An Chomhairle Náisiúnta Eacnamaíoch agus Shóisialta
National Economic & Social Council

Cost-Benefit Analysis, Environment and Climate Change

NESC Secretariat Papers

Paper No. 15

November 2018

An Oifig Náisiúnta um Fhorbairt Eacnamaíoch agus Shóisialta
National Economic & Social Development Office NESDO

An Chomhairle Náisiúnta Eacnamaíoch agus Shóisialta
National Economic & Social Council

Cost-Benefit Analysis, Environment and Climate Change

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November 2018

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Table of Contents

List of Tables

List of Figures

List of Boxes

Acronyms

CAS	complex adaptive systems
CBA	cost-benefit analysis
CEA	cost-effectiveness analysis
CH_4	methane
CO_2	carbon dioxide
CO_2 eq	CO_2 equivalents
DPER	Department of Public Expenditure and Reform
EIA	environmental impact assessment
ETS	Emissions Trading System
GDP	gross domestic product
GHG	greenhouse gas
GNP	gross national product
GWP	global warming potential
HFCs	hydrofluorocarbons
IAMs	integrated assessment models
IGEES	Irish Government Economic & Evaluation Service
MAC	marginal abatement cost
N_2O	nitrous oxide
NDP	National Development Plan
NMP	National Mitigation Plan
NPF	National Planning Framework
OMB	Office of Management and Budget
PFCs	perfluorocarbons
PSC	Public Spending Code
SCC	social cost of carbon
SDR	social discount rate
SEA	strategic environmental assessment
SF_6	sulfur hexafluoride
SOC	social opportunity cost
SPC	shadow price of capital
SRTP	social rate of time preference
TEV	total economic value
VFM	value for money
WHO	World Health Organisation

Acknowledgements

This NESC Secretariat paper is adapted from a research report commissioned by NESC from Dr Tadhg O'Mahony on appraisal and cost-benefit analysis in Ireland.

Parts of this paper draw on a report prepared by Daniel O'Callaghan and Sean Prior of the Department of Public Expenditure and Reform, *Review of the Central Parameters in the Public Spending Code* (2018). Written comments from Daniel O'Callaghan are acknowledged.

Members of the NESC Council discussed a draft of this paper and provided helpful observations. Advice and comments were provided Dr Rory O'Donnell, Director, and Dr Damian Thomas, Senior Policy Analyst, of NESC.

The authors are responsible for the conclusions presented in this paper.

1. Introduction and Outline

The practice of cost-benefit analysis (CBA) has undergone substantial change in the last two decades, driven by the inclusion of environmental and climate-change considerations. The objective of this paper is to understand these changes and the implications they have for the implementation of CBA to Irish project appraisal. It sets out briefly what CBA is and how it is applied in Ireland. It then outlines the changes in international practice, in particular changes related to the time horizon, discount rates, valuation of costs and benefits, and the carbon price. Box 1.1 provides a brief introduction to CBA.

Paper in outline

CBA is an estimation and forecasting tool that is used to provide a monetary value, in present value terms, of the social costs and benefits associated with an investment.

The tool has a long history in Irish policy evaluation as an aid to decision-making, not as a substitute for it. The central parameters used in CBA (discount rate, time horizon, shadow price of public funds and shadow price of labour) have recently been subject to a review within the Department of Public Expenditure and Reform (DPER).

This paper highlights that work internationally to incorporate environmental and climate-change issues into CBA has significant implications for how CBA is done:

- First, the long-term nature of climate and environmental impacts is forcing practitioners to rethink the approach in the direction of longer time horizons.

- Second, there is a strong focus on the social discount rate and reducing it so that the impact of longer changes is given more weight in CBA.

- Third, there is growing realisation that the estimation of the costs and benefits of most investment projects needs to include a wider range, while recognising the analytical challenges this entails.

- Fourth, the work on climate change highlights the need for a carbon price, and crucially one that is higher than that currently used in most countries, and certainly higher than the current price based on the Emissions Trading System (ETS) market price.

The paper also highlights that work in the environment and climate-change area has important insights for CBA in terms of how it deals with uncertainty.

The paper then considers the implications for Ireland of these four areas of change in CBA. It proposes a series of inter-related changes as to how cost-benefit analysis is undertaken. Taken together, these constitute a *CBA Sustainability Package* made of the following elements.

- **Discount Rate**: This paper considers that a discount rate in the range 2.6 to 3.9 would be appropriate, preferably at the lower end of that range. In addition, a lower discount rate is proposed for GHG emissions and other enduring environmental damage, which in Ireland would be set at 1.7. If dual discounting is not adopted, this reinforces the case for a general discount rate at the lower end of the proposed range. In addition, the use of declining discount rates is recommended so that some weight is placed on very long-term effects where these arise.

- **Time horizon**: Sustainability concerns and developments elsewhere point to the need to adopt longer time horizons in CBA. However the longer the time frame adopted, the greater the uncertainty that attaches to projections of costs and benefits. A pragmatic approach that balances the need to capture long-term impacts with the challenge of managing uncertainty may be to adopt a time horizon of up to 60 years for infrastructure projects. Current Irish guidance allows for time periods of up to 60 years[1] and this is applied to some major projects such as the CBA of the Dublin metro. There are other situations relating to mitigation of climate change and protection of biodiversity where the relevant time period is much longer, with consequences for future generations. Investment planning should support the transition to a low-carbon economy that is sustainable in the long term. In some cases this will involve adopting a very-long term, multi-generational time horizon in CBA. Many of the investments undertaken today will still be in place beyond 2050, so they need to be consistent with the type of low-carbon economy that is sought for the future.

- **Carbon Price:** The carbon price for CBA should be set so that it is consistent with Ireland's climate targets. The targets set out in the National Mitigation Plan provide a basis for developing a target-consistent carbon price for Ireland. In

[1] This consists of a 30-year appraisal period plus a 30-year residual period.

addition, there is a need to provide guidance on the carbon price for a longer time horizon beyond 2050 (the final year covered by the current guidance). Pending the completion of the relevant analysis for Ireland, the UK target-consistent carbon prices could be used. On this basis, an appropriate level for the carbon price is €77/tCO2e (2017 € values) in the 2018 impact year, rising to €259/tCO2e in the impact year of 2050 with ongoing increases in subsequent decades.

- **Costs and benefits**: The identification and characterisation of costs and benefits, beyond the core technical parameters, could be enhanced by central guidance. In addition, greater consideration should be given to 'co-benefits' in emissions mitigation and transition projects, including fuel savings and air-pollution reduction. It would also be useful to consider how the Total Economic Value (TEV) method could be applied to Irish central CBA guidance.

Cost-benefit analysis can be undertaken *ex ante* (before), *in media res* (during) or *ex post* (after). This paper is concerned primarily with *ex ante* analysis. However international experience shows that outcomes frequently differ significantly from the projections used in CBA. It is recommended that CBA should also be done on an *ex post* basis for major projects on a more regular basis. This would help improve the evidence base for *ex ante* analysis of new projects.

The methodology of CBA facilitates comparison of the costs and benefits of various options for achieving particular policy objectives. The Irish Public Spending Code (PSC) recommends that several options be analysed with a view to identifying the most effective option. This recommendation is important for the pursuit of policy objectives generally, including in regard to the environment.

The paper focuses mainly on these changes *within CBA* that can help make it more appropriate to the context of transition and climate change. However, the final chapter focuses on the way in which key integral characteristics of climate transition—systematicity, transformative change, wider economic, social and environmental impacts, and the need for a longer time horizon—challenge conventional approaches to CBA and reinforce the need to explore other analytical and strategic approaches to support transition.

The PSC is currently under review. In October 2018, a review of technical appraisal parameters used for CBA, including the discount rate, time horizon, shadow prices of public funds and the shadow price of labour was published by DEPR (O'Callaghan and Prior, 2018). Work within the DEPR Climate Change Unit is looking at the shadow price of carbon. Both pieces of work will feed into an overall review of the PSC being undertaken by DPER.

Box 1.1: Brief Introduction to Cost-Benefit Analysis

CBA is a practical tool that can be used to assist policy formulation. Its theoretical foundation assumes that the preferences of individuals can be valued (as a willingness to pay for benefits or to avoid losses) and aggregated to give an overall social (rather than just private) benefit or cost. If beneficiaries from a change can hypothetically compensate the losers and have some net gains left over, then the basic test that benefits exceed costs is met. This is the Kaldor-Hicks compensation test, and it is central to CBA (OECD, 2018). The centrality of this test means that CBA is concerned with economic efficiency. The distribution of costs and benefits—who gains and loses and, particularly in the context of climate change, how this varies across generations—is not normally assessed by CBA. However, CBA can potentially address this issue using weighting; for example, giving higher weights to disadvantaged or low-income groups (Kunreuther *et al.*, 2014; Fleurbaey *et al.*, 2014).

CBA identifies the status quo or baseline, and considers a set of alternatives and the marginal or incremental costs associated with each. Important analytic decisions include:

- **which and whose (including the geographical boundary) costs and benefits are recognised and how they will be measured (Cellini & Kee, 2010; Boardman *et al.*, 2006);**
- **timeframe of the analysis;**
- **how to monetise costs and benefits, and**
- **how to discount future costs and benefits.**

Given the need to make assumptions in relation to a range of issues, it is also common that a sensitivity analysis is performed. The need to pay greater attention to distributional impacts and the reality that many costs and benefits are not quantifiable, or indeed known with any degree of certainty, means that CBA should be complemented by other decision-making tools and processes, particularly in the context of the long-term transition to a low-carbon energy future.

2. Cost-Benefit Analysis in Ireland

The Irish Public Spending Code (PSC), published in 2012, consolidated and built upon the variety of different value-for-money (VFM) elements previously in operation,[2] and set out the central technical parameters that are to be used across the public sector.

