or resource constraints for the appraisal?	Yes	Light-touch appraisal
	No	Detailed appraisal

5. CONCLUSIONS

A number of general conclusions can be made regarding the use of adaptation economics in investment decision-making in an urban context and these are supported in undertaking the case studies reported in sections 8 to 11. These conclusions include the following:

- **There are a number of appropriate decision support tools** which allow the economic appraisal of adaptation. These include: (i) traditional approaches to economic appraisal and (ii) tools for decision-making under uncertainty. The choice of these depends on the type of project.
- The **fundamental difference between adaptation economic appraisal and typical economic appraisal** is greater emphasis on managing uncertainty and risk, and on accounting for the temporal difference between current and future costs and/or benefits.

There is no 'one-size-fits-all' approach to adaptation economic appraisal and it is important to carefully select the most appropriate approach for the investment decision-making and adaptation context. Our decision process diagram in Figure 2 and Figure 3, annotated in Table 9 and, are designed to assist the analyst with this selection.

- **There are challenges in selecting and applying techniques**:
    - The analysis of physical climate risk and adaptation costs and benefits are site and context specific.
    - Whilst the distinction between projects that have a primary adaptation objective, that have adaptation as a co-benefit or have climate-proofing objective, , or are clear in principle, application in practice is often not straightforward. As the use case studies in sections 8-11 illustrate, a paucity of climatic and economic data exacerbates this challenge and limits the preciseness of the economic appraisal.
    - Blurring of objectives aside, the activity of identifying and collating even partial data has the useful purpose of focussing the attention of

decision-makers and stakeholders on economic, value-for-money criteria and so supports better decision-making. Evidence from the use case studies indicates that these criteria are currently not widespread in decision-making processes in many local investment decisions; consideration of climate risks and adaptation may help to accelerate their adoption.

- Given the lack of precision in the use case studies, the net present value has been used as the primary metric of economic efficiency. However, in instances where more complete data are available the calculation of the financial internal rate of return (FIRR) and the economic internal rate of return (EIRR) can be usefully adopted.
- There are complex issues of timing with the need to inform decisions now and over time.
- There is large uncertainty involved with future climate change, which makes it difficult to take early decisions, i.e. a predict and optimize approach is usually inappropriate.
- Adaptation benefits primarily arise in the future and therefore are low in net present value terms when discounted, as compared to the up-front investment costs.
- Economic analysis is undertaken from the perspective of society, as opposed to financial analysis, and requires valuation of social and environmental aspects, where additional monetary valuation is required.
- More applied analysis and decision making under uncertainty can be used to overcome these challenges, but these are complex to apply, require detailed data and are time consuming and resource intensive.

- **There are limited examples of adaptation economic appraisal that are explicitly stated as urban focused** in sources (e.g. ECONADAPT). This may be partly due to the cross-cutting nature of the urban/built environment policy field as it includes other fields such as those for infrastructure (water, energy, transport) and environment (air, land biodiversity etc.). Thus, many examples are not necessarily classed as urban, in that they have a specific infrastructure/environment focus relevant to urban areas but not defined by it.

- **There is often a lack of data availability** for use of decision tools. The Use Case examples in Sections 8 to11 highlight various data issues which can limit the robustness of the quantitative analysis. Careful consideration is needed as to how tools can be adapted or used in a partial way with available data so that they can still provide robust results that add value for decision making. Lack of data may justify adopting a traditional decision tool since it means that the gain in quality of assessment that might otherwise be made using an uncertainty-focussed tool is lost.
- **There is a need for transparency with assumptions and omissions.** In some of the use cases, the lack of data has required a significant level of assumptions or omissions to be made of, for example, intangible damages which are difficult to monetize. In these cases, it is important for these shortcomings to be clearly stated including the implications for uncertainty in the results.

6. USEFUL RESOURCES

COACCH project: The objective of COACCH is to produce an improved downscaled assessment of the risks and costs of climate change in Europe that can be accessed directly for the different needs of end users from the research, business, investment, and the policy making community: https://www.coacch.eu/

ECONADAPT: An EC FP7 research project whose purpose was to support adaptation planning though building the knowledge base on the economics of adaptation to climate change and converting this into practical information for decision makers. This includes:

- A toolbox that provides information on methods the economic assessment of adaptation: https://econadapt-toolbox.eu/methods
- A library of sources with 700 entries, including 65 studies relevant to the city scale: https://econadaptlibrary.eu

European Climate Adaptation Platform Climate-ADAPT: Partnership between the European Commission and the European Environment Agency (EEA). It includes:

- Urban Adaptation Support Tool (UAST) to assist cities, towns and other local authorities in developing, implementing and monitoring climate change adaptation plans: Urban AST step 0-0 — Climate-ADAPT (europa.eu)

European Commission: Better-regulation-toolbox: Includes guides to a number of decision support tools including:

- Analytical Methods to Compare Options or Assess Performance: https://ec.europa.eu/info/files/better-regulation-toolbox-57_en
- Multi-criteria analysis: https://ec.europa.eu/info/sites/default/files/file_import/better-regulation-toolbox-63_en_0.pdf

European Commission study on Adaptation Modelling. This comprehensive desk review provides a comprehensive, up-to-date and forward looking overview of the range of technical, financial, economic and non-monetary models and tools for hazards, risks, impacts, vulnerability and adaptation climate assessments.

https://op.europa.eu/en/publication-detail/-/publication/9383d16e-7651-11eb-9ac9-01aa75ed71a1/language-en/format-PDF/source-search

European Commission: Guide to Cost-Benefit Analysis of Investment Projects Economic appraisal tool: https://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/cba_guide.pdf

NYC Mayor's Office of Resilience, Climate Resiliency Design Guidelines: Provides step-by-step instructions on how to supplement historic climate data with specific, regional, forward-looking climate change data in the design of City facilities (NYC Mayor's Office of Resilience, 2020).

RAMSES research project: Aims to deliver quantified evidence of the impacts of climate change and the costs and benefits of a wide range of adaptation measures, focusing on cities: https://ramses-cities.eu/home/

RESIN research project: Interdisciplinary, practice-based research project investigating climate resilience in European cities. The project is working on developing practical and applicable tools to support cities in designing and implementing climate adaptation strategies for their local contexts: https://resin-cities.eu/home/

ToPDAd research project: Tool-supported policy development for regional adaptation (ToPDAd) funded by the European Commission. The objective is to find the best strategies for businesses and regional governments to adapt to the expected short term and long term changes in climate.

7. CASE STUDY APPROACH

Overall approach

The following sections present a variety of use-cases that illustrate the use of decision-making tools in different urban contexts. These demonstrate a number of approaches, including traditional cost-benefit analysis and multi-criteria analysis. The following sections present a series of case studies from four European cities (Loulé, Turku, Genoa and Glasgow) which are used to demonstrate the potential application of some of the economic appraisal approaches presented above.

Multicriteria analysis

To provide some comparability, the analysis has also presented as a simplified Multicriteria analysis (MCA) for all the case studies based on a small number of important assessment criteria listed below:[18]

- **Effectiveness**: The ability of the measure to manage material physical climate risks to an appropriate degree and/or results in a net adaptation benefit.
- **Additional Capital Cost (CAPEX)**: The additional capital expenditure required.
- **Additional Operational Cost (OPEX)**: The additional operation and maintenance costs required.
- **Environmental Impact**: The expected environmental impact of the measure.
- **Social Impact**: The expected social impact of the measure.
- **Economic Impact**: The expected economic impact of the measure.

Each option has been assessed against the following scoring system:

- Major negative impact (--)
- Minor negative impact (-)
- Not applicable or no significant impact (0)
- Minor positive impact (+)

[18] Criteria used drawing from selected European Investment Bank appraisals of the climate change adaptation performance of urban investments in Europe.

- Major positive impact (++)

The counterfactual for this assessment is a 'without project' scenario, as there is no alternative. See section 3.1 for more information of applying MCA.

The purpose of undertaking an initial MCA is that it allows the analyst to assemble a holistic picture of the merits of each adaptation option, serving to shape the focus of the economic and complementary analysis that follows. The MCA can subsequently be up-dated as more quantitative data is collated, or more detailed economic appraisal (as in previous sections) can be developed.

8. CASE STUDY: NON-REVENUE WATER REDUCTION, LOULÉ (PORTUGAL)

8.1. Project context

Geographical: Parish of Salir, Municipality of Loulé in the south of mainland Portugal, in the Algarve.

Sector: Water supply

Project: The objective of the Project is primarily to reduce Non-Revenue Water (NRW) and increase energy efficiency through operational and asset optimization. Specific actions include:

- Replacement of existing fibre cement piping system with PVC pipes;
- Overall refurbishment of network infrastructure of Salir with the goal of allowing for a reduction in water pressures which reduces leakage; and
- Replacement of 200 water meters in the distribution network[19].

While the project was initially designed as a water project, it will have some climate adaptation co-benefits, although climate projections were not used explicitly in the design of the scheme.

Climate vulnerability: Loulé is currently categorised as an area with extremely high-water stress. Rising mean temperatures and changing precipitation are projected to increase the level of water stress, increase the demand for water[20] and potentially affect water supply[21], presenting significant operational challenges for the water sector. In Table 11 we provide a rating of the climate vulnerability of the Loulé Non-Revenue Water Reduction project based on an assessment of the economic sector sensitivity and the geographic exposure to climate variables and hazards. Increasing

[19] Not expected to result in real losses being saved and therefore provide an adaptation benefit.
[20] Water demand is measured as water withdrawals.
[21] Water supply is the total renewable surface water.

temperatures and drought are highlighted as high vulnerabilities for water supply activities in Loulé (Salir).

Table 11 – Climate vulnerability rating: Loulé Non-Revenue Water Reduction

Climate variable/hazard		Sensitivity[22]	Exposure[23]	Vulnerability
Temperature	Temperature extremes	Moderate	High	Moderate
	Wildfire	Moderate	High	Moderate
	Increasing temperatures	High	High	High
Wind	Storms	High	Moderate	Moderate
	Changes in wind patterns	Low	Moderate	Low
Water	Drought	High	High	High
	Changes in precipitation patterns and variability	High	Moderate	Moderate
	Heavy precipitation / flooding	High	Low	Low
Coastal	SLR	High	n/a	n/a
	Ocean acidification	Low	n/a	n/a
Soil	Avalanche / landslides	High	Low	Low
	Subsidence	High	Low	Low
	Coastal erosion	High	Moderate	Moderate
	Soil erosion	Moderate	Moderate	Moderate

[22] Adapted from the EU Taxonomy Climate Sensitivity Matrix.
[23] Various sources.

Economic-Climate Screening

In Table 13 we provide an initial screening of the types of impacts on economic and financial parameters that we would expect to occur under current and future climate change. This serves as an indication of the importance of climate risks to a given project and therefore whether a light-touch or detailed economic appraisal is likely to be more or less suitable. In effect, it is also a qualitative application of the decision-scaling method outlined above. In the example of Loulé we judge that the increased risk of drought conditions under future climate projections is high.

Table 12 – Economic-climate screening: Loulé Non-Revenue Water Reduction

Economic/Financial Parameter	Impact of Current Climate & Climate Change on Economic Parameter
Fixed Capital Costs (Assets)	Possible effect. The sizing of the water system, and thus the pipes, might need to be greater because of future demand increases from climate change, and may need to include greater flexibility or storage to copy with increased variability (supply and demand) including from drought
Variable Costs (Operation & Maintenance)	Possible effect. Climate change likely to increase water demand, increasing operational costs of the project once completed.
Revenue	Potential fall in revenue if lower rainfall results in lower potable water availability Potential increase in revenue if water demand increases
Non-Market Benefits	Potential effect on Non-Market Benefits if lower rainfall results in lower water availability that may result in a change of the willingness to pay value to have a secure water supply
Economic & Financial Performance indicator	Potential effect on financial & economic performance. Financial performance related to revenue and variable costs and economic

	performance related to water availability impacting health costs and economic activities.

Adaptation context: The project aims to reduce potable water losses (both physical and commercial losses). While climate change adaptation is not the primary focus, the project may have adaptation benefits by reducing water resource deficits that might otherwise result from climate change. However, this scheme has not explicitly considered climate change in the design. This may have implications for the scheme, which include negative impacts on whether the scheme is designed appropriately for a changing climate, but also potentially positive in terms of some of the revenue streams (i.e. water demand is likely to be higher). It is noted that the lack of climate consideration in the scheme design has meant no detailed climate information is available for the economic analysis here, and we also note this is an important omission, and it is recommended that the project undertake a rapid climate risk assessment to investigate these issues.

As the project is focused on water efficiency, the climate change effect on the core scheme objective – of reducing potable water losses – is expected to be minor. However, climate change could still be important, and could affect the scheme positively and negatively, as summarised by Table 13. This project has adaptation as a co-benefit – and should really also be considered climate proofing – and so the analysis is interested in the changes in the potential costs and benefits of the scheme under a changing climate, and in theory, marginal costs and benefits resulting from any climate proofing. In principle this could entail e.g. piping with larger dimensions., additional storage or flexibility on the network, or a greater increase in efficiency measures to reduce demand (against the counterfactual). However, in this case there have been no additional measures incorporated in the project for the purpose of reducing climate risks. As a consequence, it is not possible to identify the marginal costs and benefits. We therefore undertake our analysis on the project as a whole, i.e. considering the gross costs and benefits that are generated in addressing both climate-induced and non-climate objectives.