The objective of this standardised approach is to promote rigour in economic appraisals, ensure consistency and support practitioners. The guidance requires that all appraisals include clear statements in relation to the objectives of any investment and the outcomes sought and whether there are better ways to achieve these outcomes. The process of appraisal, as such, requires exploration and analysis of various options, and consideration of risks associated with different options, and also involves the making of recommendations. The identification of options includes defining an appropriate benchmark against which alternatives can be compared. The PSC notes that a 'do nothing' benchmark may be unrealistic in that there are often necessary costs that will in any event be incurred. Hence a 'do the minimum' benchmark is normally a better benchmark for comparison. The importance of assessing a number of alternatives is emphasised by Morgenroth (2011):

> If a project is only compared to a 'do nothing' comparator, then if that project is in any way effective it will dominate the 'do nothing' comparator. Consequently, such a comparison yields no insights for project prioritisation. Therefore, projects should be compared to alternative projects, and variations of the same project should also be considered in order to identify the most effective option (Morgenroth, 2011: 14).

To support the decision-making process, Part B of the PSC recommends the use of various types of analysis and different thresholds:

- below €0.5m: simple assessment required;
- between €0.5m and €5m: elements of a preliminary and detailed appraisal for projects;
- between €5m and €20m: multi criteria analysis (MCA) required; and

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[2] These included: *Proposed Working Rules for Cost-Benefit Analysis* (Department of Finance, 1999); *Guidelines for the Appraisal and Management of Capital Expenditure Proposals in the Public Sector* (Department of Finance, 1994 and 2005); *The Economic Appraisal System for Projects Seeking Support from the Industrial Agencies* (Murphy *et al.*, 2003); *Guidelines on a Common Appraisal Framework for Transport Projects and Programmes* (Department of Transport, 2009) and *Roads Project Appraisal Guidelines* (NRA, 2011).

- over €20m: cost benefit analysis (CBA) or cost effectiveness analysis (CEA) required.

The core technical parameters of Irish CBA guidance in the PSC (DPER, 2015) include the following:

- **The social discount rate** (SDR) allows the future flows of costs and benefits of a project to be understood in present value terms. Ireland currently applies an SDR of 5 per cent.

- **The shadow price of carbon** used in Ireland is the market value of carbon allowances under the EU Emissions Trading System (ETS). The PSC recommends that the carbon price start at €5.80 per tonne of CO_2 for 2014, followed by futures prices in the years up to 2019. It also states that the projected prices from the reference scenario in the Impact Assessment of the EU 2030 Framework for Climate and Energy Policy should be applied from 2020. On this basis, the carbon price for 2020 is €10 per tonne and this increases to reach €100 per tonne in 2050 (DPER, 2015).

- **The shadow price of public funds** is an economic cost reflecting an assumed distortion in economic output that is implied by raising taxation revenue to fund expenditure. The Irish PSC applies a rate of 130 per cent.

- **The shadow price of labour** is used to measure labour costs in a situation in which the extent of unemployment means that the market wage is not a reliable measure of the underlying cost of labour. If there is high unemployment, the shadow price of labour will be below the market wage. Current Irish guidance applies conversion factors of 80 to 100 per cent.

The technical reference, or Part E, of the PSC guidance (DPER, 2015), lists these four parameters but proposes that individual government departments and agencies should also quantify additional parameters applicable in their own sectors where relevant expertise and project experience have developed over time. For example, guidance is provided by the Department of Transport, Tourism and Sport (DTTAS, 2016) on the values to be used for a range of parameters in relation to transport, including the value of time, fuel costs, the monetisation of the environmental impact of the emissions of various gases from transport, and the valuation of the costs of accidents.

In terms of time horizon, it is defined as the economically useful life of the project in the PSC (DPER, 2012). The following sectoral guidance is also given:

- Transport projects such as road and rail should be appraised over a 30-year period (DTTAS, 2016). A residual value calculation is also recommended. Two approaches are outlined: (i) the project capital value at the terminus year; (ii) calculating a residual value based on the net present value of the costs and benefits of the asset over its remaining life.

- Appraisal of enterprise grants across a seven-year time horizon (Murphy *et al.*, 2003).

In terms of costs and benefits, the guidance states that a comprehensive approach should be taken to ensure that all relevant costs and benefits are included, both tangible and intangible. As the impacts will be determined by the characteristics and context of the project, the practitioner has latitude to determine the costs and benefits. The PSC states that it can be useful to consider the different costs and benefits arising by considering the impacts on different stakeholders affected.

Externalities are defined in the Public Spending Codes as follows: 'benefits or costs which affect third parties who are not charged for the benefit or compensated for the costs' (DPER, 2012: 20). The PSC advises analysts that 'only those externalities which represent a significant project outcome and which can be valued on the basis of a reliable, well-established methodology should be included in the actual CBA' (*ibid.*: 20). Where there are significant externalities that cannot be captured in monetary terms, the PSC states that they should be 'excluded from the cost-benefit calculation but nonetheless fully assessed in the cost-benefit report in such a way as to ensure their full consideration in the decision-making process' (*ibid.*: 21). This would involve qualitative assessment of significant factors that cannot be captured in monetary terms. The guidance states that the approach to identifying costs and benefits is to be done by considering the impacts on different stakeholders and environmental externalities.

Guidance in relation to greenhouse gas (GHG) emissions is covered by circular S431/65/07, issued in 2009 by the Department of Finance. This deals with accounting for the impacts of public capital investment projects on GHG emissions by CO_2 equivalents (CO_2 eq.). Guidance is provided on physical quantification of GHGs, carbon pricing, the discount rate, time horizon and sensitivity analysis. The circular states that the carbon price should be included in CBA 'where necessary, significant and appropriate' (Department of Finance, 2009). It stipulated:

- the approach to estimating the flow of GHG emissions from different sources;

- the use of global warming potential (GWP) to convert this flow to tonnes of CO_2 eq.; and

- a valuation per tonne set by the EU ETS carbon market price.

In 2012, the Senior Officials Group on Climate Change and the Green Economy established a new Interdepartmental Working Group, chaired by DPER, to update the work previously undertaken. This group decided that the ETS price should be applied to the non-ETS sectors. The Public Spending Code, Section E (DPER, 2015), sets out the carbon prices up to 2050 as outlined above. The Climate Change Unit of the DPER is at present undertaking a review of the shadow price of carbon.

The PSC provides scope for government departments to adapt the PSC as required for their own sectors. However, Section E of the PSC stipulates that departments with responsibility for oversight of sectoral guidance are required to ensure that appraisal frameworks are consistent with the PSC, while revisions and updates to sectoral appraisal frameworks must be approved by DPER.

The PSC does not include guidance on distributional impacts, equity or the 'just transition'. At a sectoral level, transport guidance requires qualitative appraisal in the case of impacts on 'accessibility and social inclusion' (DTTAS, 2016: 24).

The PSC points out that 'decision makers need to be assured that the overall welfare of society is raised as a result of the proposed action' (DPER, 2012: 8). CBA seeks to achieve this by putting monetary values on all of the relevant costs and benefits. The guidance recognises that there are limitations to CBA. These include the difficulty of monetising intangible costs and benefits, and the presence of complex, unclear or sometimes apparently conflicting objectives and subjective assumptions by the appraiser regarding non-economic variables. In addition, the guidance notes that CBA is a forecasting technique that involves predicting the future: 'This is inherently difficult and there is a risk of a false accuracy attaching to the results of detailed CBA models. Ultimately, the CBA is as good as the underlying assumptions and data' (*ibid.*: 11).

Cost-benefit analysis can be undertaken on either an *ex ante* or *ex post* basis, or during a project's lifetime. *Ex post* CBA of investment projects is not widely undertaken by agencies that fund investment projects (Florio & Vignetti, 2013). It is understandable that more attention is paid to evaluation of infrastructure investment in advance of commitment of resources to major projects than of projects that have already been decided and implemented. There are, however, benefits to *ex post* CBA of investment projects. First, it can provide information on the performance of projects that can inform CBA for new investments. Second, there is potential to shed light on the appropriateness of the decision-making process and the role played by CBA in it (*ibid.*). There is a regulatory requirement for *ex post* evaluation of EU Cohesion Policy programmes.

There is evidence from a number of international studies of optimism bias in CBA; i.e. actual costs being higher than projected while benefits are often lower. Drawing on a database of 258 major infrastructure projects covering 20 nations on 5 continents, Flyvbjerg (2009) found that 9 out of 10 projects had cost overruns. He also examined the accuracy of travel demand forecasts for road and rail infrastructure from 208 projects in 20 nations. For rail, he found that actual passenger use was 51.4 per cent lower on average than forecast. In the case of roads, actual vehicle traffic was on average 9.5 per cent higher than forecasts. Other evidence on optimism bias is presented by Morgenroth (2011).

Box 2.1: Cost-Benefit Analysis and GDP

CBA is derived from the theory of welfare economics. It is concerned with costs and benefits in relation to the welfare of individuals as measured by willingness to pay. While CBA measures welfare in monetary terms, this is not the same as the impact on the level of economic activity as measured by gross domestic product (GDP), although there is overlap between these.

A CBA will include significant items not captured in GDP, in particular impacts on the environment and health. At the same time, not of all the increase in GDP associated with a project would count as a welfare gain in a CBA. For example, suppose the reduction in travel costs associated with a transport investment leads to an increase in labour-force participation. The increase in wage income would add to GDP. However, not all of this would be included as a benefit in a CBA. The net benefit to the worker concerned will be less than the wage income; some of the extra income will be absorbed in travel costs and other necessary expenses while some of the income is required as compensation for the effort of working. If an investment leads to an increase in productivity, this will increase GDP and also represent a gain in welfare for the purpose of a CBA (Department for Transport, 2018).

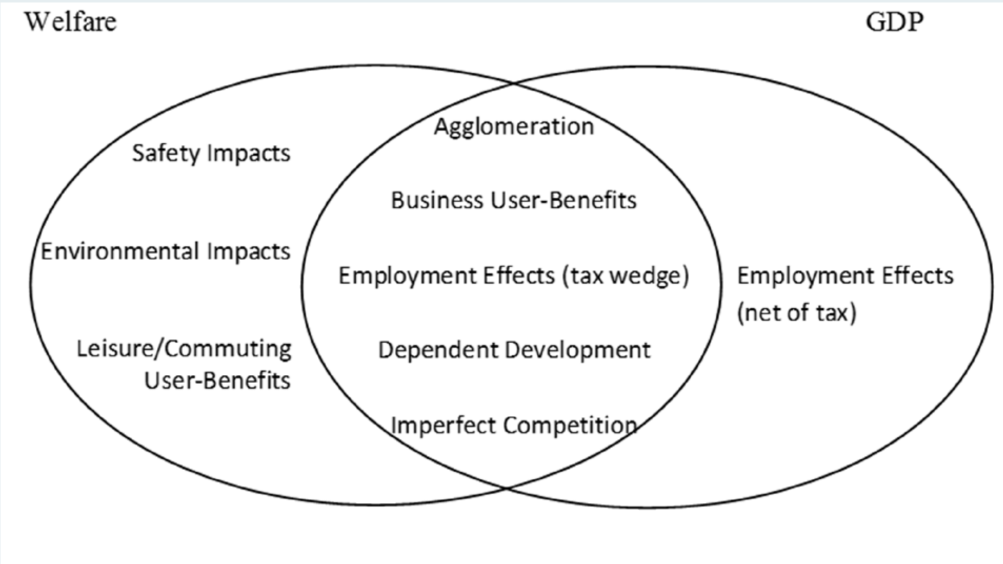
An illustration of the possible effects of a transport investment are shown in Figure 2.1, distinguishing between effects on welfare, GDP or both. The overlapping circles in the centre identify effects that increase both GPD and welfare. Most of the effects shown in the overlapping circle represent wider economic effects (for example, agglomeration economies) of a transport investment beyond the direct benefit of time savings to travelers. These wider economic effects are not included in traditional CBA. They have however received attention in the literature in recent years and the UK Department for Transport (2018) provides guidance on the treatment of these effects in CBA.

While CBA is required to determine the value for money of public investments, policy-makers are also concerned with the impact on GDP or related measures. ESRI evaluations of earlier National Development Plans examined the impact on gross national product (GNP), the environment and a range of other economic and social matters. The ESRI evaluations drew on CBA results where available but were mainly based on other macroeconomic and microeconomic approaches (see, for example, Morgenroth & FitzGerald, 2006).

GDP is not a measure of well-being nor an indicator of sustainability. There is an extensive literature on the development of alternative aggregate indicators of performance that measure well-being and sustainability. One concern with the growth of GDP is the link to the growth of GHG emissions. A sustainable path for GDP would require, among other things, a decoupling of the growth of GDP and GHG emissions. There is evidence of this happening in some countries, but GDP growth in Ireland continues to have a strong relationship with the growth of emissions.

There is no evidence of systematic optimism bias for Ireland, although a number of reports of the Comptroller and Auditor General have found cost overruns on projects. In light of this, Morgenroth (2013) recommends *ex post* evaluation in Ireland of a comprehensive set of infrastructure projects to establish whether optimism bias has been a feature of the analysis of Irish investment projects. Barrett (2006) also recommends that both *ex ante* and *ex post* evaluations be undertaken and published for all major transport investments. The PSC refers to the international evidence on optimism bias and, to minimise the risk of optimism bias, recommends that the appraiser should systematically test low-benefit outturns against the highest-cost outturns for the critical variables as part of the sensitivity analysis. A pessimistic view of the project timings should be included in this sensitivity analysis (DPER, 2012).

Figure 2.1: The Potential Impacts of a Transport Investment on Welfare (CBA) and GDP



Source: Department for Transport (2018).

3. Implications of Environmental Concerns for Cost-Benefit Analysis

3.1 Introduction

The challenge of climate change has been highlighted by the Intergovernmental Panel on Climate Change (IPCC) (Kolstad *et al.*, 2014) as one that raises a series of compounding difficulties for economic methods. In describing 'Social, Economic and Ethical Concepts and Methods' in Chapter 3 of the IPCC Fifth Assessment Report (Working Group III), Kolstad *et al*. (*ibid.*) give a useful review of the limits of economics in guiding decision-making. It is emphasised that, while economics can aggregate welfare (well-being), this is only one of several criteria for choosing among alternative mitigation policies as 'other ethical considerations are not reflected in economic valuations… [and] may be extremely important for particular decisions… economics alone cannot be used to determine who should bear the burden of mitigation' (*ibid.* :224).

As the methods of economics are concerned with value, they do not take into account justice and rights in general. While economics may address 'distributive justice', it is not well suited to account for many other aspects of justice, including compensatory justice. Even in areas where the methods of economics can be applied in principle, they cannot be accepted without question. Particular simplifying assumptions are always required, and these assumptions are not always accurate or appropriate. Decision-makers need to keep in mind the resulting limitations of the economic analyses. Less quantifiable considerations may receive less attention than they deserve. In the context of climate change, particular difficulties are raised for economic methods:

- First, many of the common methods of valuation in economics are best designed for marginal changes, whereas some of the impacts of climate change and efforts at mitigation are not marginal.

- Second, the very long time-scale of climate change makes the discount rate crucial at the same time as it makes it highly controversial.

- Third, the scope of the problem means it encompasses extremes of wealth and poverty, so questions of distribution become especially important and especially difficult.

- Fourth, measuring non-market values, such as the existence of species, natural environments or traditional ways of life of local societies, is fraught with difficulty.

- Fifth, uncertainty includes the likelihood of irreversible changes to societies and to nature, and even a small chance of catastrophe.

Hulme (2009) provides a lucid review of the difficulties of CBA in the context of climate change. He points out that the economic principle of CBA is easy to state but, in the case of climate change, difficult to implement. Hulme suggests that, following the rationale of CBA, it makes sense to continue reducing emissions until the cost of doing so outweighs the benefits.

However, many of the attributes of climate change muddy the waters and confound such a linear approach. In the words of Hulme, ‘Many of the characteristics of climate change challenge the standard application of cost-benefit analysis as an economic tool to support decision-making’ (*ibid.*: 116). Hulme goes on to cite the global scale of the costs and benefits of climate change, which are beyond the scale of regular policy contexts; the lack of market value for many of the relevant impacts resulting from climate change; the risk and uncertainty about the eventual extent of impacts,[3] and finally the timescales involved in the costs and benefits, which can vary from decades to centuries. In relation to the very long time-scales involved, this has the implication that ‘how we value the distant future becomes an essential, if not *the* essential, component for cost-benefit analysis applied to climate change’ (*ibid.*: 116).

To bring CBA into line with the requirements of low-carbon transition and the variety of long-term challenges now faced, what is required, in our view, are not just increases in the carbon price, but an integrated package of measures that include longer time horizons, lower discount rates and wider approaches to valuation of costs and benefits.

However, as highlighted by Hulme, more than adjustment to CBA is required. There is a need to acknowledge that the challenges associated with climate change and transition require a broader and deeper review of the methods of evaluation and approach that can guide decisions.

OECD Review 2018: Cost Benefit Analysis and the Environment

The recent OECD (2018) review of CBA and environment points out that, over the last two decades, there have been a number of developments in the theory and practice of CBA that, taken together, ‘alter the way in which many economists argue CBA should be carried out’ (OECD, 2018: 23). It describes how important ‘Environmental CBA’ has become by stating that ‘a proper consideration of the economic case for each project option would need to draw on developments in

[3] This includes ‘fat tails’ in the probability of impacts that include lower probability but potentially catastrophic and irreversible impacts.

environmental CBA' (*ibid.*: 22). It defines environmental CBA as the application of CBA to projects or policies that have the deliberate aim of environmental improvement or actions that affect, in some way, the natural environment as an indirect consequence. This includes climate-change mitigation and adaptation and a range of other environmental impacts such as air pollution, noise, soil contamination, water pollution and habitats. Many environmental economists propose that CBA is a good analytical method as it simplifies the impact of a project to a single monetary indicator. Others, including some ecological economists, suggest that it oversimplifies uncertainty in the analysis, including questions on the ability to monetise all impacts and the ethics of doing so.

The OECD review highlights a number of areas where evolution in the theory and practice of CBA is occurring:

i. major advances in finding money values for the costs and benefits of environmental impacts;

ii. the treatment of distributional issues in CBA including intergenerational fairness;

iii. selecting a discount rate, an area shaken by climate economics, both technically and in its ethical underpinnings;

iv. circumscribing CBA as to the limits in which it operates and by extension the recommendations it can provide;

v. taking account of sustainability and natural capital; and

vi. how is CBA actually done (and how to do better)?

The limits on CBA referred to in point (iv) above arise from the theoretical foundations of CBA. One of the central principles of CBA is that a project is evaluated by comparing the benefits (gains in human well-being) to the costs (losses in human well-being). Human well-being in turn is based on the aggregation of the preferences of individuals. Not everyone accepts this theory. Randall (2014) argues that the theory underlying CBA is incomplete as a moral basis for decision-making. Other considerations, including intrinsic values, also need to be taken into account. If it is accepted that CBA does not provide a comprehensive rule for decision-making, the question arises as to what are its limits. A prominent example where this arises concerns sustainability. Sustainability may not be adequately valued by human preferences and hence in CBA. The OECD (2018) suggests that one response to this is to specify sustainability limits in physical terms. If limits on natural capital that need conserving could be established on sustainability grounds, CBA would then operate on decisions within these limits.

This chapter focuses on five key CBA issues that are shaped by efforts to incorporate climate change and transition thinking into conventional CBA analysis:

- Time Horizon needs to be longer;
- Discount Rates should be lower;
- A wider range of costs and benefits should be examined;
- The Carbon Price should be higher; and
- Dealing with Uncertainty—Some Lessons/Techniques

3.2 Time Horizon

The time horizon is a crucial influence on CBA. The European Commission (2008) defines the time horizon as the period over which one sums up the costs and benefits to check whether or not the project was a success. The time period could also be defined as the technical or physical life of the project, which for a bridge could be 100 years or more, or just five years for an IT project. An additional way of setting the time horizon is to look beyond the project itself to the impacts associated with it. The World Health Organisation (WHO) uses a 100-year time horizon because of the long-term health impacts from air pollution improvement (Hutton & Rehfuess, 2006). The long-term impacts of mitigation projects on greenhouse gases (GHGs) can continue for centuries after the activities that released them have ceased (IPCC, 2001).