As no assessment of physical climate risk to the assets has been undertaken, this project is unaligned with the EU Taxonomy and is ineligible as climate finance. If such a risk assessment were to be undertaken, and material risks managed to an appropriate degree, the project has the potential to provide a substantial contribution to adaptation. The incremental cost associated with these actions could then be designated as adaptation finance.

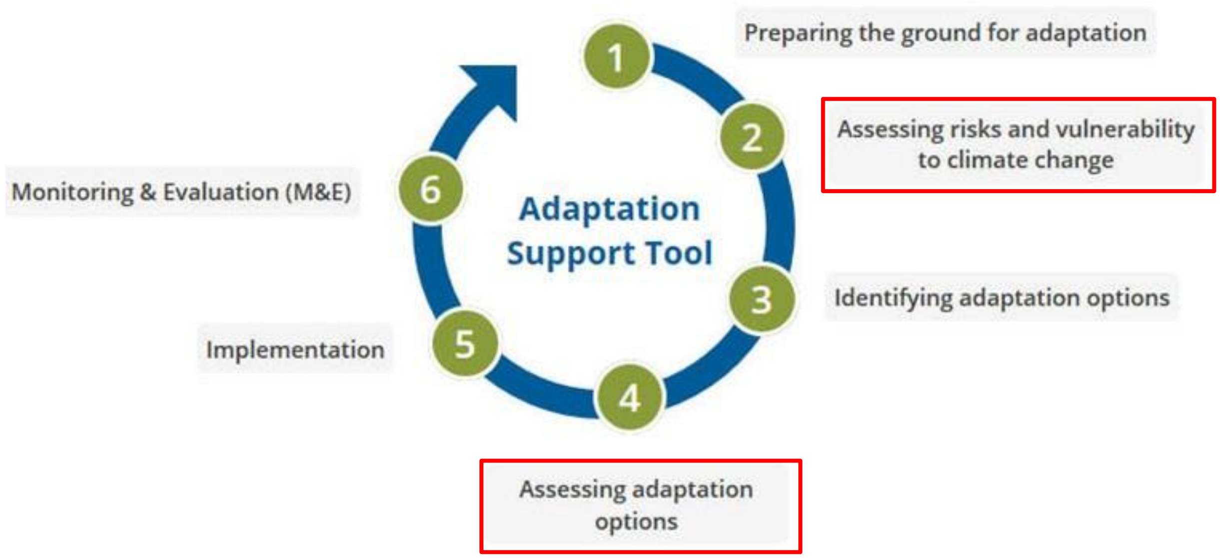
Table 13 – MCA and EU Taxonomy Alignment: Loulé Non-Revenue Water Reduction

Adaptation component	Material physical climate risks managed	Effectiveness / Performance	Capex / Opex	Environmental / social / economic impact	EU Taxonomy alignment: adaptation
Water management and efficiency project in the parish of Salir.	• Drought (acute) • Changes in precipitation patterns and variability (chronic) • Increasing temperatures (chronic)	Minor positive (+) – Reduce potable water losses.	No significant impact (0) – No additional capital investment or operational or maintenance costs to realise secondary adaptation benefits.	Minor positive (+) – Increase the availability of potable water to the community and to economic activities, and a consequent increase in revenues.	**Adapted activity**: Unaligned – no assessment of physical climate risk to the assets. **Enabling adaptation**: DNSH – Minor adaptation benefit

8.2. Decision tool

Stage in adaptation decision-making cycle: In order to evaluate the identified investments we need to undertake an ex-ante appraisal, incorporating data on risk and vulnerability to climate change into the project screening (Stage 2). This ensures that we establish early as to whether climate change risks are likely to be material to the project justification. We then need to undertake an assessment of the adaptation component of the investment (Stage 4).

Figure 6 – Stage in the adaptation Decision-making cycle: Loulé Non-Revenue Water Reduction



Choice of approach: In order to identify which decision tool(s) are likely to be most appropriate to use to evaluate the project against economic criteria, we utilise the process diagram presented in Figure 2 above and reproduced below (Figure 7. In Table 14 we provide a commentary that shows how we respond to the series of questions incorporated in the process diagram. Reflecting on the principles for the selection of an approach to such an economic appraisal in section 3, Light-touch CBA with sensitivity analysis is an appropriate approach to the financial/economic appraisal of the Loulé Non-Revenue Water Reduction project. Figure 7 and Table 14 summarises the justification for the choice of this approach.

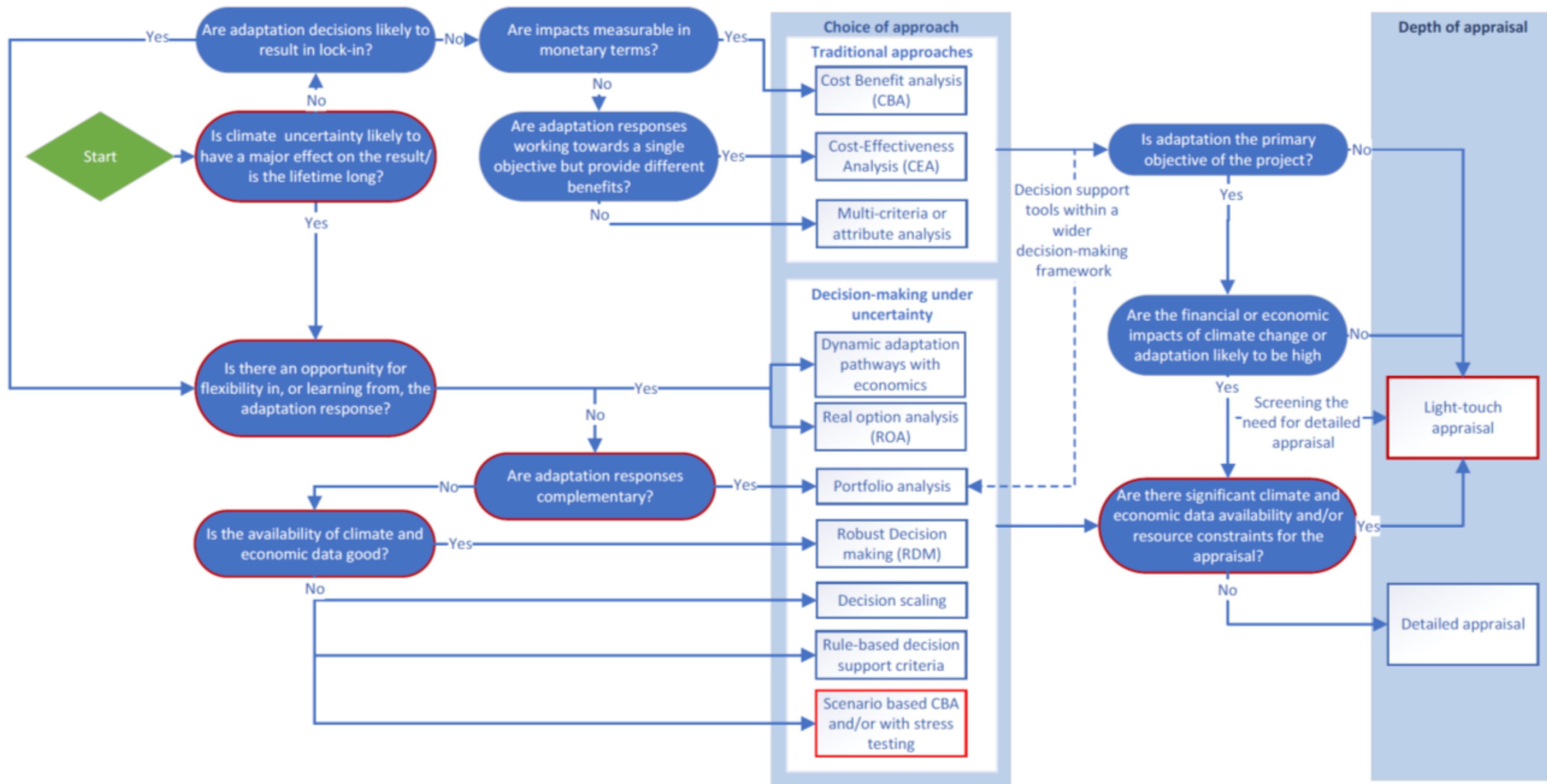
Table 14 – Justification for choice of method: Loulé Non-Revenue Water Reduction

Question	Answer	Comment
Is climate change likely to have a major effect on the result/is the lifetime long?	Yes	Climate change is projected to impact negatively on water availability, thereby increasing the importance of protecting

		water supply to the community. Climate change will also increase water demand, which may present additional challenges for the system. The pipe infrastructure has a long (30+ years) lifetime
Is there the opportunity for flexibility in, or learning from, the adaptation response	Possibly	The intervention as planned is largely an efficiency option, reducing leakage, and so would be considered no or low regret, as it provides benefits now, and , because the direction of the future climate signal is likely to lead to negative effects which will increase these benefits. However, there are some major lock-in risks from the nature of the investment, because it is a major physical investment, with a long lifetime, i.e. for system level upgrades and major pipe upgrades that will influence the system for decades, and thus could be expensive to change later. This might mean it is better to develop a new system with flexibility built in.
Are adaptation responses complementary?	No	The counterfactual for this assessment is a 'without project' scenario, as there is no alternative presented by Loulé.
Is the availability of climate and economic data good?	No	Data available with regard to both the operational costs and the non-financial benefits of the water saving scheme is incomplete. The mean values for relevant climate variables are available for two climate change scenarios from general projections, but these have not been transposed to the scheme, with any analysis of water supply and demand (and demand balance) with hydrological modelling, and there is no consideration of the potential risk of increasing dry spells

		and droughts which could be important for the scheme.
Choice of method	Given nature of scheme and limitations on data above, CBA with sensitivity analysis. More typically, a water project would apply a decision-scaling or robust decision-making approach. In this case, the data available was judged sufficient to at least construct an indicative CBA rather than rely on rule-based methods that require the CBA output in any case.	
Are there any significant climate and economic data availability and/or resource constraints for the appraisal?	Yes	See above. CBA allows the decision-maker to use an economic efficiency criterion. Limited scenario data (climate and population) allow sensitivity analysis
Depth of appraisal	Intermediate. Given the limitations above, the analysis could be light-touch, as the investment does not have adaptation as a primary objective and it is not judged to be of sufficient scale to justify the resources required for detailed appraisal. However, major water investment project should be considered more detailed climate risk assessment, and if potential issues are identified, or water resilience is a primary objective, detailed appraisal is warranted.	

Figure 7 – Justification for choice of method: Loulé Non-Revenue Water Reduction



8.3. Results of the economic appraisal

Based on limited data available benefit-cost ratios indicate the underlying project does not pass a cost-benefit test (BCRs are less than 1 and therefore the costs outweigh the benefits) when considered for both an economic and financial analysis. This is the case across a range of alternative climate change and population change scenario combinations (Table 15). However, it is important to emphasise that these results are only illustrative since neither the costs nor benefits assessed are comprehensive. In the case of costs, only the capital investment is included. On-going annual management costs are not included. In the case of benefits, the economic values are only partial. Non-market benefits are proxied using resource cost-based measures rather than measures of the population's willingness to pay to consume water or to conserve it (for non-use purposes) within the natural environment. Consequently, the true benefits are likely to be under-estimated. Looking at the climate scenarios, the water saving scheme has reduced effectiveness, in absolute terms, in the scenario where water availability is increasingly constrained in future years, as a function of the fact there is less water available to be saved. It is therefore possible that more effective adaptation measures are those that are targeted directly at reducing demand, or possibly those enhancing water availability. In an extreme case (not assessed) with rising demand and falling supply, this could indicate water transfers from other areas or desalination plant. These options would be likely to entail higher costs and therefore higher consumer prices.

Table 15 – Benefit-Cost Ratios: Water Loss Saving scheme – Loulé

Decision Rules	Low Population – RCP[24]4.5	High Population – RCP8.5	Average

[24] A Representative Concentration Pathway (RCP) is a greenhouse gas concentration trajectory adopted by the IPCC. Four pathways were used for climate modelling and research for the IPCC fifth Assessment Report. RCP 4.5 is described as an intermediate

Benefit Cost Ratio (Financial)	0.03	0.03	0.03
Benefit Cost Ratio (Economic)	0.06	0.05	0.05

Assumptions: The assumption made by the city that the effectiveness of the scheme in saving the equivalent of 30% of the current water loss has a critical bearing on the financial and economic cases for the scheme. The assumption that the level of current water availability is at a maximum sustainable level ensures that any change from that level will be measured as an addition or subtraction. This assumption about the relationship between groundwater and water available for human uses may not be realisti

Opportunities, Challenges and Lesson learned: The lack of climate change consideration in the scheme to date is a major omission, and creates a major challenge for the economic analysis here. Data available with regard to both the operational costs and the non-financial benefits of the water saving scheme is incomplete and so limits the robustness of the quantitative analysis. The case study does, however, emphasize the usefulness of quantitative data on both socio-economic and climate scenarios since these have material effects on the measures of benefits of water-conserving measures, and allow us to demonstrate the robustness of the investment.