There are no hard and fast rules for setting the time horizon of CBA (Pearce *et al.*, 2006). However, two factors have a major impact: uncertainty and the approach to discounting.

First, CBA has to work with the uncertainty of long term projections. For example, infrastructure created today could still be in use in 80 years but there is much uncertainty as to the value of the benefits it will be providing in the distant future.

One response to uncertainty is to use shorter time horizons in CBA. This has the advantage that there can be a greater degree of confidence in the resulting number. However, using shorter time horizons will underestimate the potential gains and costs that accrue in the long term. In particular, short-time horizons work against projects focused on long-term issues like climate change and transition.

Various techniques can be used to help try to reduce uncertainty. These include scenario approaches and sensitivity analyses (O'Mahony, 2014). Employing varieties of scenario approaches, as identified in Dutch guidance, offers an approach to improve the technical robustness of responding to uncertainty (CPB/PBL, 2013).

Second, in CBA, there is interaction between the level of the discount rate and the time horizon: higher discount rates reduce the effective time horizon. Hence, with a high discount rate, adoption of a long time horizon makes little or no difference. This is because higher discount rates have the effect of reducing the estimated value of long-term impacts, even significant impacts, when measured in present value terms. The next section discusses discount rates. It is clear that in general the need for lower and declining discount rates is widely accepted in the literature on how to use CBA for climate change and other environmental issues.

Long-time horizons: What is practical?

The key questions are what is practical and what other countries are doing. This section outlines the guidance provided in a number of countries and in the EU.[4]

- **France**: The report of the Quinet Commission noted that there are multiple transitions under way regarding ecology, climate, biology and the digital revolution. In the light of these, the report identified the need for an overall study on the future of society and long-term development. Investment would then be evaluated in the context of these long-term reference scenarios. The report recommended that the time horizon be extended in many sectors to approach the lifetime of the investments in question, which may sometimes exceed a century. Because many of today's infrastructure investments will still be in operation at the end of the century, it is necessary to consider this period, although the difficulty of doing so was acknowledged. The general approach recommended by the Quinet report is to extend the time horizon to 2070 and then to calculate the residual value for a further 70 years (to 2140). In the case of GHG emissions, calculations would extend beyond 2140 (Quinet, 2013).

- **UK**: The UK Green Book specifies a time horizon of 10 years for many interventions, but in some cases (such as buildings and infrastructure) this is extended by up to 60 years. In addition, an even longer period may be used where there are likely to be significant economic and social effects. Examples of this given in the Green Book include immunisation programmes, the safe treatment and storage of nuclear waste and interventions that reduce climate-change risks. The UK Green Book details the declining discount rate applied to issues of intergenerational wealth transfer for up to 125 years. An addendum to the Green Book specifically addresses the long-term impacts of projects on GHG emissions, highlighting that emissions must be accounted for further into the long term. Guidance on carbon valuation is provided up to 2100 (DECC, 2011).

- **Netherlands**: The guidance refers to an infinite time horizon (CPB/PBL, 2013). In practice two years are chosen, the beginning year *y* and end year for analysis in

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[4] This section draws on the literature review done by DPER (O'Callaghan & Prior, 2018).

$y^{(x)}$. These discern the baseline conditions and the effects in the distant future year when impacts become structural in nature. Impacts in intervening years are interpolated as a growth curve.

- **Norway**: The guidance suggests that CBA should seek to capture all relevant effects of the measure under consideration, including those in the distant future (Norwegian Ministry of Finance, 2012). A 40-year time frame is used for transport projects but a 75-year period for railway projects. The guidance splits the time period into an analysis and residual period.

- **EU**: The time horizons range from 10 years for productive industry, to 25 years for roads and 30 years for railways (Sartori *et al.*, 2014). However, examples in the EU guidance include a rail project that has a time horizon defined by 'economically useful lifetime' at 30 years, but the financial and economic flow calculated in residual value is estimated for a further 52 years (*ibid*.).

- **New Zealand**: The guidance suggests a 'whole of life costs' approach and specifies up to 2067 (50 years) in its online software tool CBAx.[5]

- **US**: The Department of Transportation (2017) proposes that the useful lifetime of a transport project may exceed 50 years but that, due to uncertainty, the time horizon should be up to 40 years. The US EPA has applied a wide range of timespans, including 36 years for power plants, up to 2300 for the social costs of carbon and 10,000 years for a radioactive waste facility.

There is little doubt that long-term horizons are needed, and particularly in relation to climate change and transition. It is also clear that there is a trend towards longer time frames, particularly for transport projects.

3.3 Social Discount Rate

A social discount rate (SDR) is a means of understanding the future flows of costs and benefits. The rate chosen reflects a society's relative valuation of today's welfare versus future welfare. It is generally set nationally and reflects national circumstances. The SDR is a key coefficient in CBA. It is used to put a value today on the flow of all costs and benefits across the time horizon of the appraisal, and any residual value estimated at the end of the period.

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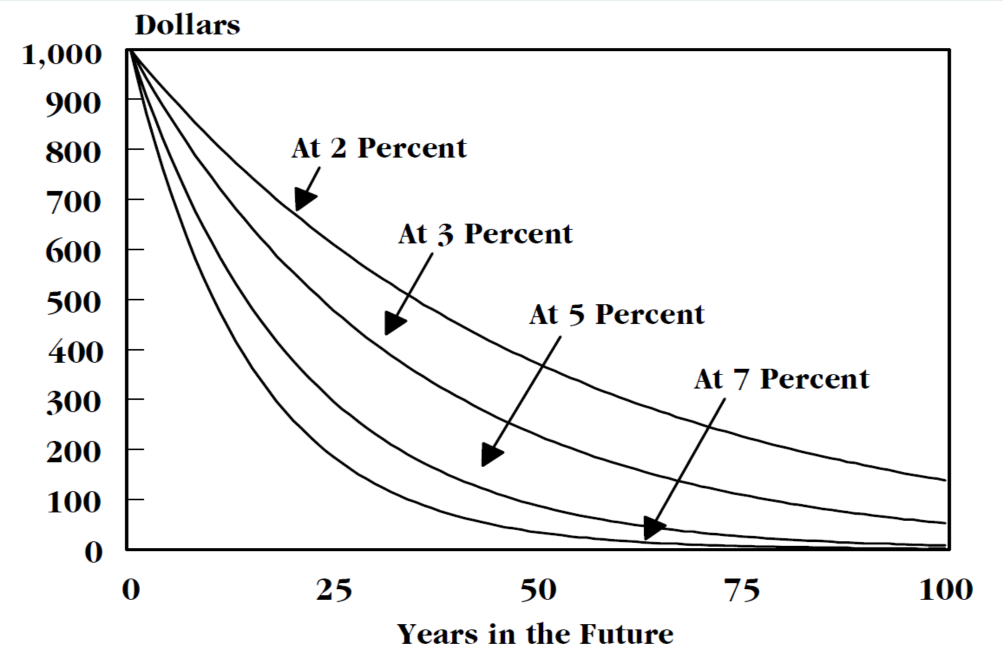
5 See http://www.treasury.govt.nz/publications/guidance/planning/costbenefitanalysis/cbax

The setting of the social discount rate needs to take account not only of society's preference between consumption today and in the future but also the ethics of how the risks of costs and benefits are spread across generations and distributed within the current generation. Setting the social discount rate at a high rate reduces the impact of costs and benefits; which are longer term, and as such will tend to reduce the chances of funding of public investment projects. If the SDR is set too low, economically inefficient investments may be supported (ADB, 2013). This arises because, if the discount rate is low then projects that yield a low rate of return may still be shown to have benefits in excess of costs. Higher rates have a substantial impact in relation to projects that support mitigation and environmental protection, where public investment tends to be in the form of early up-front capital, whereas the benefits to welfare and well-being are spread out over the long term (Portney, 2008). This leads Hulme to suggest that the discount rate is therefore *the* issue when it comes to mitigation and climate-change impacts (Hulme, 2009).

Figure 3.1 shows the impact of different discount rates on present values. It shows that the present value of $1,000 received in 25 years would be just around $600 if a 2 per cent discount is used; its value would be calculated at less than $300 if 5 per cent is used. The graph also illustrates the impact of the interaction between the time horizon and the rate. In the long term, any forecast benefits that arise in 100 years would be given almost no value in a calculation of present value if a 5 per cent discount rate is used.

Figure 3.1: The Present Discounted Value of $1,000 under Different Discount Rates



Source: Congressional Budget Office (2003: 29).

3.3.1 Establishing the Discount Rate

Two main conceptual approaches are used to choose the national discount rate: the social rate of time preference (SRTP) and social opportunity cost (SOC). This section describes both.[6]

Social rate of time preference

The SRTP is the rate at which society is willing to postpone a unit of current consumption in exchange for more future consumption. A zero rate places the same value on the future as the present. A positive SRTP places greater value on the present while a negative SRTP places greater value on the future. The rationale for this approach to setting the discount rate is that public investment is viewed as displacing current consumption. If this sacrifice of current consumption is to be beneficial for society, it needs to provide future benefits that are sufficient to compensate for the loss of current consumption.

Two methods are used to estimate the SRTP. One is the real, after-tax rate of return on government bonds or other low-risk marketable securities (ADB, 2013). The other way of choosing the SRTP, and one that is widely used, is the Ramsey growth model, which is based on the following formula:

$$SRTP = p + g * e$$

where:

> p is the pure time preference;
>
> e is the elasticity of the marginal utility of consumption, i.e. the percentage change in an individual's marginal utility corresponding to each percentage change in consumption; and
>
> g is the expected growth rate of per capita consumption.

(Ramsey, 1928)

The focus of the original article by Ramsey (1928) was to find the optimal balance between saving and investment. The approach was applied subsequently to the choice of discount rate in CBA. The idea is that the goal is to maximise the utility (or satisfaction) derived from consumption (of both public and private goods and services) over time.

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[6] Two further approaches are (i) the weighted average of SOC and SRTP, and (ii) the shadow price of capital (SPC). In practice, neither of these approaches tends to be favoured. The weighted average ignores the possibility of reinvestment and it is practically difficult to derive the weightings. The SPC, while theoretically the most attractive, can be difficult to apply in practice (ADB, 2013).