Lessons for Transferability: Salir is largely separated from the wider water network, which may help in reducing some of the complexity of any analysis and allow for individual variables to be determined more easily. Whilst this case study has been undertaken at a very local scale it is clear that this analysis could be valuable across water-constrained areas of Southern Europe. The study demonstrates that both

scenario, and RCP 8.5 is a scenario where emissions continue to rise throughout the 21st century socio-economic climate scenario data is available and can be used to generate forecasts of water resource use and availability; these can be scaled to the specific context, as appropriate. However, the incomplete nature of the available data means that the results can be illustrative only.

Minimum data to facilitate further economic analysis

- **Climate data**: reflect the full range of climate uncertainty by identifying the value of climate variables:
  - Between different climate models, and;
  - Different potential climate scenarios, for decadal time periods in the future.
  - This should include both slow-onset change, but also importantly, changes in extremes.
- **Impact data**: modelling the effects of the full set of climate data using empirically identified relationships with local water availability.
- **Economic data**: unit value of water derived from data on local or Portuguese preferences, including for environmental benefits. i.e. what are citizens willing to pay for a cubic meter of available water?
- **Effectiveness of adaptation**: data on the extent to which the investment results in a reduction in climate risk to water availability, and on additional adaptation investments which could have been included to climate proof the scheme, or increase flexibility for later changes.

Availability of this data – the climate data in particular – would, in principle, allow a positive response to the question in the process diagram: Is the availability of climate and economic data good? Answering “yes” to this question could allow the analyst to use a decision-making method that more fully incorporates uncertainty such as decision scaling, Portfolio Analysis, ROA or RDM. In this instance, it is clear that this is a relatively small project whose costs could well be significantly increased by adopting these methods since their use requires expertise that implementing authorities may not have. It is also the case that climate change adaptation is not a primary objective. However, developing water projects in water scarce areas should really be incorporating some level of climate risk assessment, and looking at whether scheme design could be enhanced, especially given the long life-times involved.

If, however, resources were available, these uncertainty-based methods could be considered. The appropriate method would then depend on: the existence of a range of complementary measures to reduce climate risks over the full range of uncertainty (decision scaling); the extent to which there is flexibility of response as the size of climate risks becomes apparent over time (Real Option Analysis); the preference decision-makers have regarding economic maximization relative to robustness (if the latter, then Robust Decision-Making).

9. CASE STUDY: BLUE-GREEN URBAN REGENERATION, TURKU (FINLAND)

9.1. Project context

Geographical: City of Turku, located on the southwest coast of Finland at the mouth of the Aura River.

Sector: Urban development (including public realm).

Project: Turku's Kirstinpuisto district is undergoing regeneration, converting brownfield light industrial buildings and empty lots to apartments, offices, and shops.

The area has a stormwater drainage network that is poorly equipped for weather extremes. To address this an urban design and stormwater management strategy has been developed which integrates planning and building design with grey, blue and green infrastructure. The strategy reduces peak loading of the drainage system by retaining a significant amount of stormwater within redeveloped areas. Excess stormwater is conveyed by the drainage network to the sea, with the benefit of improved water quality due to the blue-green features within the newly developed areas.

It is noted that while the project was designed as an urban development project with multiple objectives, one of which was to address current climate risks, addressing future climate change was not explicitly included the design of the scheme.

Climate vulnerability: The City of Turku's 2018 climate risk and vulnerability assessment (CRVA)[25] identifies the two most significant physical climate risks to the city as:

[25] https://www.turku.fi/sites/default/files/atoms/files/turku_climate_plan_2029.pdf

- **Stormwater flooding**: due to increased precipitation and existing flooding issues. Although climate projections were not included in the city's CRVA in 2018, analysis in 2021 indicates a 25-30% increase in diurnal precipitation and 30-50% in hourly precipitation under the high emissions scenario (RCP8.5) by 2080-2100 (compared to 1986-2005 baseline)[26] .
- **Ecosystem changes**: due to loss of habitat, warming climate, and increasing spread of pests and disease.

Table 16 rates the climate vulnerability of the Turku blue-green urban regeneration project based on an assessment of the economic sector sensitivity and the geographic exposure to climate variables and hazards. SLR and subsidence are highlighted as high vulnerabilities for drainage in Turku, and heavy precipitation/flooding and changes in precipitation patterns and variability are moderate risks.

[26] https://www.vesitalous.fi/wp-content/uploads/2021/03/Vesitalous_0221_lowres-1.pdf

Table 16 – Climate vulnerability rating: Turku blue-green urban regeneration

Climate variable/hazard		Sensitivity[27]	Exposure[28]	Vulnerability
Temperature	Temperature extremes	Moderate	Low	Moderate
	Wildfire	Moderate	Moderate	Moderate
	Increasing temperatures	High	Moderate	Moderate
Wind	Storms	High	Moderate	Moderate
	Changes in wind patterns	Low	Moderate	Low
Water	Drought	Moderate	Moderate	Moderate
	Changes in precipitation patterns and variability	Moderate	Moderate	Moderate
	Heavy precipitation/flooding	High	High	High
Coastal	SLR	High	High	High
	Ocean acidification	n/a	n/a	n/a
Soil	Avalanche / landslides	High	Low	Moderate
	Subsidence	High	High	High
	Coastal erosion	High	Moderate	Moderate
	Soil erosion	Moderate	Moderate	Moderate

Adaptation context: The integrated stormwater management strategy combines structural controls, and Sustainable Drainage Systems (SuDS) designed for a 1-in-10 year rainfall event (current climate and return periods). The centralized structural control involves a linear park in the middle of the site with several connected detaining ponds, providing blue-green infrastructure for stormwater management and recreational space for residents. On each lot, SuDS measures are incorporated by imposing a limit on the impervious area allowed, and requiring a volume of stormwater retention within the lot. SuDS features from private lots connect to the centralised stormwater controls in the linear park.

[27] Adapted from the EU Taxonomy Climate Sensitivity Matrix.
[28] Various sources.

In addition, newly developed buildings are raised 1m from the street level to enhance resilience to stormwater flooding, delivering protection for homes and residents which is much greater than a 1-in-10 year rainfall event. This appraisal focuses on the stormwater management system, and therefore raising of the building heights is not been included in this appraisal.

It does not appear a climate risk and resilience assessment was carried out to inform design of the project; instead the City has followed what it considers to be good practice for enhancing climate resilience. For example, the City has increased the design capacity of stormwater pipes (which were previously designed for a 1-in-3 year rainfall event) and adopted requirements for blue-green infrastructure in the design. We consider this a major omission, given that climate change will alter the return period of extreme events. A current 1 in 10 year rainfall event will become more common, and what was previously a more extreme event (e.g. a 1 in 25 year event) will become more frequent. This highlights that the scheme is not necessarily climate smart, eg. SuDS are good at coping with low flood levels (nuisance flooding) but are often insufficient to cope with major flood events (however the design of the buildings has considered this risk by raising the buildings heights by 1m).

It is also noted that the lack of climate analysis to inform the scheme design has meant no detailed climate information is available for the economic analysis here.

Economic-Climate Screening

In Table 17 we provide an initial screening of the types of impacts on economic and financial parameters that we would expect to occur under current and future climate change. This serves as an indication of the importance of climate risks to a given project and therefore whether a light-touch or detailed economic appraisal is likely to be more or less suitable. In effect, it is also a qualitative application of the decision-scaling method outlined above. In the example of Turku, we judge that the increased risk of flood events under future climate projections will be mitigated to some extent by the implementation of the stormwater management strategy but that there may remain a residual risk to e.g. property and human health.

Table 17 – Economic-climate screening: Turku blue-green urban regeneration

Economic/Financial Parameter	Impact of Current Climate & Climate Change on Economic Parameter
Fixed Capital Costs (Assets)	Potential effect. While the scheme as is provides adaptation to current extremes, there might be some implications for design and capital costs to design to also future climate change. This might imply some additional measures or design changes.
Variable Costs (Operation & Maintenance)	Negligible effect
Revenue	Not applicable – no good or service involved. Scheme is not designed to generate revenues, although some potentially relevant issues (insurance, reduced city expenditure)
Non-Market Benefits	Avoided losses (property floods, disruption and lost time, etc.). Benefits may increase with climate change, but also a risk that system may get overwhelmed from higher flood intensity which results in increased impacts Ecosystem services benefits: improvements to air quality and water quality, potential to sequester carbon, potential to reduce urban heat, potential to enhance biodiversity, enhancements to amenity and recreation, potential to provide educational benefits.

Economic/Financial Parameter	Impact of Current Climate & Climate Change on Economic Parameter
Economic & Financial Performance indicator	Potential negative effect on financial & economic performance

Table 19 below, brings together an indicative MCA of the project relative to the do-nothing baseline. It highlights that the project costs are likely to be sizeable (Euro million) but that there are also significant benefits, some of which will effectively be low regret adaptation to current climate risks (and with potential benefits under a changing climate, although additional risks as well). This indicative exercise serves to scope out both the size of the project, and the economic and financial components that are most sensitive to climate change. This information then feeds into our use of the decision process diagram that informs appropriate decision methods to adopt.

Adaptation to climate risks is not the primary objective of the project – rather, it is urban regeneration, though one of the co-benefits of the project is to reduce current climate risks (and implicitly build some resilience). However, in theory this type of project should undertake an analysis of climate change, and if appropriate adjust the design, i.e. to climate proof. As this has not been incorporated in the scheme, this makes it more difficult to prescribe the exact type of project, but we would be interested in the marginal benefits of adaptation to add to other scheme benefits streams, and in theory the marginal costs and benefits resulting from any additional climate proofing. In principle the latter could entail e.g. a stormwater management scheme design that had a greater capacity to accommodate stormwater volumes. As the impact of climate change has not been assessed for the underlying scheme, it is not possible to identify the marginal costs and benefits. We therefore undertake our analysis on the project as a whole, i.e. considering the gross costs and benefits that are generating in addressing both climate-induced and non-climate objectives.

As no assessment of physical climate risk to the assets has been undertaken (based on climate projections), this project is unaligned with the EU Taxonomy and is ineligible as climate finance. If such a risk assessment were to be undertaken, and material risks managed to an appropriate degree, the project has the potential to provide a substantial contribution to adaptation. The incremental cost associated with these actions could then be designated as adaptation finance.

Table 18 – MCA and EU Taxonomy Alignment: Turku blue-green urban regeneration

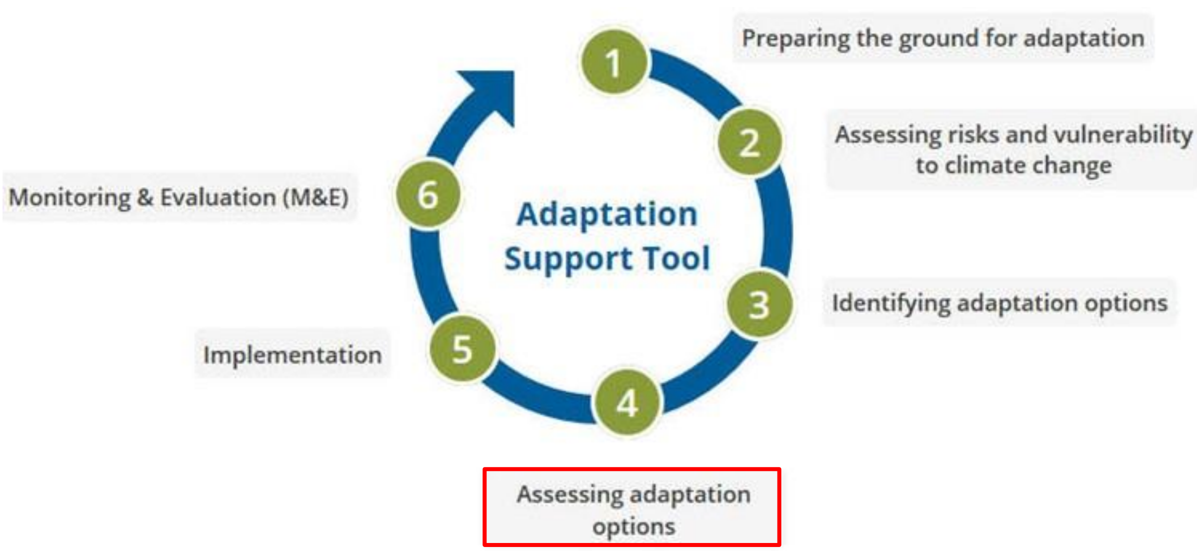
Adaptation component	Material physical climate risks managed	Effectiveness / Performance	Capex / Opex	Environmental / social / economic impact	EU Taxonomy alignment: adaptation
Integrated stormwater management	• Heavy precipitation/ flooding (acute) • Changes in precipitation patterns and variability (chronic)	Positive (+) – Stormwater management and creation of urban habitats	Negative impact (--) – Capital investment and maintenance costs.	Major positive (++) – Avoided flooding damages to property and avoided impacts on health and well-being from flooding (deaths, injuries, mental health). Social, economic and environmental benefits from blue-green infrastructure as compared to conventional grey adaptation infrastructure.	**Adapted activity**: Unaligned – not clear whether a full assessment of physical climate risk to the assets has been undertaken. **Enabling adaptation**: Unaligned – not clear whether a full assessment of physical climate risk has been undertaken to inform design of this project.

				Creation of urban habitats, reducing risks to biodiversity	

9.2. Decision tool

Stage in adaptation decision-making cycle: In order to evaluate the identified investments we need to undertake an ex-ante appraisal, incorporating data on risk and vulnerability to climate change into the project screening (Stage 2) reported above, in brief. This ensures that we establish early as to whether climate change risks are likely to be material to the project justification. We then need to undertake an assessment of the adaptation component of the investment (Stage 4).