The first item of the equation is the pure rate of time preference; this is the satisfaction derived from consumption at the present time compared to the future. The second item of the equation is based on the idea that consumption in the future is discounted if people are expected to become richer. This second item is the product of the expected annual growth of per capita consumption times the elasticity of the marginal utility of consumption. Saving today means giving up consumption now to allow for higher consumption in future. If it is expected that people will be richer in the future and each additional unit of consumption yields less benefit, then higher consumption in future is less valuable than consumption today. Hence, benefits and costs incurred in the future are discounted to take account of the expectation that people will be richer than they are today.

The choice of the level of the individual elements of the Ramsey equation is now considered. In relation to the first variable, *p*, the rate of pure time preference, it is widespread practice to place more weight on the present compared to the future.

There are two dimensions to this. First, there is impatience or an inherent demand for consumption now rather than later. Second, there is the risk of death and the possibility of extinction of the human race. Empirical studies to estimate the rate of pure time preference have focused on the second component; i.e. death rates and the probability of extinction. A survey of empirical estimates reported by ADB (2013) reported a range of 1 to 3 per cent for the rate of pure time preference. However, the choice of the appropriate rate of time preference is not one that can be resolved by empirical research. The UK Treasury Green Book (2003) adopted a value of 1.

Ramsey's own view was that the value of *p* should be equal to zero on ethical grounds: 'it is assumed that we do not discount later enjoyments in comparison with earlier ones, a practice which is ethically indefensible and arises merely from the weakness of the imagination' (Ramsey, 1928: 543). Prominent economists who have shared this view include Pigou, Harrod and Solow.

The choice of discount rate has featured prominently in debates on analysis of the valuation of the effects of climate change. The Stern (2007) report reached very different conclusions regarding the costs of the future damage from climate-change compared to other economic analysts who had used similar modelling approaches. This arose primarily through Stern setting the value of *p* at close to zero (0.1). Stern argued that it was unethical in the context of the risks of climate change to place a lower value on the well-being of future generations merely because they would exist in the future. A value of 0.1 was placed on *p* to take account of the possibility of extinction. This is in line with a literature review in the IPCC Fifth Assessment report that recommended that p should be zero or near zero (Kolstad *et al.*, 2014). A survey of experts found a median value of 0.5 and a mean of 1.1 (Drupp *et al.*, 2015). The most common (i.e., the modal) response in this survey was in fact zero (i.e. no pure time preference discounting).

The next variable is *e*, the marginal utility of consumption. The idea of declining marginal utility of consumption is intuitive and widely shared. An extra euro of consumption to someone who is rich will yield less benefit compared to someone who is poor. When the term *e* in the equation is set to 1, an increase in consumption of 1 per cent to a poor person is worth the same as an increase of 1 per cent to a rich person. However, when *e* is set to 1, it also implies that in absolute terms the increase is worth more to the poor person. Consider, for example, one person who consumes five times more than another. With e=1, it means that one euro to the poorer person is worth five times more than an additional euro to the richer person. When e=2, one euro to a poorer person is worth 25 times more than to a rich person.

The marginal utility of consumption is not something that can be directly observed. Researchers have adopted three methods to estimate *e*: direct survey methods, indirect behavioural evidence, and revealed social values in governments' tax and spending policies. A survey of a wide range of research found that most estimates fall within the range of 1 to 2 per cent (ADB, 2013). The European Commission estimated values of between 1.2 and 1.79 for selected non-cohesion-fund countries (European Commission, 2008).

An implication of using the Ramsey formula is that, the more one adopts an egalitarian perspective, the lower the SRTP one would use, assuming consumption is growing. People in the future are expected to be richer than today. Prioritising those who are relatively poorer therefore implies prioritising consumption today, given the assumption of higher consumption in future. Up to a point, this could be offset by setting a relatively lower value on the first term in the equation, the pure rate of time preference.

Expected per capita consumption growth (*g*) is commonly measured by indicators such as income. Empirical estimates for the rate of growth of per capita consumption may be based on growth models, which take into account both the past long-term development path and the expected future growth based on reasonable assumptions. Using the Ramsey equation, the faster the expected growth of future consumption, the higher the discount rate will be. This implies that, other things being equal, the faster the projected growth of the economy, the lower the apparent benefits from an investment project. Normally, this will be counter-balanced by the fact the underlying rates of return for an investment project will typically be higher the faster the growth of the economy. There will, however, be projects for which the returns are not naturally linked to economic growth, such as reclamation of bogs.

The OECD notes that, while the SRTP and the Ramsey formula is an empirical estimation, it does involve judgements for parameterisation of the factors that are included in the calculation, and is consequently regarded as arbitrary by some practitioners (OECD, 2018).

Social opportunity cost

A second approach to setting the SDR is that of Social Opportunity Cost (SOC). This approach adopts an investor perspective: public investment is viewed as displacing private investment (rather than consumption) so that public investment has an opportunity cost in terms of forgone private investment. Therefore, the rate of return on public investment needs to match the return on the alternative private investment if it is to generate net value for society. With this approach, the SDR is based on the pre-tax return on private investment.

Countries that employ the SOC approach—such as New Zealand, Australia, Canada and the US,[7]—tend towards discount rates of up to 10 per cent (ADB, 2013). This reflects the high rates of return that can be achieved on private investment.

The SOC approach has substantial disadvantages. The private rates of return on which it is based do not reflect externalities such as loss of biodiversity and the costs of climate change. Furthermore, private rates of return can be influenced by market volatility and asset bubbles (Sartori *et al.*, 2014).

Constant declining social discount rates

The SDR can be applied as either a constant or declining rate. When one applies a standard constant discount rate, the present value of long-term costs and benefits becomes very low. Consider, for example, a discount rate of 3.5 per cent. The present value of €100 of benefits in 50 years' time is €18, while the present value of this amount in 100 years is negligible at €3. Hence standard discounting with a constant discount rate gives little weight to the interests of future generations. This effect may be counter-balanced by applying a discount rate that delivers over time.

In formal terms, the use of a constant discount rate is known as exponential discounting. The rate of discounting is the same regardless of where it occurs in time; if benefits are discounted at 4 per cent between year one and year two, they are also discounted at 4 per cent between year 100 and year 101. Hyperbolic discounting is a form of discounting in which the rate of discounting applied between two periods depends on how far into the future the two periods concerned are. Hyperbolic discounting means that people are more impatient about trade-offs in the short term than in the long term. For example, it means that having to wait a few days this week matters more than having to wait a few days in a year's time (from the perspective of today). The term hyperbolic discounting originally referred to a situation in which the discount factor[8] follows this type of

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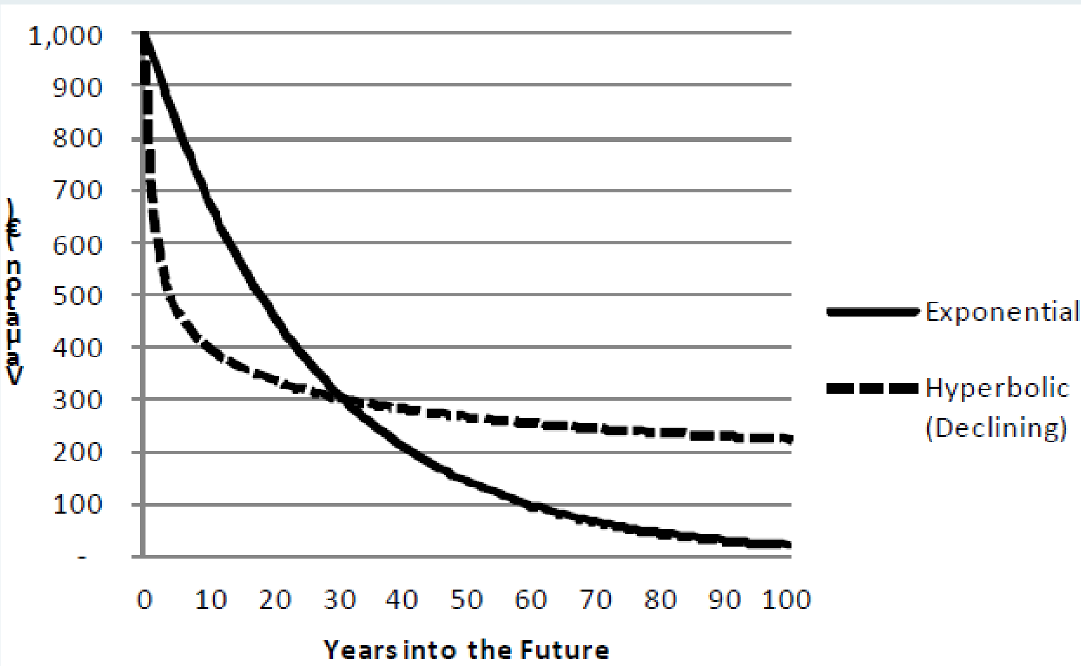
[7] In the case of the US, different methods and a range of rates are used across different government agencies.

[8] The discount factor is the factor by which a future value is multiplied to calculate the present value. For example, with a 4 per cent discount rate, the discount factor after one year will be 0.96. The present value of €100 in one year's time is €96.

mathematical function but, according to Groom *et al*. (2005), the term is increasingly applied to any declining discount rate. There is considerable empirical evidence that hyperbolic discounting is a better approximation to people's behaviour than exponential discounting (Angeletos *et al.*, 2001).

The difference between exponential and hyperbolic discounting are shown in Figure 3.2 taken from Morgenroth (2011). This Figure shows the value of €1000 received at different times in the future according to these two approaches. The exponential discount function shown here uses a constant 4 per cent discount rate. In this example, €1000 received (or lost) in 100 years' time is valued at just €20 using exponential discounting. With hyperbolic discounting the value declines more rapidly initially (reflecting greater impatience in the short term) while the value declines much slower in the long term; with this approach, €1,000 in 100 years' time is valued at just over €200. Morgenroth proposes combining the exponential and hyperbolic approaches using the higher discount factor of the two. This means using exponential discounting up to the point where the two line cross (at 31 years) and then using hyperbolic discounting. The advantage of this is that this does not bias the analysis against projects that yield benefits in the near future while costs and benefits in the distant future get a higher weighting.

Figure 3.2: Comparison of the Value Today of €1,000 Received in the Future Using Exponential (4%) and Hyperbolic (Declining) Discounting



Source: Morgenroth (2011).

The use of declining discount rates is now commonplace in many OECD countries, including the United Kingdom, France, Norway and Denmark, and has strong theoretical and empirical support (OECD, 2018). For example, the UK rate starts at 3.5 per cent for the first 30 years. This rate falls to 3.0 per cent, 2.5 per cent, 2.0 per cent, 1.5 per cent and 1.0 per cent in years 31, 76, 126, 201 and 300 respectively. However, once more the devil is in the detail; what is crucial is how much these rates actually decline. Kula (2008) argued that these declining figures were insufficient to actually affect the results of appraisal to a notable degree, i.e. they didn't decline enough.[9] The literature suggests that there is a consensus for using declining discount rates over time (IPCC, 2014) and Weitzman (2015) clarifies this further arguing that the declining discount-rate argument has become sufficiently mainstream that climate-change discounting is generally viewed as incomplete without it.

Dual discounting: adopting different rates for certain environmental and other projects

A low discount rate supports long-term investment in mitigation of climate change and other environmental protection. However, it may also lead to a higher total level of investment, resulting in more use of materials and energy and hence greater pressure on natural capital (Barbier *et al.*, 1990). This is not necessarily the case in Ireland at present in that the level of public expenditure is subject to limits under the EU fiscal rules. But an option worth exploring is the use of different discount rates for environmental purposes.

Dual discounting is the practice of applying different discount rates to different classes of commodities, commonly consumption and environmental goods (Weikard & Zhu, 2005).[10] For example, the long-term environmental issue of the legacy of nuclear waste, where decommissioning could take 100 years, led to nuclear energy projects receiving a 2 per cent discount rate (Kula, 1996).

Where environmental goods are relatively scarce compared with other consumption goods, and, more importantly, if environmental goods have limited substitutability, (i.e. loss of environmental goals cannot easily be compensated for by more consumption of conventional goods), it is argued that they should command a different and lower discount rate. It has also been argued that rising relative prices for some environmental goods and services could be as effective as reducing the discount rate (Sterner & Persson, 2008).

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[9] The UK rules have been revised since the Kula (2008) analysis. The current rate declines to 3.0 per cent in year 31 and to 2.5 per cent in year 76. It remains at this level to year 125.

[10] An ecological discount rate in which each environmental good would have its own special rate has also been proposed (Maddison & Day, 2015). A challenge with this approach is that the parameter values contained in the formula may be unknown.

The UNDP-UNEP Millennium Ecosystem Assessment has identified 15 of 24 ecosystem services that function as humanity's life-support system and that are now in serious decline (MEA, 2005). Studies such as Steffen *et al*. (2015) have identified four of nine 'planetary boundaries' that have been crossed, thereby placing humanity in a danger zone. Because the ecosystem services are in decline globally and the production of market goods and services is increasing, Baumgartner *et al*. (2015) argue that there should be lower discount rates for ecosystem services. This conclusion is based on empirical analysis of 10 ecosystem services and five countries.

There are very different types of natural capital, some of which cannot be replaced or entail significant risks (EEA, 2015). A burgeoning literature places empirical evidence at odds with the theoretical assumption of 'perfectly substitutable capital', that if natural capital declines it can be replaced with financial or physical capital. Against this backdrop, Kyllonen and Basso (2017) suggest that there is a much greater willingness among economists to use resource-specific discount rates.

After the IPCC Fourth Assessment Report (IPCC, 2007), the *Stern Review on the Economics of Climate Change* (Stern, 2007) spawned important debates in economics in general. The debates centred on the social discount rate that should be applied in evaluating climate-change impacts and mitigation costs. Stern did not use a single discount rate but applied a stochastic approach. The Stern review's average discount rate for climate change damages was approximately 1.4 per cent. The review was supported by a variety of leading economists such as Solow, Mirrlees, Sen, Stiglitz, Sachs, Arrow, DeLong and Deaton, but criticised by others such as Tol, Weitzmann and Nordhaus. Most of the criticism argued that Stern adopted too low a discount rate.

The average discount rate used in the Stern report of 1.4 was calculated on the basis of the Ramsey formula for the SRTP, by combining a long-term per capita growth rate (g) of 1.3 per cent with an elasticity of marginal utility of consumption (e) of 1 and a social time preference (p) of 0.1. It is on the value for p, the rate of pure time preference, that debate centred. Proponents of the alternative view argued that the higher returns evident in financial markets[11] are the basis for applying a higher p value. Stern draws on a long heritage of prominent economists that support zero or near zero as the appropriate rate of time preference.[12] Adopting a rate of discount based on observed market rates of return is also at odds with the conclusions from sustainability science in the context of substitutability, as

[11] See Kyllonen and Basso (2017) for the discussion on why consumption discount rates rather than rates of return from financial markets should be used. The choice of the discount rate is an ethical one and not simply one of *efficiency* as determined by investment returns. Within Ramsey then, p would not simply be *impatience for consumption*, but *concern for future welfare*, e would not only be the *relative effect of a change in consumption on welfare* but also *aversion to intertemporal inequality*.

[12] Kolstad *et al*. (2014) cite a long heritage of thinkers that argue in support of a rate for p of zero or near-zero.

previously discussed. In the *Fifth Assessment Report*, the IPCC conclude that, in the context of climate change, 'a broad consensus is for a zero or near-zero pure rate of time preference for the present' (Kolstad *et al.*, 2014: 229). Establishing *p* is essentially an ethical question informed by analysis, as it implicitly determines the value of future generations, and indeed of the environment, in the context of climate-change damages. However, as IPCC reports are reviewed and accepted by the world's governments in addition to global expert review, this suggests that there may be a strong political and analytical argument for establishing *p* at 0.1 in the case of climate-change damages and GHG emissions.

While the Stern report's approach to discounting involves no pure time discounting, it did include discounting based on the prospect of a higher level of income and consumption in the future. In a long-term context, an overall discount rate of 1.4 per cent still involves substantial discounting of future environmental damage. For example, this discount rate would mean that real environmental damage in 100 years' time would have a net present value of 24 per cent of the future real cost. In addition, per capita consumption growth of 1.4 per cent annually is not necessarily sustainable in the long term. If the global economy were to grow by 1.4 per cent annually for the next 100 years, and global population growth expands as projected by the UN, the global economy at that stage would be around six times larger in real terms than it is today. In contrast to those economists who claimed that the Stern report put too much weight on the future, some ecological economists have criticised it for not paying sufficient attention to the interests of future generations and adequately addressing ethical concerns (see, for example, Splash, 2007).

The OECD (2018) study of CBA and the environment noted that there is re-emerging interest in dual discounting. According to the report, dual discounting is more important than the use of declining discount rates from the perspective of valuing projects with a strong environmental component. However, it considers that it is a challenge to make dual discounting operational and notes that one way of doing this is to estimate shadow values for environmental goods that reflect growing scarcity and limited substitutability.

The impact of using a different discount rate for mitigation projects is significant. Kula and Evans (2011) provided an example in which they operationalised dual discounting. They tested two different analyses which valued avoided carbon emissions (specifically CO_2 absorbed or 'sequestered' by tree growth) in a forestry project in County Tyrone. In the first example, the standard Green Book rate of 3.5 per cent was applied to all costs and benefits, while in the analysis with dual discounting a 1.5 per cent discount rate was applied to the CO_2 benefits and 3.5 per cent to all other costs and benefits. The results show that dual discounting would enhance the economic viability of investment projects that yield environmental benefits. With a single discount rate, over 30 years the project yields a net cost of -£27,323. Where dual discounting is applied the project yields a net benefit of £7,141, turning the project from a net negative investment into a net positive one.

Where dual discounting is not employed, it could be argued that this strengthens the case for using a lower SDR.

3.3.2 Level of the Social Discount Rate Used Internationally

Most European-wide institutions and some European countries apply the SRTP approach to the discount rate, typically lower than the SOC and in low single figures (Spackman, 2017). For regulatory appraisal where the impact is on consumers rather than business investment, the US specifies a rate of 3 per cent based on the real rate of return on long-term government debt (*ibid.*), which is a type of SRTP approach. A survey by Drupp *et al*. (2015) asked experts on discounting for their recommended SDRs for projects with intergenerational implications. The most frequent response was 2 per cent while the average (mean) of the responses was 2.27 per cent. The experts were also asked for their recommendations on the individual variables in the Ramsey equation. An interesting feature of this survey was that the recommended level for the overall SDR was considerably lower than was implied by computing the Ramsey specification of the discount rate using each expert's recommendation on the individual elements of the Ramsey equation. This was for a variety of reasons, including uncertainty about the rate of long-term growth. Another reason concerned the future relative costs and benefits of non-monetary goods such as environmental amenities. This survey illustrates that judgment on the overall level of the discount rate may differ from judgment of the appropriate level of the individual elements of the Ramsey equation.

There is no agreement on the level of the SDR. However, rates in the industrialised countries have been converging to lower levels for decades. Table 3.1, from the OECD (2018), presents rates among several advanced economies in the OECD. A survey of discount rates used in OECD countries reported an average rate of 4.78 for energy and 4.64 per cent for transport (OECD, 2018). Rates are typically lower in high-income European economies.

The UK uses a standard discount rate of 3.5 per cent and this declines for periods beyond 30 years as noted above. The UK also uses dual discounting in the form of a lower discount rate for effects on health (1.5 per cent) and this is applied on a declining basis after 30 years.