Figure 8 – Stage in the adaptation decision-making cycle: Turku blue-green urban regeneration



Choice of approach: In order to identify which decision tool(s) are likely to be most appropriate to use to evaluate the project against economic criteria, we utilise the process diagram presented in Figure 2 above and reproduced below (Figure 9). In Table 19 we provide a commentary that shows how we respond to the series of questions incorporated in the process diagram. Reflecting on the principles for the selection of an approach to such an economic appraisal in section 3, Given the current nature of the scheme, and the data available, light-touch CBA is an appropriate approach to the financial/economic appraisal of the Turku blue-green urban regeneration. However, we would recommend that a scheme such as this, with an important climate adaptation component, should take future climate change into account, and this would normally require a more detailed analysis. Figure 9 and Table 19 summarise the justification for the choice of this approach.

This choice was dictated by:

- The absence of key data which would be required for other appraisal approaches (as explained below);
- The absence of a climate change risk assessment informing design of the project, and the fact that climate adaptation is not the primary driver for the urban regeneration project; and,
- Climate uncertainty exists but the trend of increasing rainfall is clear, and uncertainty in projections would not change the need for the project, although it might change the design and the level of resilience developed. Development projects involve land-use change and thus do involve a high degree of lock-in, e.g. building a development in an area of existing flood risk, could lock-in exposure to future events. However, the specific investments considered here – the SuDS elements are typically considered quite low regret options- in that they can be upgraded, removed, replaced, or supplemented with another option in future if required.

Figure 9 – Justification for choice of method: Turku blue-green urban regeneration

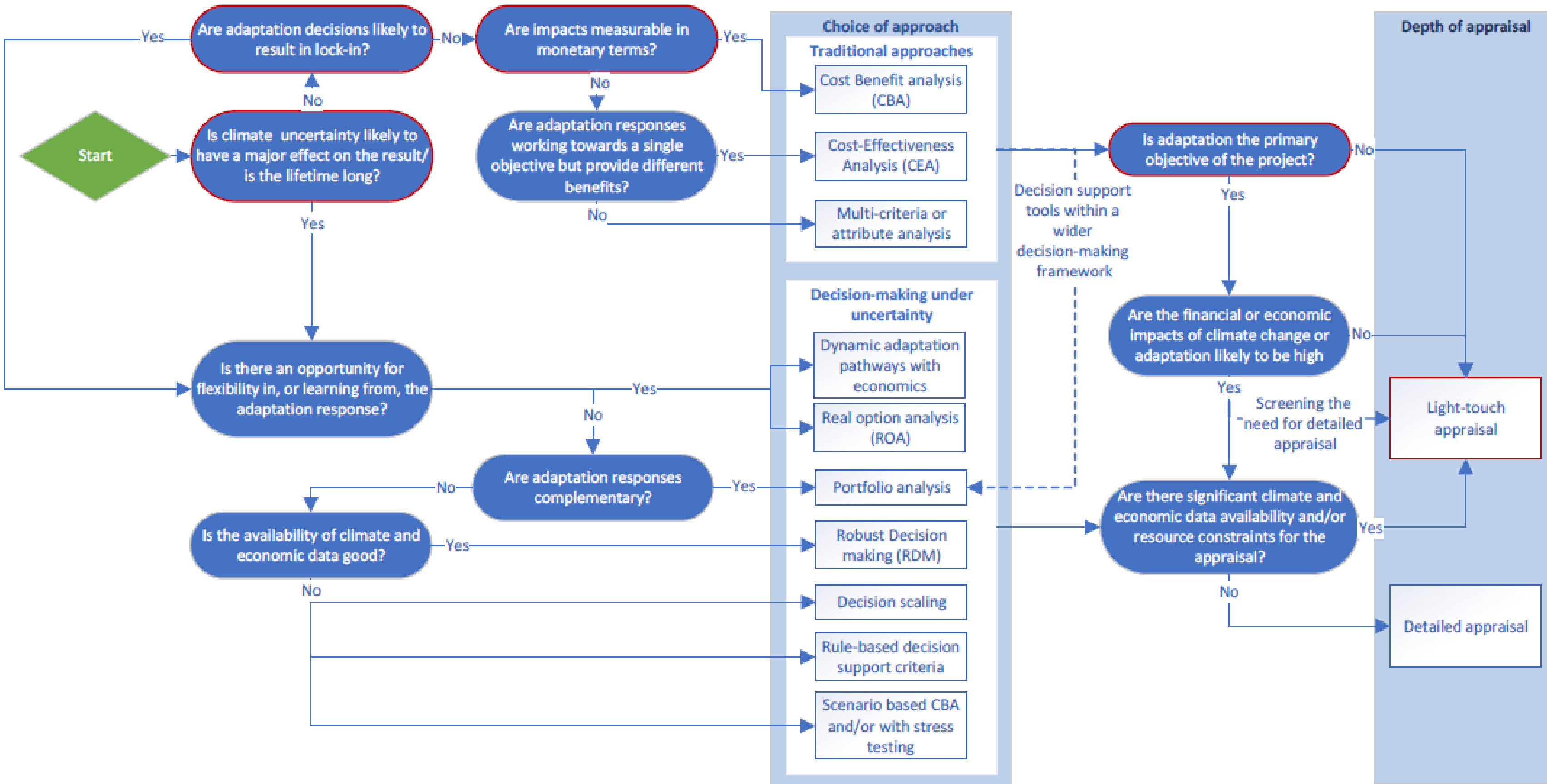


Table 19 – Justification for choice of method: Turku blue-green urban regeneration

Question	Answer	Comment
Is climate change likely to have a major effect on the result/is the lifetime long?	Yes No	Urban development projects have long lifetimes, in that they change land use patterns for decades. The development around an area of existing flood also has a high potential for potential climate impact. Raising the building heights provides additional protection from stormwater flooding, however, there is a question over where these have been raised sufficiently to cope with future climate change risk – though these elements are not the focus of the economic appraisal here. For the specific SuDS schemes, climate change has the potential to reduce the performance of the SuDS scheme over time. However, there is potential to expand or change these measures in the future.
Are adaptation decisions-likely to result in lock in?	Yes No	As above, urban development in areas of high climate risk today involve high lock-in, and the overall scheme lock-in is high. The grey infrastructure as part of the apartment buildings could create lock in, but is not the focus of this appraisal. The SuDS elements of the project generally avoid lock-in as they can be expanded to increase capacity in future, or they can be removed, replaced, or supplemented with another option in future if required.
Are Impacts measurable in monetary terms?	Yes	See data and data sources section below. There is partial data available on a number of the cost and benefit parameters, including avoided flood impacts

Choice of method	CBA – Monetised data on impact reduction means that CEA is not needed; CBA can be used. We do not have the available data on climate uncertainties to undertake methods based on uncertainty analysis such as ROA.	
Is adaptation the primary objective of the project	No	Climate change adaptation is not the primary objective of the urban regeneration project. Managing stormwater flooding is the primary objective of the stormwater management system as part of the project, however a full CRA has not been completed to inform design of the system.
Depth of appraisal	Light-touch	

Data & data sources: the following data is available for the appraisal:

- Aggregate historical flood event damages, estimated based on two historical events in 2012.
- Future extreme precipitation projections for Turku in 2070 under the high emissions scenario (RCP8.5).
- Estimate of benefits: some information on avoided flood damages and on ecosystem services provided by blue-green infrastructure.
- Estimate of capital costs for the development of the stormwater management system.

There is a lack of data on property development benefits, recurring annual maintenance costs, flood damage cost estimates for a range of historical flood event frequencies, and modelled flood damages and associated costs for future time periods for the new development under a range of climate scenarios.

9.3. Results of the economic appraisal

The partial cost-benefit analysis shows that benefits equate to €2.8 million whilst the costs equate to €3 million, suggesting a BCR <1. Although the results show costs slightly outweigh benefits, it is important to note that both the benefit and cost estimations are incomplete.

The main omission in the benefit estimation is that benefits only estimate reductions in flood risks for 1 in 10 year events (because of limited data available). There would be benefits from flood events of lower frequency and <1-in10-year events, as well. There might also be some protection against more extreme events, e.g. >1-in-20, 1-in-30 year events etc. – however, there is also a risk that the design of the scheme cannot cope with these events, and as they increase under climate change, this undermines the protection the scheme was intended to provide. Additionally, while avoided flood damages have been included, wider disruption (e.g. lost time from transport disruption, potential injuries (or even fatalities) and mental health benefits arising from avoided flooding have not been included, and this could be valued by City stakeholders.

The main omission in the cost estimation is that of maintenance costs over the infrastructure lifetime which are not yet available but may also be sizeable. However, it's likely that the additional benefits would outweigh the additional costs, suggesting that **BCR will be >1.**

We can also consider the economic performance of the scheme under different climate scenarios to test the sensitivity of the assessment:

- Under scenarios where rainfall and flooding are more frequent and severe in future: the benefits of the project may increase or remain roughly the same up to a point, due to the stormwater management system providing flood risk reduction benefits more frequently. However, with time, the increased flood intensity would be expected to overwhelm the design standard of the scheme, which is targeting a 1 in 10 year flood event. While the SuDS may be an early low regret action, this indicates further analysis of rising risks, and potentially additional measures, should be investigated.
- Given there is high confidence that rainfall will increase in Turku, testing the economic rationale under scenarios where rainfall and flooding are less frequent and severe in future is less important. However, if we were to consider this scenario the flood risk reduction benefits of the project are

likely to be smaller. However the ecosystem services benefits would remain, therefore enhancing the rationale for completing the project.

Assumptions:

- A linear interpolation of climate change-induced flood damage costs is used.
- A conservative assumption of project lifetime (30-years) is used. It is likely to be longer in practice. Whilst the maintenance costs would then be higher, so would the flood risk management benefit.
- For the purposes of simplified CBA, no changes to the economy and society are considered in the estimation of future costs and benefits.

Opportunities, Challenges and Lesson learned

The appraisal of the stormwater management system was complicated because of a number of reasons:

- There was incomplete data about the costs and benefits of the scheme, including how these might change under different climate scenarios (e.g. how flood risk may increase, and how damages may be reduced or increased under different climate scenarios). To enable the appraisal to be undertaken, simplifications were required to be made, including the use of incomplete data.
- An absence of complete data is likely to be the norm in economic appraisal. This constraint should be recognized but should not prevent an appraisal using available data to at least highlight whether the measures are likely to meet an economic efficiency criterion, provided the analysis focuses on low regret options.
- Limited climate scenario data should not be assumed to represent all climate futures. Specifically, it is important to be aware of what data is lacking so that climate uncertainties are fully appreciated by those tasked with making decisions. Simplified climate scenario analysis/ sensitivity analysis can help to test the economic performance of options.

Lessons for transferability:

The simplified CBA approach adopted is transferable to use in other contexts. The estimate of flood damages and the construction costs of the stormwater system are specific to the project site in Turku, but could be estimated for other cities. The estimation of ecosystem services used the Benefits Estimation Tool (B£ST)[29], which can be used to provide high-level estimates in other contexts.

The climate data utilised may be transferred to other urban contexts in Finland; it should be checked with national climate change hubs as to whether these data can be transferred to other regional contexts.

Minimum data to facilitate further economic analysis

- **Climate data**: reflect the full range of climate uncertainty by identifying the value of climate variables:
    - Between different climate models, and;
    - Different potential climate scenarios, for decadal time periods in the future, including changes in extreme events.
- **Impact data**: modelling the effects of the full set of climate data using empirically identified relationships between precipitation and damage to property and human health.
- **Economic data**: unit damage cost data for property and human health. Capital and maintenance cost data on the property development.
- **Effectiveness of adaptation**: data on the extent to which the investment can cope with different flood levels, and at what point additional actions are needed, and assessment of these options.

Availability of this data – the climate data in particular – would, in principle, allow a negative response to the question in the process diagram: Are there significant climate and economic data availability and/or resource constraints for the appraisal.?

[29] CIRIA Benefits Estimation Tool (B£ST)

Answering “no” to this question could allow the analyst to undertake a detailed appraisal.

If the initial climate risk appraisal had indicated that climate uncertainties may have a significant effect on the outcome of the economic analysis we would follow the process diagram through to potentially use a decision-making method that more fully incorporates uncertainty such as Portfolio Analysis, ROA or RDM. The appropriate method would then depend on the existence of a range of complementary measures to reduce climate risks over the full range of uncertainty (Portfolio Analysis); the extent to which there is flexibility of response as the size of climate risks becomes apparent over time (Real Option Analysis); the preference decision-makers have regarding economic maximization relative to robustness (if the latter, then Robust Decision-Making). In this case, given that we believe for the SuDS there is not substantial lock-ins, it may be the case that this flexibility allows the use of ROA. However, for the overall scheme, and the development, a much greater focus on detailed appraisal and decision making under uncertainty would be recommended.

10. CITY CASE STUDY: GAVOGLIO URBAN PARK, GENOA (ITALY)

10.1. Project context

Geographical: City of Genoa, northern Italy.

Sector: Urban Development

Project: Genoa is one of the most important northern Italian cities which, with its approximate 680,000 inhabitants (2,400 inh/km^2), is part of the so called “Industrial Triangle”.

Despite its success, the city suffers from a chronic underinvestment in the ageing infrastructure. The very urban fabric of Genoa and its development over and around riverbeds, further contributes to the acuteness of problems directly connected to climate change, notably from flash floods.

“Gavoglio Urban Park” is a new green open space reclaimed from an urbanised valley in the city centre of Genoa. The project occupies an area of about 16,000 square meters and is almost entirely built using 12 different Nature-Based Solutions (NBS). The ambition of the project is to demonstrate and test applicability of such solutions across Genoa.

While the project was designed as a green urban park, with multiple objectives, it will have climate adaptation co-benefits.

Climate vulnerability: The new SECAP - Sustainable Energy and Climate Action Plan (PAESC in Italy) transposes the EU’s “2030 climate & energy framework” ambition into local actions integrating energy efficiency, increase of the renewable energy share whilst acknowledging the issues specific to Genoa, particularly in the domain of Climate Adaptation, namely hydrogeological risk, heatwaves and scarce soil permeability rate.

The area suffers from hydraulic risk and high stormwater flows - between 2000 and 2014 an unusual number of particularly extreme events has occurred, causing widespread damages and fatalities[30]. Heatwaves have increased due to the combination of generalised rising temperatures, intense urbanisation and poor soil permeability. Table 20 rates the climate vulnerability of the area of the under construction Gavoglio urban park project based on an assessment of the economic sector sensitivity and the geographic exposure to climate variables and hazards. Increasing temperatures, and heavy precipitation/flooding are highlighted are high vulnerabilities for urban development activities in Genoa.

Table 20 – Climate vulnerability rating: Gavoglio urban park, Genoa

Climate variable/hazard		Sensitivity[31]	Exposure[32]	Vulnerability
Temperature	Temperature extremes	High	Moderate	Moderate
	Wildfire	High	Moderate	Moderate
	Increasing temperatures	High	High	High
Wind	Storms	High	Low	Moderate
	Changes in wind patterns	Low	Moderate	Low
Water	Drought	High	High	High
	Changes in precipitation patterns and variability	Moderate	Moderate	Moderate
	Heavy precipitation / flooding	High	High	High
Coastal	SLR	High	Low	Moderate
	Ocean acidification	n/a	n/a	n/a
Soil	Avalanche / landslides	High	Low	Moderate
	Subsidence	High	Low	Moderate
	Coastal erosion	High	Low	Moderate
	Soil erosion	Low	Low	Low

30 Source Polaris, Genova e i suoi torrenti: una lunga storia di alluvioni, danni e vittime (cnr.it)

31 Adapted from the EU Taxonomy Climate Sensitivity Matrix.

32 Various sources.

Adaptation context: The project is a model of Urban Regeneration that revolves around the reclamation and re-naturalisation of a valley riverbed with multiple and holistic beneficial outcomes. Climate change adaptation is a significant focus of the project but not the main goal [33]. Further, climate projections and explicitly adaptation planning were not included in the design of the scheme. Despite the significant investment and maintenance costs the many benefits are also expected to be significant.

Adaptation to climate risks is not the primary objective of the project – rather, it is urban regeneration project – with adaptation as a co-benefit. The most relevant aspect is therefore to quantify the benefit stratum of this co-benefit. It is also the case that urban regeneration projects should be designed with the future climate in mind, i.e. climate proofing. This has only been taken partially in consideration (detail climate modelling for the area during design stage was not available), although many of the NBS would be expected to have low-regret characteristics. However, in theory, should future climate modelling be available at later stages and should the project adopt new design solutions, these would in turn require some analysis of the marginal costs and benefits of climate proofing. This would include aspects such as additional capacity for stormwater flows or additional measures, ensuring tree planting used resilient species that could cope with greater heat and drought extremes, etc. However, as additional measures are not incorporated in the project for the purpose of reducing climate change risks, it is not possible to identify the marginal costs and benefits. We therefore undertake our analysis on the project as a whole, i.e. considering the gross costs and benefits that are generating in addressing both climate-induced and non-climate objectives.

Economic-Climate Screening

In Table 21 we provide an initial screening of the types of impacts on economic and financial parameters of the project that we would expect to occur under current and

[33] SECAP 2020-2030, 5.4.2.8 Salute

future climate change. This serves as an indication of the importance of climate risks to a given project and therefore whether a light-touch or detailed economic appraisal is likely to be more or less suitable. In effect, it is also a qualitative application of the decision-scaling method outlined above. In the example of Genoa we judge that the increased risk of urban heat island effects on human health under future climate projections will be significantly reduced by the project conditions. Note the table focuses on the urban heat effects – the consideration of storm water and flood risk management is not considered in the table and would have likely different results.

Table 21 – Economic-climate screening: Gavoglio urban park, Genoa

Economic/Financial Parameter	Impact of Current Climate & Climate Change on Economic Parameter
Fixed Capital Costs (Assets)	Modest effect. Potentially some additional climate proofing costs might be relevant, though the analysis has not considered them.
Variable Costs (Operation & Maintenance)	Negligible effect
Revenue	Not applicable since primarily a public resource
Non-Market Benefits	Reduced health impacts resulting from lower urban heat island (UHI) effect (current and under future climate change), however, climate change could affect the functioning of the green infrastructure, reducing the ecosystem service it provides, though no information on these risks is available. Reduced storm water flows (not considered in the case study)
Economic & Financial Performance indicator	Potential non-market benefits, but also analysis of how these change under climate change

Table 22 below brings together an indicative MCA of the project relative to the do-nothing baseline. It highlights that the project costs are likely to be sizeable (Euro million) but that there are also significant benefits some of which will effectively be adaptation to climate change risks. This indicative exercise serves to scope out both the size of the project, and the economic and financial components that are most sensitive to climate change risks. This information then feeds into our use of the decision process diagram that informs appropriate decision methods to adopt.

As no assessment of physical climate risk to the assets has been undertaken, this project is unaligned with the EU Taxonomy and is ineligible as climate finance. If such a risk assessment were to be undertaken, and material risks managed to an appropriate degree, the project has the potential to provide a substantial contribution to adaptation. The proportion allocated as adaptation finance should then reflect the relative priority (as a proportion of total project costs) of climate change adaptation for the project.

Table 22 – MCA and EU Taxonomy Alignment: Gavoglio urban park, Genoa

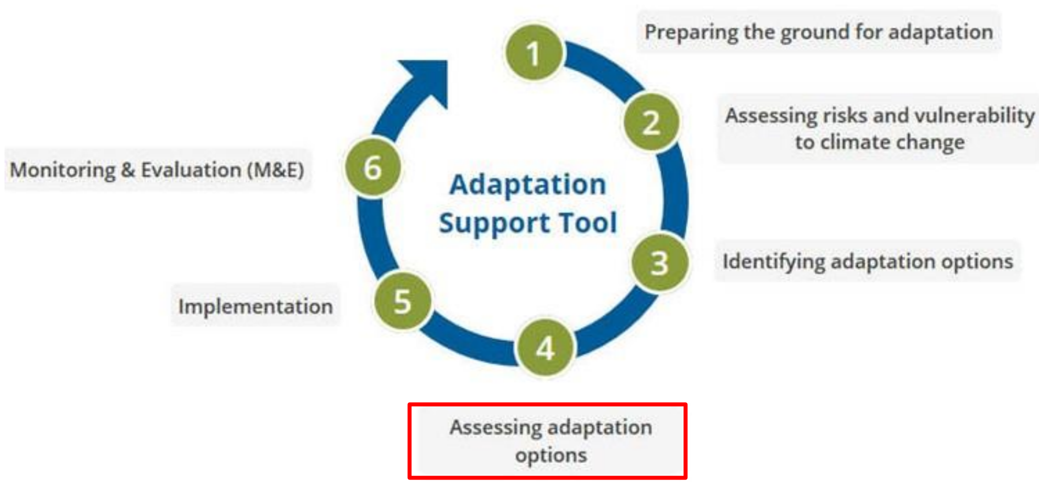
Adaptation component	Material physical climate risks managed	Effectiveness / Performance	Capex / Opex	Environmental / social / economic impact	EU Taxonomy alignment: adaptation
Nature-Based Solutions	• Temperature extremes (acute) • Increasing temperatures (chronic) • Heavy precipitation/flooding (acute)	**Major positive (++)** Improved stormwater management and reduction of the Urban Heat Island (UHI) effect	**Major negative impact (--)** – Significant capital investment and maintenance costs.	**Major positive (++)** • Health benefits • Improved community access to green and recreation (amenity benefit) • Localised air quality improvement and increased carbon	**Adapted activity**: **Unaligned** – no assessment of physical climate risk to the assets. **Enabling adaptation**: **Substantial contribution**

				sequestration	

10.2. Decision tool

Stage in adaptation decision-making cycle: In order to evaluate the identified investments we need to undertake an ex-ante appraisal, incorporating data on risk and vulnerability to climate change into the project screening (Stage 2) reported above, in brief. This ensures that we establish early as to whether climate change risks are likely to be material to the project justification. We then need to undertake an assessment of the adaptation component of the investment (Stage 4).

Figure 10 - Stage in the adaptation decision-making cycle: Gavoglio urban park, Genoa



Choice of approach: In order to identify which decision tool(s) are likely to be most appropriate to use to evaluate the project against economic criteria, we utilise the process diagram presented in Figure 2 above and reproduced below (Figure 11). In Table 23 we provide a commentary that shows how we respond to the series of questions incorporated in the process diagram. Reflecting on the principles for the selection of an approach to such an economic appraisal in section 3, Light-touch CBA is an appropriate approach to the economic appraisal of the Genoa Gavoglio urban park. Table 23 and Figure 11 summarises the justification for the choice of this approach. This choice was dictated by:

- The absence of key data (as explained below);

- Reducing climate change risk not being a primary objective of the project; and,
- The high level of uncertainty in the future climate change risks.

Table 23 – Justification for choice of method: Gavoglio urban park, Genoa

Question	Answer	Comment
Is climate change likely to have a major effect on the result/is the lifetime long?	No	Whilst reduction in human health-related UHI impacts, exacerbated by climate change, are significant they are likely to be minor relative to the recreational and amenity benefits of the development project
Are adaptation decisions-likely to result in lock in?	No	There would be lock-in for the park development overall from land-use change, and associated with some of the other components, for the urban green components, there is low lock-in.
Are Impacts measurable in monetary terms?	Yes	Whilst health impacts have significant non-market dimensions, there is availability of unit costs currently used in air quality modelling that can be transferred to the Genoa context. Similarly, there is available data on heat-health relationships that allow the health effects to be quantified.

Question	Answer	Comment
Choice of method	CBA – Partial data can be collated on aspects of the costs and benefits of the project to allow for an indicative CBA. There is insufficient data, however, to allow us to use uncertainty-based decision methods.	
Is adaptation the primary objective of the project	No	Climate change adaptation is a significant focus of the project but not the primary objective.
Depth of appraisal	Light-touch	

Data & data sources: Data was available on:

- Current population vulnerable to health and productivity effects of high temperatures.
- Modelled average temperature increase for Genoa (RCP4.5 and RCP8.5, 2050).
- Re-development data on benefits (Reduction of UHI effect through green infrastructure
- The health impacts of high temperatures in terms of excess mortality were estimated by combining historical temperature-death relationships[34] with an allowance for the UHI effect[35] under three climate scenarios (RCP8.5, RCP4.5 and RCP2.6). Then the estimates of numbers of premature deaths under the alternative RCP scenarios were converted to monetary amounts by applying a value for the change in the risk of fatality. Changes in mortality risk and associated benefits from introducing the green infrastructure to Genoa were

[34] Gasparrini A, Guo Y, Sera F, et al (2017). Projections of temperature-related excess mortality under climate change scenarios. Lancet Planet Health 2017, 1: e360–67

[35] Sera F, Armstrong B, Tobias, A, et al (2019). How urban characteristics affect vulnerability to heat and cold: a multi-country analysis. International journal of Epidemiology, 1-12. Doi: 10.1093/ije/dyz008