Table 3.1: Discounting guidance in several OECD countries

Country	Risk-free discount rate (%)	Rationale	Risk premium (%)	Overall discount rate (%) (short to medium term)	Long-term discount rate
UK	3.5%	Simple Ramsey Rule, SRTP. Growth risk not incorporated, project risk minor	0%, although 3.5% contains 1% for 'catastrophic risk'	For all projects and regulatory analysis: 3.5%	The discount rate declines gradually to 1% after 300 years
United States	For CBA: 3%, with sensitivity up to 7%	3% = consumption rate of interest, risk-free (SRTP). 7% = average corporate returns (SOC)	7% is a risky rate of return, but no project-specific risk premia	Depending on source of funding, projects and regulatory analysis: 3–7%	OMB (2003) recommends lower rate for 'intergenerational' projects, US EPA (2010) recommends 2.5%
United States	For CEA: 2%	SRTP	None	2%	No guidance on long-term CEA
France	2.5%	Quinet (2013), risk-free rate of return.	*β**2% 2% comes from the estimated risk of 'deep recession' (see Barro, 2009)	For risky projects: 2.5%+ *2%	Risk-free rate: declining to 1.5% after 2070. Risk premium: 2% for *β* =1 rising to 3.5% after 75 years
Norway	2%	CAPM approach, risk-free return to government bonds	1%: systematic risk premium of 1%, aggregate β=1, fixed for all projects	Risky projects and regulatory analysis: 3%	Risk-free rate declining to 1% after 100 years
Nether-lands	0%	CAPM, opportunity cost approach	3% systematic risk premium, fixed for all projects	All projects and regulatory analysis: 3%	Accepts declining discount rates, but with real interest rates <0% opted for fixed risk-free rate of 0%, and fixed systematic risk premium

Source: OECD, (2018), Table 8.5.

3.3.3 Choosing the Irish Social Discount Rate[13]

In our view, the current Irish practice of basing the social discount rate on the social rate of time (SRTP) preference, rather than the social opportunity cost (SOC) of capital, is appropriate. The SOC is based on the rate of return on private investment and, for a variety of reasons explained above, this is not a satisfactory way of setting the SDR. The Ramsey equation provides helpful guidance in choosing a range for the SDR. Judgement is involved in selecting values for the individual elements of the Ramsey equation as well as the overall level of the SDR.

The rates for the SDR in Ireland have varied over time as follows:

- from 1984 to 2007: 5 per cent (SOC approach);
- from 2007 to 2015: 4 per cent (SRTP approach); and
- from 2015 to 2018: 5 per cent (SRTP approach).

Because of Ireland's rate of growth in consumption historically, *g* is the most important factor when Ireland's SRTP is computed using the Ramsey equation. Over the long period 1970 to 2016, the annual average growth in real per capita consumption in Ireland was 2.3 per cent. During the most recent decade of that period, 2006 to 2016, consumption growth was slightly negative. Over the period 1970 to 2006, the growth of per capita consumption was higher, at 3 per cent annually. The strong growth of consumption in Ireland experienced in earlier decades reflected the country's catching-up with richer economies. In future decades one would expect somewhat slower growth in per capita consumption. The European Commission's projection of average long-run potential GDP growth per capita for Ireland for the period 2020 to 2040 is 1.6 per cent annually (European Commission, 2018). The economic projections of Bergin *et al*. (2016) are for growth in total consumption of 3.0 per cent annually for 2016-2020 and 2.6 per cent for 2021-2025. Allowing for population growth, this implies a fall in annual per capita growth in consumption to below 2.0 per cent.

Table 3.2 presents a calculation of the Ramsey formula:

$$SRTP = p + g * e$$

where:

p and e in the range of 0.5 to 1.5;

g in the range of 1.0 to 2.3 per cent.

[13] This section draws on the analytical work developed by DPER (O'Callaghan & Prior, 2018).

Table 3.2: Alternative values in the Ramsey SRTP formula for Ireland

p	*e*	*g*	SRTP
0.5	1	2.3	2.8
1	1	2.3	3.3
1.5	1	2.3	3.8
0.5	1.5	2.3	3.95
1	1.5	2.3	4.45
1.5	1.5	2.3	4.95
0.5	1	1.6	2.1
1	1	1.6	2.6
1.5	1	1.6	3.1
0.5	1.5	1.6	2.9
1	1.5	1.6	3.4
1.5	1.5	1.6	3.9
0.5	1	1	1.5
1	1	1	2
1.5	1	1	2.5
0.5	1.5	1	2
1	1.5	1	2.5
1.5	1.5	1	3

The central shaded area of the table highlights the situation where *g* is held at 1.6 (the long-term projection of Ireland's potential per capita growth by the European Commission). While growth for the coming years will probably exceed 1.6 per cent, it has been argued above that one should adopt a long term perspective when doing CBA. Hence, this projection of long term per capita growth is used. In the DPER review of the PSC, the preferred value for the pure rate of time preference (p) is around 1 and the preferred range for the marginal utility of consumption (e) is between 1 and 1.5 (O'Callaghan & Prior, 2018). If the prospective growth rate is set at 1.6 per cent and a value for p of 1.5 is also included, this produces a range for the discount rate of 2.6 to 3.9 per cent. Given the arguments in the literature for lower rates of pure time preference, the lower end of this range would seem appropriate.

Returns on government bonds

Another way of inferring the SRTP is to use the after-tax real rate of return on government bonds. In the US, the Office of Management and Budget (OMB) sets an upper and lower bound for the SDR. The lower bound is set on the basis of the SRTP while the upper bound is based on the SOC approach. In the US the SRTP is set at 3 per cent, based on historical real returns on government bonds. A recent report by the Council of Economic Advisors (2017) in the US argued that, in the light of the long-term decline in government bond yields, this rate should be reduced. While this US analysis projected that there would be some increase in government bond yields, it expected that future rates in real terms would be well below 2 per cent. On the basis of past data, current market- and survey-based forecasts, it concluded that plausible estimates were that the SRPT and the lower bound for the discount rate should be at most 2 per cent. It also suggested that there were reasons to consider revising downwards the upper bound of the US discount rate based on a SOC of 7 per cent.

In the case of Ireland, current yields on long-term government bonds are extremely low, while over the 20-year period 1996 to 2017, the real rate of return on government debt was 2.4 per cent,[14] before taking account of taxation. Real rates on government bonds in Ireland reinforce the case for a lower discount rate.

Dual discount rate for carbon emissions and other environmental effects

As discussed above, a discount rate can be established for GHG emissions, sometimes referred to as carbon emissions. This is also relevant to other environmental impacts where there the environmental asset is critical to well-being. Using the same assumptions for g (1.6) and for e (1) and applying a value for p at 0.1, the resulting discount rate for carbon emissions in Ireland would be 1.7. The latter is in line with recommendations in the Stern report.

There are strong arguments here in favour of no pure time discounting (as discussed above). In a long- term context, it is worth noting that a discount rate of 1.7 per cent (i.e. no pure time discounting) still involves considerable discounting of future environmental damage. With this discount rate, real environmental damage in 100 years' time would have a net present value of around 19 per cent of the future real cost.

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[14] This was calculated as general government interest as a percentage of general government debt over this period and adjusted for inflation.

Table 3.3: Alternative Ramsey values and the discount rate specific to carbon emissions and other critical environmental impacts in Ireland

p	*e*	*g*	SRTP
0.1	1	2.3	2.4
0.1	1.5	2.3	3.55
0.1	1	1.6	1.7
0.1	1.5	1.6	2.5
0.1	1	1	1.1
0.1	1	1	1.1

Conclusion

The discount rate for Ireland should be based on the approach of the social rate of time preference (SRTP). The Ramsey approach applied to Ireland suggests a social discount rate in the range of 2.6 to 3.9 per cent. The European Commission recommends a discount rate of 3 per cent for non-cohesion member states. Discount rates have been falling in advanced European economies. Many are now in the range of 3 to 4 per cent.[15] The SRTP can also be based on the post-tax rate of return on government bonds. Historical rates of return on government bonds would point towards choosing a discount rate at the lower end of the range identified.

A social discount rate for Ireland in the range 2.6 to 3.9 per cent would be appropriate, preferably at the lower end of this range. In addition, a discount rate for carbon emissions and other long-term environmental damage of 1.7 per cent should be applied. We also support the use of declining discount rates so that some weight is placed on very long-term effects where these arise. The rates should be reviewed periodically in light of uncertainties in *g* and judgements on *p* and *e*. The effect of changing the discount rate in this manner would coincide with policy priorities that integrate sustainability into development.

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15 The social discount rates for some European countries are as follows: the UK, 3.5 per cent; the Netherlands, 3 per cent; Denmark, 4 per cent; Sweden, 3.5 per cent; Germany, 3 per cent; France, 4.5 per cent (for risky projects). Rates are typically lower for longer-term periods.

3.4 Taking Account of a Wider Range of Costs and Benefits

Identifying the costs and benefits of a proposed investment is a complex process. The costs include both the cost of the project and any damage associated with it. The benefits can reflect enhancements linked to the project or damage avoided. The characteristics of the project itself, the flows of costs and benefits that it generates, and the characteristics of the receiving context, together determine the impacts of a project. Flows of costs and benefits occur throughout the project's technical lifecycle, but also beyond in the case of GHG emissions and ecosystem impacts.

There is an important distinction between 'financial costs', 'private costs' and 'social costs' (Halsnaes *et al.*, 2007). 'Financial costs, in line with private costs, are derived on the basis of market prices that face individuals' (*ibid.*: 1). Social costs are based on market prices adjusted for opportunity costs and take externalities into account. CBA seeks to measures costs on the basis of social costs including environmental ones.

The focus on environment brings a wider range of costs and benefits into view. These include: noise, air pollution, GHG emissions, soil contamination, water pollution, ecosystem degradation (for example, depleted water resources or loss of species associated with an infrastructure project), landscape deterioration and vibrations (Sartori *et al*., 2014). The use of this list of potential impacts would help ensure that CBA analysis is more robust and to protect against risks. It also helps decision-makers to adopt projects driving the transition to a low-carbon economy and society. While the benefits of mitigation may be global and long-term, co-benefits are relatively certain and short-term, and accrue to the country making the efforts (Hamilton *et al.*, 2017). These co-benefits of mitigation are often neglected in analyses by policy-makers (Sims *et al.*, 2007). The World Bank (2016) estimate for the EU is that, for each tonne of GHG emissions reduced, the accompanying co-benefit of the associated reduction in air pollution is worth an additional $200.