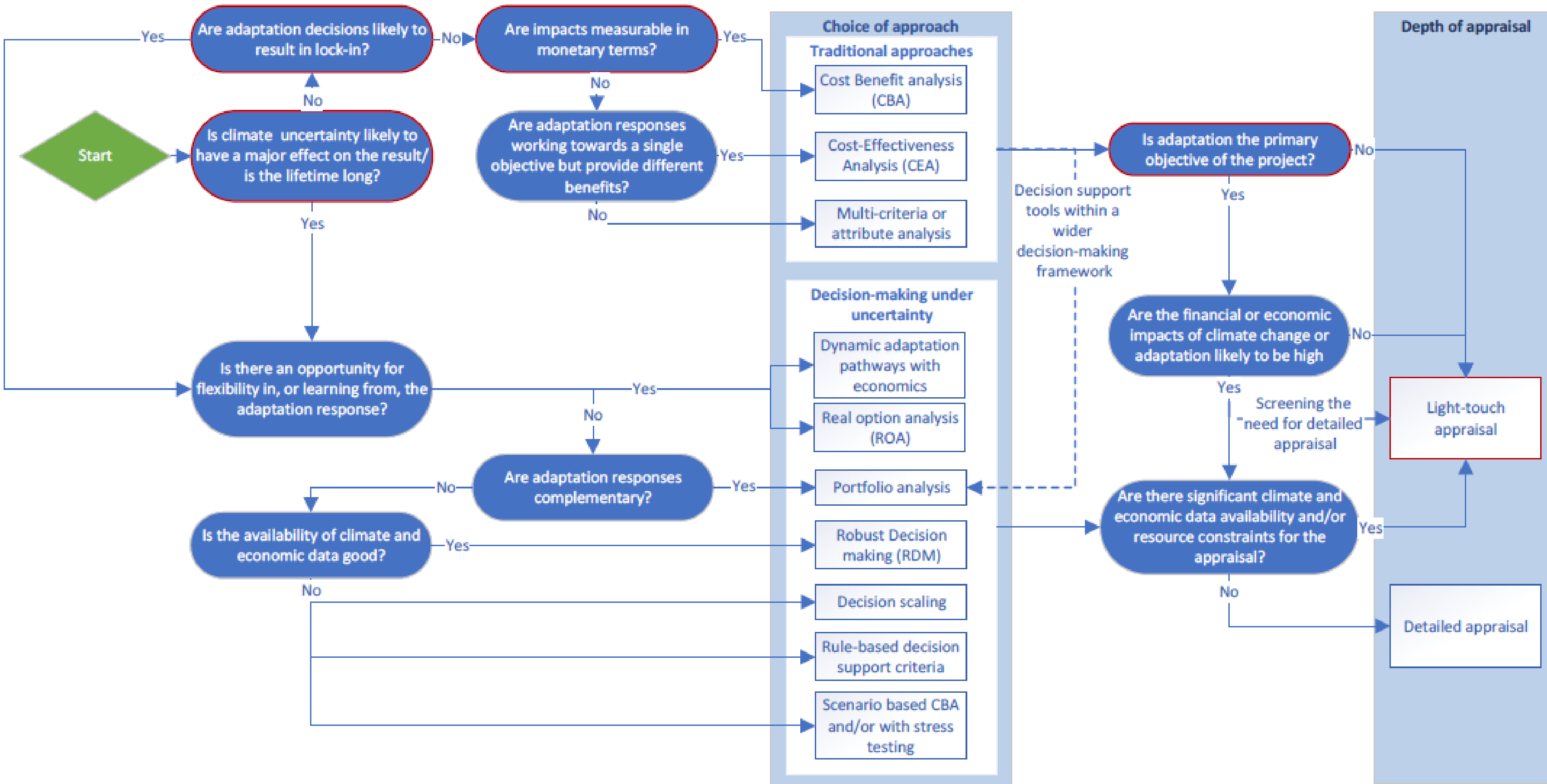
quantified using a proxy[36] for the cooling effect of increasing the amount of vegetation in the project area. This allowed an estimation of the mortality cost without implementing the green infrastructure scheme and calculation of the possible benefits of the scheme under the three climate change scenarios over the 30-year project lifetime. Labour productivity costs in the construction and service sectors associated with high temperatures, in the absence of adaptation, were estimated using typical percentage reductions from the literature and scaling this figure to the estimated GVA in the vicinity of the new park to arrive at and a discounted total gross value of lost productivity over the green infrastructure 30-year lifetime (Euro 476 million). Note that this is an aggregate figure over the project lifetime and therefore captures productivity gains in the surrounding neighbourhoods over a 30-year period.

- Capital costs of the scheme are taken from the project literature and, in the absence of ongoing management costs over the lifetime of the project; assumptions are made for the annual maximum cost.

There was a lack of data on other socio-environmental benefits, recurring annual maintenance costs of the development, historical and modelled future health and productivity damage cost estimates for a range of extreme heat event frequencies between climate scenarios and within individual climate models.

[36] Kallaos, J., et al. (2015) D2.3 Climate resilience in architecture, infrastructure and urban environments. Analysis of RAMSES case study cities. EC Grant Agreement No. 308497 (Project RAMSES).

Figure 11 – Justification for choice of method: Gavoglio urban park, Genoa



10.3. Results of the economic appraisal

The analysis shows the economic benefit/cost ratio for the project would be very high – around 100 including health only, and close to 200 including both health and productivity. While indicating very positive benefit/cost ratios for the scheme it is stressed that the analysis is based on partial and indicative data and intended to be illustrative only. A number of key caveats are given including:

- That recreational and amenity benefits are not included;
- The use of the RCP8.5 climate scenario for estimating baseline climate change risks means that estimates of health and productivity effects are likely to be high relative to those that would result under other RCP scenarios; and,
- The estimates do not account separately for the urban heat island effect which may be expected to further exacerbate the size of the climate risk.
- The potential impacts of climate change on the green infrastructure –and the ecosystem services it provides – have not been taken into account. It is possible that climate change may reduce these services, e.g. with green vegetation die off reducing cooling under heatwaves or during extended drought periods. This highlights the importance of climate proofing green infrastructure.

Assumptions: The measurement of the adaptation benefits associated with health and labour productivity improvements is caveated with a number of simplifying assumptions. These include:

- The radius used for benefits of the scheme to the population (and assumed economic activity);
- The transfer of an estimate of the effectiveness of green infrastructure in cooling an urban area from a different context in Europe; and,
- The value per premature death used for monetisation of benefits.

Opportunities, Challenges and Lesson learned

A key challenge was the choice of appropriate assumptions in the absence of key data. Assumptions on the size of population and local economy impacted by mortality risks and productivity losses resulting from high temperatures, and the RCP climate scenarios used meant that the estimated adaptation benefits were at the highest range compared with other possible assumptions on these risks.

Transfer of climate-impact/adaptation functions allow us to present illustrative quantitative estimates of climate risks and adaptation benefits but these are not tailored to the local context in Genoa. Therefore, to improve the accuracy of the quantitative estimates of adaptation benefits and costs, ideally, spatial modelling of the planned green infrastructure scheme in Genoa, its impacts on ambient temperatures and their associations with health and labour productivity should be undertaken.

Even though the quantitative data assembled is both partial and non-context specific, it demonstrates both that economic analysis can still be undertaken to show that economic efficiency criteria are likely to be met.

Minimum data to facilitate further economic analysis

- **Climate data**: reflect the full range of climate uncertainty by identifying the value of climate variables:
  - Between different climate models, and;
  - Different potential climate scenarios, for decadal time periods in the future.
- **Impact data**: modelling the effects of the full set of climate data using empirically identified relationships between heat and damage to human health for the local population.
- **Effectiveness of adaptation**: data on the extent to which the investment results in a reduction in climate risk to human health. Further work would also be useful to look at the potential options for climate proofing the green infrastructure in the park.

Availability of this data – the climate data and impact data in particular – would, in principle, allow a negative response to the question in the process diagram: Are there significant climate and economic data availability and/or resource constraints for the appraisal.? Answering “no” to this question could allow the analyst to undertake a detailed appraisal. If the initial climate risk appraisal had indicated that climate uncertainties may have a significant effect on the outcome of the economic analysis then – in common with the Turku case study – we would follow the process diagram through to potentially use a decision-making method that more fully incorporates uncertainty such as Portfolio Analysis, ROA or RDM. The appropriate method would then depend on: the existence of a range of complementary measures to reduce climate risks over the full range of uncertainty (Portfolio Analysis); the extent to which there is flexibility of response as the size of climate risks becomes apparent over time (Real Option Analysis); the preference decision-makers have regarding economic maximization relative to robustness (if the latter, then Robust Decision-Making). In this case, given that we understand that there are a wide range of other actions that could reduce the adverse health impacts of climate change-exacerbated urban heat island effect, including green roofs, cool rooms and sun screens, etc – it may be the case that complementarity of these actions allows for the use of Portfolio Analysis.

11. CITY CASE STUDY: ADAPTATION IN HOUSING RETROFIT, GLASGOW (UNITED KINGDOM)

11.1. Project context

Geographical: City of Glasgow, Scotland, UK.

Sector: Urban Housing

Project: This case study provides an initial economic appraisal of a programme that would stimulate the uptake of alternative, property-based overheating reduction adaptation measures across the Glasgow Region housing stock, as a part of a broader heating retrofit programme. A detailed feasibility study for a retrofit programme (GHG mitigation) to increase energy efficiency to reduce winter heating has been carried out, whilst the current case study highlights the need to explore synergies with adaptation wherever possible. In the absence of data on how individual energy efficiency and heat reduction retrofit measures can be combined, we consider heat reduction retrofit measures independently. However, it is intended by Glasgow City Council to subsequently investigate ways n which the two sets of retrofit measures can be combined.

Climate vulnerability:

A detailed climate risk and adaptation assessment was carried out for Glasgow as part of the development of the Glasgow City Region Adaptation Strategy. Although not specifically targeting the retrofit scheme there is a chapter on the built environment, which provides good background evidence for this case study, and highlights that the key climate considerations relevant to the programme. These include:

- Flood risk, with increasing frequency of both heavy rainfall events, and flooding along the River Clyde (river and surface water).
- Sea-level rise and coastal flooding posing a risk to a smaller number of houses.

- More frequent and severe exposure to wind and driving rain, which can damage building fabric and increase maintenance costs.
- Reduction in heating demand as a result of increasing temperatures.
- Increases in maximum temperature and potential increases in cooling demand, and risks from overheating. It is also highlighted that a retrofit programme of energy efficiency measures to address winter overheating might inadvertently increase these over-heating risks.

This case study focuses specifically on the risk of high temperatures and overheating, which is currently a low but emerging risk for Glasgow, and poses a challenge as it is not a risk that the city currently has much experience in managing. These effects are likely to be most pronounced for Glasgow City, because of the urban heat island effects. It is also important to recognize that it is the relative change in over-heating that is important, and the fact that the local population is not acclimatized to heat. This relative risk is reflected in different heat-alert thresholds for cooler and warmer areas across Europe, and even across the UK. Some studies (Undorf et al, 2019) using the new UKCP18 data for Glasgow indicates a heat wave frequency (defined in relative terms based on Glasgow's climate) could happen on average of approximately 1 in 2 years by the 2050s.

Understanding the benefits of investing in overheating reduction measures increases the evidence base for proactive management of this risk. There are a number of other high risks, including flooding, and storm damage, which are not assessed as part of this study, as they have received greater consideration in previous assessments.

Table 24 – Climate vulnerability rating: Glasgow Housing Retrofit.

Climate variable/hazard		Sensitivity[37]	Exposure[38]	Vulnerability
Temperature	Temperature extremes	High	Moderate	Moderate
	Wildfire	High	Low	Low

[37] Adapted from the EU Taxonomy Climate Sensitivity Matrix.
[38] Various sources.

	Increasing temperatures	High	Moderate	Moderate
Wind	Storms	High	High	High
	Changes in wind patterns	Low	Moderate	Low
Water	Drought	Moderate	Low	Low
	Changes in precipitation patterns and variability	Low	Moderate	Low
	Heavy precipitation / flooding	High	High	High
Coastal	SLR	High	Moderate	Moderate
	Ocean acidification	n/a	n/a	n/a
Soil	Avalanche / landslides	High	Low	Low
	Subsidence	High	Low	Low
	Coastal erosion	High	Moderate	Moderate
	Soil erosion	Low	Low	Low

Adaptation context: Given the current low vulnerability of the local population to extreme heat risks, the programme of implementation of alternative, property-based overheating reduction adaptation measures should be regarded as one which has adaptation as its primary benefit. However, this programme is likely to be integrated into a broader programme of household retrofit, of the same housing stock for energy efficiency, fuel poverty and carbon emission reduction objectives, which is being designed. This retrofit programme could exacerbate the risk of overheating and so heighten the need for adaptation measures.

Economic-Climate Screening

In Table 25 we provide an initial screening of the types of impacts on economic and financial parameters on the adaptation retrofit components of the project that we would expect to occur under current and future climate change. This serves as an indication of the importance of climate risks to a given project and therefore whether a light-touch or detailed economic appraisal is likely to be more or less suitable.

Table 25 – Economic-climate screening: Glasgow overheating retrofit

Economic/Financial Parameter	Energy efficiency retrofit programme	Impact of Current Climate & Climate Change on Economic Parameter	Marginal Adaptation investment to address overheating risk
Fixed Capital Costs (Assets)	Capital cost of energy efficiency measures	No discernible effect	Additional capital cost of adaptation measures
Variable Costs (Operation & Maintenance)	Operating cost of energy efficiency measures	Climate change will reduce winter heating demand and may affect operating costs	Operating cost of additional adaptation measures
Revenue	Reduced winter heating (reduced fuel bills)	From above, CC will reduce the levels of energy savings from energy efficiency measures.	Not applicable since adaptation options relevant to domestic housing
Non-Market Benefits	Reduced cold related health impacts, improved comfort and well-being, reduction in fuel poverty	Non-market costs could lead to possible overheating (combination energy efficiency measures and warmer temperatures)	Reduced cardiovascular health impacts and sleep-related effects resulting from lower overheating (current and under future climate change).

Economic/Financial Parameter	Energy efficiency retrofit programme	Impact of Current Climate & Climate Change on Economic Parameter	Marginal Adaptation investment to address overheating risk
Economic & Financial Performance indicator	EIRR/FIRR of retrofit programme Abatement cost-effectiveness (Euro/tCO_2 reduced)	Potential benefits relating to work productivity likely to be adversely affected by disturbed sleep associated with bedroom ambient temperatures.	Reduction in productivity losses

Table 26 below brings together an indicative MCA of the project relative to the do-nothing baseline. It highlights that the programme costs over the entire housing stock in the Glasgow Region are likely to be sizeable (Euro million) but that there are also significant benefits some of which will effectively be adaptation to climate change risks. This indicative exercise serves to scope out both the size of the project, and the economic and financial components that are most sensitive to climate change risks. This information then feeds into our use of the decision process diagram that informs appropriate decision methods to adopt.

As no specific assessment of physical climate risk to the assets has been undertaken, this project is unaligned with the EU Taxonomy and is ineligible as climate finance. If such a risk assessment were to be undertaken, and material risks managed to an appropriate degree, the project has the potential to provide a substantial contribution to adaptation. The proportion allocated as adaptation finance should then reflect the relative priority (as a proportion of total project costs) of climate change adaptation for the project.

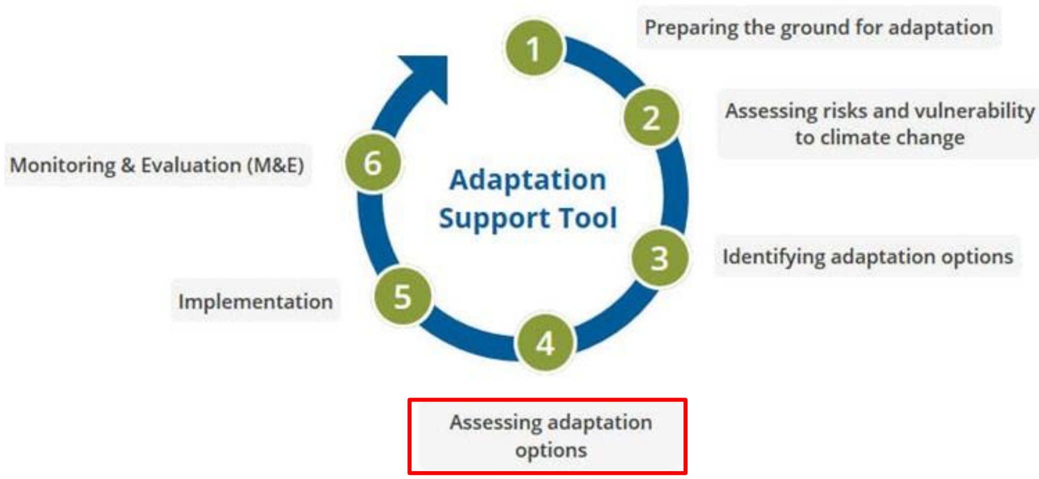
Table 26 – MCA and EU Taxonomy Alignment: Glasgow Overheating Retrofit

Adaptation component	Material physical climate risks managed	Effectiveness / Performance	Capex / Opex	Environmental / social / economic impact	EU Taxonomy alignment: adaptation
Installation of additional measure to reduce overheating	• Increasing temperatures – average climate (and increased peak temperatures in heatwaves)	Positive (+) Reduction of high indoor temperatures in domestic housing that result from warm summer weather	Negative impact (--) Significant capital investment, as well as operational (energy) costs for some options.	Major positive (++) • Health benefits • Work productivity benefits	**Adapted activity**: Unaligned – no assessment of physical climate risk to the assets.

11.2. Decision tool

Stage in adaptation decision-making cycle: In order to evaluate the identified investments we need to undertake an ex-ante appraisal, incorporating data on risk and vulnerability to climate change into the project screening (Stage 2) reported above, in brief. This ensures that we establish early as to whether climate change risks are likely to be material to the programme justification. We then need to undertake an assessment of the adaptation component of the investment (Stage 4).

Figure 12 – Stage in the adaptation decision-making cycle: Glasgow Overheating Retrofit



Choice of approach: In order to identify which decision tool(s) are likely to be most appropriate to use to evaluate the project against economic criteria, we utilise the process diagram presented in Figure 2 and Figure 3 and reproduced below (Figure 13). In Table 27 we provide a commentary that shows how we respond to the series of questions incorporated in the process diagram. Reflecting on the principles for the selection of an approach to such an economic appraisal in section 3, Light-touch CBA is an appropriate approach to the economic appraisal of the Glasgow retrofit. Table 27Table 23 and Figure 13 summarises the justification for the choice of this approach. This choice was dictated by:

- The absence of key data (as explained below);
- Reducing climate change risk being a primary objective of the project; and,
- The high level of uncertainty in the future climate change risks.

Table 27 – Justification for choice of method: Glasgow Overheating Retrofit

Question	Answer	Comment
Is climate change likely to have a major effect on the result/is the lifetime long?	No	Reduction in human health-related impacts and productivity losses, exacerbated by climate change, are significant; these effects are negligible in the absence of climate change.
Are adaptation decisions-likely to result in lock in?	Yes	There would be a certain amount of lock-in associated with the majority of the adaptation measures. Also lock-in from the development of an energy efficiency programme without adaptation.
Are Impacts measurable in monetary terms?	Yes	Whilst health impacts have significant non-market dimensions, there is availability of unit costs currently used in air quality modelling that can be transferred to the Glasgow context. Similarly, there is some data on heat-productivity relationships that allow the adverse productivity effects to be quantified.

Question	Answer	Comment
Choice of method	CEA, partial CBA and light-touch PA – Partial data can be collated on aspects of the costs and benefits of the programme to allow for an indicative CBA. There is insufficient data, however, to allow us to use uncertainty-based decision methods in a quantitative way.	
Is adaptation the primary objective of the project	Yes	Climate change adaptation is likely to be the primary objective of the programme.
Are the financial or economic impacts of climate change or adaptation likely to be high	No	
Depth of appraisal	Light-touch	

Data & data sources: Data was available on:

- Generic capital costs applicable to a range of alternative options. Data is taken from a report for the UK Climate Change Commission[39] by Wood et al. (2019) as well as product market websites[40];
- Estimates of effectiveness of a range of alternative options that reduce overheating. Data is taken from the same report for the UK Climate Change Commission.
- Housing stock, by type, of the Glasgow City Region. Data was obtained from the Scottish Government's Statistics database.[41]

[39] Wood Environment & Infrastructure Solutions UK Limited (2019) Updating an assessment of the costs and benefits of low-regret climate change adaptation options in the residential buildings sector Final Report REF GH/07-18.

[40] https://www.checkatrade.com/blog/cost-guides/mvhr-cost/

[41] http://statistics.gov.scot/data/dwellings-type

- Modelled impact costs – per property and property type – associated with risks of premature mortality under the UKCP09 High climate change scenario (50th percentile) for two time-periods; 2025-2040 and 2040-2080. Data is taken from a study undertaken for UK Ministry of Housing, Communities and Local Government by AECOM (2019). Ideally, data from a range of climate scenarios should be used;
- Modelled impact costs – per property type – associated with lost productivity as a consequence of overheating, taken from the same study by AECOM (2019).
- There was a lack of data on recurring annual operational and maintenance costs of the adaptation measures, historical and modelled future health and productivity damage cost estimates for a range of climate scenarios and within individual climate models.

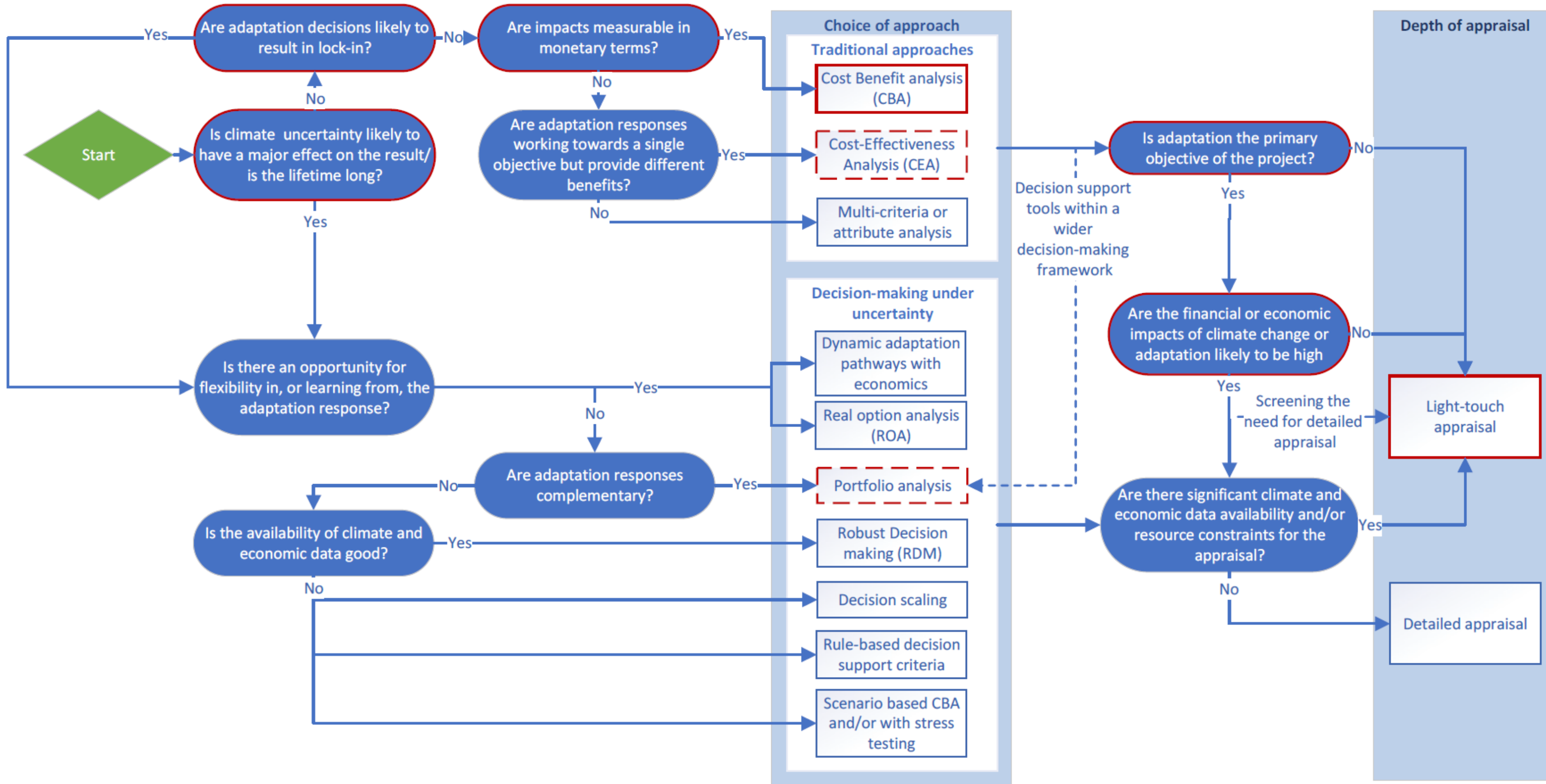
In summary, the method adopted was as follows:

- The data on capital costs and the estimates of the effectiveness of the range of options judged to be appropriate was combined to derive an estimate of the cost-effectiveness – in this case the cost of achieving a 1% reduction in cooling degree-hours.
- The capital cost and effectiveness data are grouped in order for portfolios at the property level to be subsequently selected on the basis of budgetary feasibility, constituting a light-touch semi-quantitative version of Portfolio Analysis.
- The impact cost data relating to mortality risks and productivity losses, referred to above, are derived from modelling of domestic residences in Sheffield, England, of new-build rather than retrofit, adjusted to the Glasgow context on the basis of the proportion of cooling-degree days Glasgow currently experiences relative to Sheffield – equivalent to 72%. Threshold temperatures for the mortality and productivity impacts are 27°C (day) and 26°C, respectively. Whilst the data clearly provides a proxy for the Glasgow retrofit context, their assumed equivalence is more realistic given that the adaptation to overheating is likely to be implemented alongside the

introduction of retrofit energy efficiency measures with climate change and fuel poverty alleviation objectives that approximate to the material conditions found in new-build. The availability of impact cost data allows us to undertake a very indicative cost-benefit analysis.

- This impact cost data was combined with the housing stock data in order to derive aggregate impact costs that also act as an indication of the maximum benefits that can be achieved by adaptation measures. Whilst the analysis has been applied to the entire housing stock in the Glasgow City region a sub-set of that stock can be assumed, as appropriate.
- The data on the effectiveness of specific options was then combined with the maximum benefit estimates to identify the actual benefits likely to be realised. By way of example, if an option such as mechanical heat ventilation recovery has 50% effectiveness, with maximum benefit being £4.7 million in Year 1, the actual benefit will be £2.35 million. A 60-year time period is considered; some measures e.g. curtains are assumed to be replaced periodically over that period.
- To complete the indicative cost-benefit analysis, the measures of discounted benefits are then compared with the data on total discounted capital costs to derive estimates of net present value and benefit-cost ratios.

Figure 13 – Justification for choice of method: Glasgow Overheating Retrofit



11.3. Results of the economic appraisal

The analysis first applies a CEA to identify the most effective options. The two graphs below present the results of the cost-effectiveness analysis for flats and town-houses, respectively; the results for semi-detached, town and detached houses are all very similar.

Figure 14 - Capital cost of reducing overheating (cooling degree hours) by one percent in a Flat

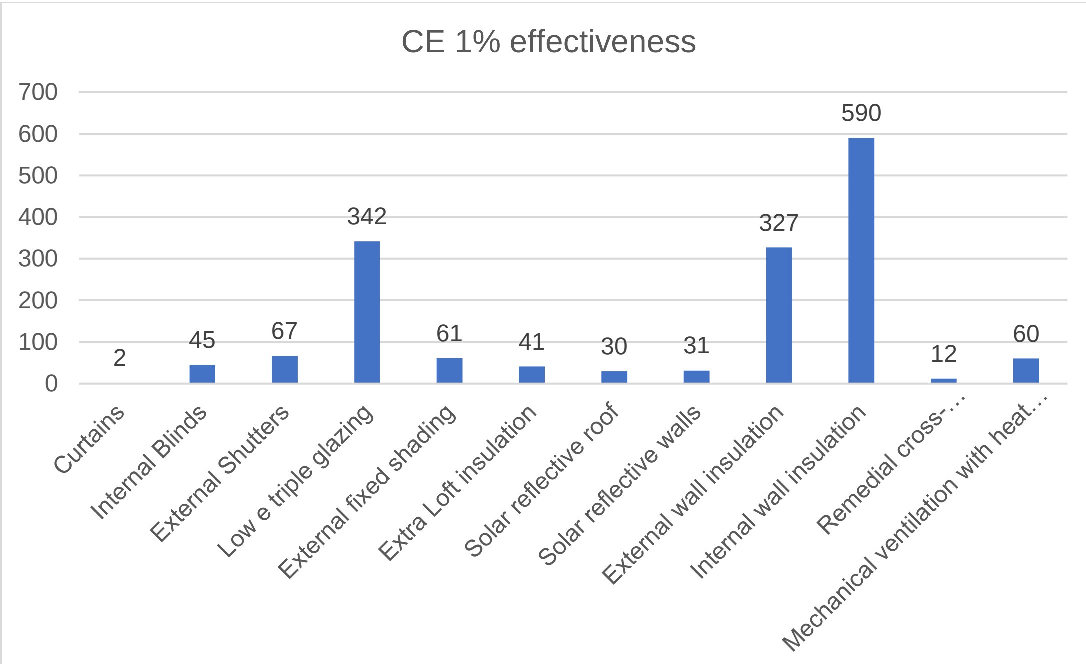
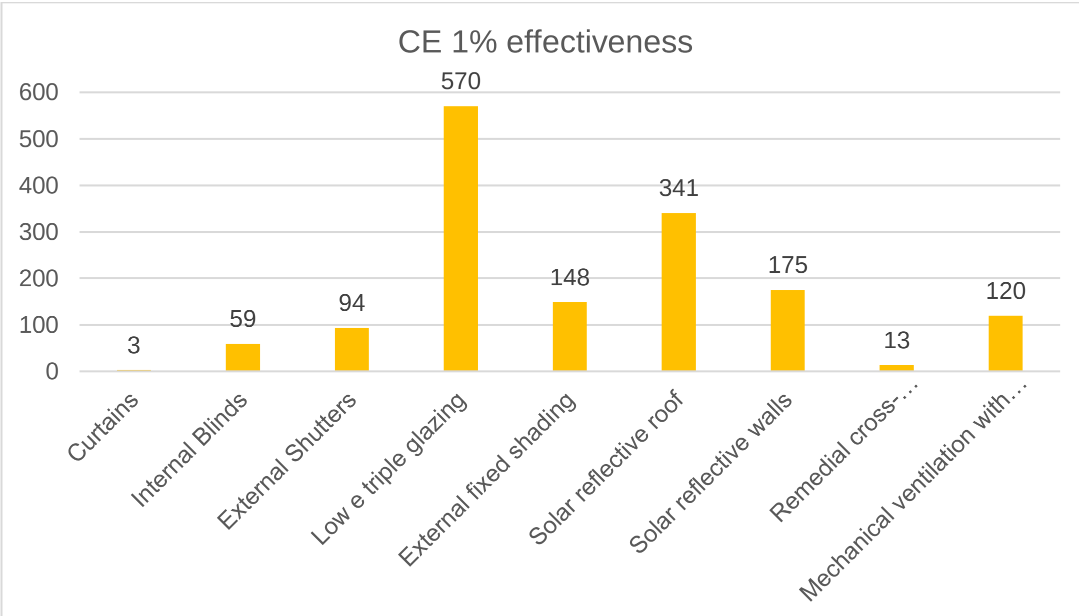


Figure 15 – Cost of reducing overheating (cooling degree hours) by one percent in a Town House



It should be noted that the cost component of the cost-effectiveness analysis is comprised of capital and installation costs only. It is likely that the ranking of measures will be affected by the inclusion of operational costs; for example, MHVR would become less cost-effective given its electricity requirements.

Two factors mean that the results of the Cost-Effectiveness Analysis should not be the only appraisal method utilised in deciding on measures that might comprise an overheating reduction programme in the Glasgow Region.

- The decision context suggests that not all the options are applicable for Glasgow properties. For practical and planning consent (aesthetic) reasons we do not expect – for example – that Low e triple glazing, external fixed shading and external shutters to be considered in practice. Conversely, the measures presented are limited to those for which we have identified cost and effectiveness data.
- Whilst all the measures considered in the cost-effectiveness analysis have some effectiveness and allow us to estimate the cost-effectiveness against a

1% reduction in overheating (cooling degree hours), the measures have mixed capabilities with regard to their effectiveness.

These two factors suggest that there is merit in considering the effectiveness of groups of measures in combination with each other. In this regard, Portfolio Analysis would be likely to offer a useful method of economic appraisal. In the absence of a) data that expresses the range of uncertainty in respect to the extent of overheating under alternative climate change scenarios, and; b) data that identifies the extent of effectiveness attributable to each measure under each climate scenario, in Table 28 to Table 31 we present possible portfolios for each housing type, along with the measures' effectiveness in the absence of climate change. More precisely, the measures listed for each property type are those that could be selected to include in smaller individual portfolios; we have not undertaken an assessment of the quantitative complementarity of the individual measures listed. We also do not account for the likelihood of some measures such as curtains already being in place in some properties, or not being feasible for all properties, e.g. solar roofs for flats. Data on cost ranges is presented in order to highlight that the measures within such portfolios may be constrained by an overall financial budget. Thus, feasible combinations of measures may be selected on that basis.

Table 28 – Cost & Effectiveness data on Overheating measures for Detached Properties

Adaptation Measure	Capital Cost per dwelling (£)		Effectiveness
	Low	High	%
Curtains	0	70	17
Internal blinds	228	1,437	23
Solar reflective roof	373	479	20
Solar reflective walls	746	958	25
External wall insulation	8,873	10,297	1
Remedial cross-ventilation/room protection*	0	2,434	100
Mechanical ventilation with heat recovery	2,000	4,000	25

*Equals replacement of two windows

Table 29 – Cost & Effectiveness data on Overheating measures for Flats

Adaptation Measure	Capital Cost per dwelling (£)		Effectiveness
	Low	High	%
Curtains	0	70	20
Internal blinds	228	1,916	24
External shutters	1,386	3,951	40
Solar reflective roof	839	1,078	32
Solar reflective walls	1,212	1,556	44
External wall insulation	8,770	10,177	29
Internal wall insulation	4,992	5,627	9
Remedial cross-ventilation/room protection	0	2,400	100
Mechanical ventilation with heat recovery	2,000	4,000	50

Table 30 – Cost & Effectiveness data on Overheating measures for Semi-Detached Properties

Adaptation Measure	Cost per dwelling (£)		Effectiveness
	Low	High	%
Curtains	93		24
Internal blinds	304	2,634	30
External shutters	1,848	5,388	53
External fixed shadings	1,416	5,933	50
Solar reflective roof	932	1,197	10
Solar reflective walls	1,119	1,437	48
External wall insulation	13,000	15,086	16
Cavity wall insulation	239	475	5
Remedial cross-ventilation/room protection	0	2,844	100
Mechanical ventilation with heat recovery	2,000	4,000	35

Table 31 – Cost & Effectiveness data on Overheating measures for Town Houses

Adaptation Measure	Cost per dwelling (£)		Effectiveness
	Low	High	%
Curtains	0	140	24
Internal blinds	456	3,113	30
External shutters	2,772	6,824	51
External fixed shadings	1,888	7,911	33
Solar reflective roof	1,492	1,916	5
Solar reflective walls	2,144	2,754	14
Remedial cross-ventilation/room protection	0	2,594	100
Mechanical ventilation with heat recovery	2,000	4,000	25

The analysis has been extended to undertake a cost-benefit analysis of some measures. This seeks to assess whether these options pass an economic test, and not just to assess the relative effectiveness (as in CEA). In Table 32 we summarise the results of cost-benefit analyses for three different adaptation measures, where benefits are represented by the reduction in productivity loss costs in the workplace as a result of lost sleep in previous nights – borne by employees and employers, and the reduced risk of premature death that is primarily borne by the elderly population. We transfer the unit values used from AECOM (2019) who used a Value of a Life Year (VOLY) of £60,000 and average GDP/capita of £29,674 (2015 prices) to derive unit values. As described above, maximum benefit (i.e. equivalent to 100% effectiveness) is adjusted by the actual rates of effectiveness, as presented in Table 28 to Table 31. Thus, in Table 32 the aggregate cost and benefit data derived through using the method described above are combined to produce summary data on the outcomes of the cost-benefit analysis for the different measures.

Table 32 – CBA Results of Overheating Reduction Measures

Measure	Net Present Value	Economic B-C Ratio	EIRR	Financial B-C Ratio	PV Productivity Benefits	PV Health Benefits	PV Costs
Curtains	284,884,040	4.9	32	2.2	225,073,977	279,792,354	–102,797,487
MVHR	–1,933,629,625	0.3	0.003	0.1	358,568,532	546,751,380	–2,604,921,000
Remedial Cross-Vent	207,068,352	1.3	7	0.6	1,042,791,393	1,337,172,658	–1,787,207,738

The results of the cost-benefit analyses shows that the economic benefit/cost ratios for the three measures vary; they are greater than 1 for installation of curtains and remedial cross-ventilation – primarily new windows – but below 1 for the mechanical ventilation with heat recovery systems. While indicating very positive benefit/cost ratios for the scheme it is stressed that the analysis is based on partial and indicative data and intended to be illustrative only. A number of key caveats are given including:

- That non-mortality health benefits are not included;
- The use of the High UKCP09 climate scenario for estimating baseline climate change risks means that estimates of health and productivity effects are likely to be high relative to those that would result under other scenarios (though note that this doesn't affect the effectiveness of measure, rather the size of the benefits of implementing each measure) ; and,
- The management and operational costs of the measures are not included; clearly this would further adversely affect the NPV of the MVHR measure which requires electricity to operate it.

Assumptions: The measurement of the adaptation benefits associated with health and labour productivity improvements is caveated with a number of simplifying assumptions. These include:

- The number of properties adapted to equate to the total housing stock of 867,000 in the Glasgow City Region;
- The transfer of estimates of the effectiveness of the overheating reduction measures from the new-build context;
- The value per premature death used for monetisation of benefits. It should be noted that in sensitivity analysis that values mortality risk by the Value of Statistical Life (VSL) metric rather than the Value of Life Year metric the health benefits are around 20 times higher than presented in Table 32. Whilst this would not make a difference to the Financial Benefit-Cost ratios, the Economic Benefit-Cost ratios would significantly improve and have values greater than 1.

Opportunities, Challenges and Lesson learned

A key challenge was the choice of appropriate assumptions in the absence of key data. Assumptions on the size of housing stock impacted by mortality risks and productivity losses resulting from high temperatures and overheating, together with the High climate scenario used meant that the estimated adaptation benefits were at the highest end of likely values, compared with other possible assumptions on these risks (i.e. they are likely to overestimate benefits).

Transfer of climate-impact/adaptation functions from the Northern English context allow us to present illustrative quantitative estimates of climate risks and adaptation benefits but these are not tailored to the local context in Glasgow. They do not take account of the Glasgow urban heat island effect, which might underestimate overheating levels. Therefore, to improve the accuracy of the quantitative estimates of adaptation benefits and costs, ideally, modelling of the effectiveness of alternative overheating reduction measures should be undertaken on representative types in the Glasgow housing stock, and their impacts on ambient temperatures and their associations with health and labour productivity should be undertaken.

Even though the quantitative data assembled is both partial and non-context specific, it demonstrates both that economic analysis can still be undertaken to show whether economic efficiency criteria are likely to be met.

Minimum data to facilitate further economic analysis

- **Climate data**: reflect the full range of climate uncertainty by identifying climate variables:
  - Between different climate models, and;
  - Different climate scenarios,
  - for decadal time periods in the future, including the urban heat island effects.
- **Impact data**: modelling the effects of the full set of climate data using empirically identified relationships between heat and building over-heating, as well as heat and damage to human health for the local population and heat and productivity (noting the need for specific metrics for these two variables.
- **Cost data**: estimated costs for adaptation measures for retrofitting buildings, taking account of the stock types in Glasgow;
- **Effectiveness of adaptation**: data on the extent to which the investment results in a reduction in climate risk to labour productivity and human health. Further work would also be useful to look at the potential options for reducing ambient heat levels in the wider urban environment (e.g. green infrastructure) in order to reduce any urban heat island effect.

Availability of this data – the climate data and impact data in particular – would, in principle, allow a different response to the question in the process diagram: Are there significant climate and economic data availability and/or resource constraints for the appraisal.? Answering “no” to this question could allow the analyst to undertake a detailed appraisal. If the initial climate risk appraisal had indicated that climate uncertainties may have a significant effect on the outcome of the economic analysis then we would follow the process diagram through to potentially use a decision-making method that more fully incorporates uncertainty such as Portfolio Analysis in a more quantitative way than has been done here.

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