A key challenge for CBA practitioners is to work towards more systematic means of identifying the impacts associated with a given project. EU guidance for CBA appraisal recommends that the appraisal of any given project should include consideration of the project's impact on:

- resource efficiency and climate-change targets for 2020;
- the prevention and remedying of environmental damage;
- protection of the Natura 2000 sites and protection of species covered by the Habitats Directive and the Birds Directive;

- principles including that the polluter should pay, of preventive action and rectifying environmental damage at source; and

- sector-specific Directives (Sartori *et al.*, 2014).

These considerations, along with the potential impact of climate change on the project or projects, require attention early in project design and preparation, during project screening and scoping.

However, it may not be possible to design a CBA process that will capture all costs and benefits. Heinzerling *et al.* (2005) suggested that the Clean Air Act in the US would not have been likely to pass a modern cost-benefit test as knowledge of the benefits to human health of reducing particulate pollution was not available until many years after the Act was considered and implemented.

There are a number of tools that CBA practitioners and those providing central guidance might draw upon to support this complex task, including:

- Strategic environmental assessment[16] and environmental impact assessments[17] are procedures designed to help ensure that the environmental implications of decisions are taken into account before the decisions are made.

- Sector-specific guidance includes the range of costs and benefits for specific sectors such as transport, water and environmental investments (Sartori *et al.*, 2014).

- The Total Economic Value (TEV) approach seeks to represent a comprehensive economic valuation of the marginal change in all environmental effects or the underlying ecosystem services. The use of TEV is recommended in the guidance of the UK Treasury (Dunn, 2012) and by Sartori *et al*. (2014). TEV is favoured as an approach as it is useful as a framework for thinking and to identify environmental effects, although it has been argued that 'total' may be something of a misnomer. The OECD (2018) explains that it is not possible to describe the 'total value' of an ecosystem. Changes in ecosystems are non-linear and can lead to collapse. They are greater than the sum of their parts, as ecosystems are interrelated 'complex adaptive systems' (CAS). This means that the value of any one service is inter-linked with the value of the other services of the ecosystem, and environmental and social capital are not fully substitutable

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[16] Strategic environmental assessment (SEA) is a proactive tool that aims to ensure that environmental, and possibly other sustainability aspects such as economic and social, are considered effectively in plan and programme-making.

[17] Environmental impact assessment (EIA) is a reactive technical instrument to identify and manage significant impacts on the environment from implementing a project that has already been identified.

with other forms of capital (EEA, 2015). It also means that, while some types of capital can be valued for marginal change, this is not possible for ecosystem services that operate through non-marginal changes.

Once the impacts are identified, the CBA process works to monetise the range of costs and benefits to assist decision-makers in deciding which projects are beneficial to welfare. In valuing costs and benefits, it is useful to distinguish four categories: (i) *project costs,* (ii) *damage costs, (iii) benefits as avoided damages* and (iv) *benefits as enhancements.*

Project costs are the resources required to implement the project. *Damage costs* arise where a project leads to a decline in an environmental, social or economic asset, negatively affecting welfare. A *benefit as avoided damages* arises where the project avoids a damage cost that would otherwise occur; for example, a reduction in pollution. A *benefit as enhancement* occurs where the project improves the scale or quality of welfare, including of environmental assets; for example, savings in travel time, increased life expectancy or improvement of landscape.

It is usually more straightforward to estimate project costs than it is to measure and monetise the other categories. Estimating damage costs, and both of the benefit types (avoided damages and enhancements), often requires measuring and then giving a monetary valuation to changes in non-market or public 'goods'. Placing a monetary value on non-market effects such as pollution requires the use of shadow prices. Shadow prices are used to measure real social costs and benefits when these are not priced by the market or where market prices are distorted. For example, the shadow price of labour where there is no unemployment would be the market rate for labour in that area, but if there is high unemployment the shadow price rate would be lower. The unit value of environmental impacts should increase over the life cycle of the project (Sartori *et al.*, 2014). Where monetisation is not possible, environmental impacts should be identified in physical terms for qualitative appraisal alongside the CBA.

A further key consideration is the distribution of benefits and costs across society. It is possible to apply weights to help reflect the ways in which these affect particular groups. In the recent OECD international review, one-third of the countries responded that addressing distributional impacts is compulsory or often done (OECD, 2018). In the UK, the Green Book states that a distributional analysis is necessary where an intervention has a redistributive objective or is likely to have a significant redistributive effect (HM Treasury, 2018).

3.5 Carbon Price

In conducting a CBA for a project, it is necessary to place a value on the carbon emissions[18] that are either generated or saved. This requires the application of a 'price' per tonne of carbon.

3.5.1 Mechanics of Accounting for GHG emissions flows

A number of elements determine the monetary value for carbon emissions. First, the emissions associated with a project are measured or estimated. Three source categories can be identified:

- direct GHG emissions caused by the construction, operation and possible decommissioning of the proposed project, including from land use, land-use change and forestry;

- indirect GHG emissions due to increased demand for energy; and

- indirect GHG emissions caused by any additional supporting activity or infrastructure that is directly linked to the implementation of the proposed project (e.g. transport, waste management).

(Sartori *et al.*, 2014)

The emissions, direct or indirect, that occur during the economic lifetime of the project, such as oil consumption in road transport, have long-term impacts on climate. In addition, the emissions can occur outside of the appraisal time period or be delayed; for example, with a landfill site, emissions continue for many years after the site has been closed.

The second element is to agree the time-frame for the analysis, as noted in Section 3.2. This has technical implications for the measurement of the cost of the externality of GHG emissions in CBA. That section outlined efforts in a number of countries to work with longer time-frames and/or residual values.

Third, the physical flow of GHG emissions is multiplied by standard IPCC 'Global Warming Potential' (GWP) factors for each GHG, where each GHG is expressed as a weighting of carbon emissions by CO_2 equivalents. For example, when looked at over a 20-year period, the estimated GWP for CH_4 is between 84 and 86 while N2O

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[18] For simplicity the discussion in the text refers to carbon emissions, as in carbon dioxide or CO_2, but it is important to recognise that this necessarily includes the main GHGs, known as the 'basket of six': carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6).

is between 264 and 266 (Myhre *et al.*, 2014). The time period considered alters the GWP applicable to different GHGs. Some gases are short-lived while others have effects on warming that last millennia (IPCC, 2013).

The fourth element is to develop a price per unit of CO_2 equivalents (i.e. a carbon price). This section focuses on three approaches used to set the price of carbon.

The final element is the discount rate or rates in the CBA. In the case of climate change where the costs tend to be long-term, a high discount rate (as noted in Section 3.3) will have a very significant impact.

3.5.2 Setting the Carbon Price: Three Approaches

Valuing the price of carbon is complex because of the technical challenges, uncertainty and the ethical issues that arise. This section outlines three approaches reviewed by the OECD in 2015 (Smith & Braathen, 2015).

Social cost of carbon (SCC)

The SCC is an estimate of the money value of damages caused by a one-tonne increase in GHG emissions. It is reported as the present value of future climate-change damages for each additional unit of emissions added to the atmosphere's growing stock of emissions. The reported SCC thus includes the impact of the chosen discount rate. Costs are calculated by:

- applying alternative emissions trajectories associated with global development from the global scenario literature;
- estimating the related physical and economic damages arising from these trajectories using Integrated Assessment Models (IAMs); and
- monetising each of the various damage estimates and aggregating as a single figure in net present value.

There is much variation globally in relation to SCC estimates. Two influential reports provide an illustration:

- $33 in 2010 in 2007$ per metric ton of CO_2 (Interagency Working Group on the Social Cost of Carbon, 2013);
- $220 per ton of CO_2 (Moore & Diaz, 2015).

Ackerman and Stanton (2012) estimated alternative values for the SCC by varying the discount rate, damage function and climate sensitivity. This yielded far higher SCC estimates of up to $893 in 2010. They also illustrate that a SCC of $21 n 2010 would lead the US government to deem all but the weakest emissions restrictions to be too burdensome on the economy.

Target-consistent cost

A target-consistent approach means setting the price of a tonne of CO_2 to be equal to the marginal abatement cost (MAC) of achieving a given target; i.e. the cost of the last tonne of carbon savings necessary to achieve a given emissions reduction target. The target could be a national target or the cost of achieving a national commitment to an international climate-change agreement.

The case for this approach is that, if there is a binding national limit on emissions, then an increase in emissions in one area must be balanced by emission reductions elsewhere. In this context, if an investment project results in higher carbon emissions, then the relevant cost of carbon is the cost of securing an offsetting reduction in emissions elsewhere. Conversely, the value of emissions saved is counted on the basis of the cost savings from the effort elsewhere that would have been required.

If the target reduction in emissions is to be met by reductions within the country, then the relevant marginal abatement cost would reflect the costs of reducing emissions internally. However, if the target can be met through the purchasing of emissions allowances within a credible international trading regime, the cost of purchasing allowances in such a system would need to be taken into account in the marginal abatement cost (Smith & Braathen, 2015).

A number of studies have made estimates of the carbon prices required to achieve global climate targets. The Deep Decarbonisation Pathways Project (DDPP) conducted a review of 2°C compatible pathways to 2050 for the recent international High-Level Commission on Carbon Prices. The study was built on an analysis of national-scale scenarios[19] to 2050 from 16 countries, representing 74 per cent of 2010 global emissions. The estimates of the required price of carbon are from £150 to £250/tCO_2 in 2025, increasing to £270 to £370/tCO_2 in 2045. The required price in 2050 exceeded £1,000, reflecting the difficulty of eliminating residual emissions (DDPP, 2017).

The High Level Commission, chaired by Stiglitz and Stern, reviewed a number of sources to propose a carbon price and recommended *'that the explicit carbon-price level consistent with achieving the Paris temperature target is at least US$40 to $80/t$CO_2$ by 2020 and US$50 to $100/t$CO_2$ by 2030'* (High-Level Commission on Carbon Prices, 2017). The Commission believed that this price range would be able to deliver the temperature objective of the Paris Agreement, 'provided the pricing

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19 Ranging from sophisticated combinations of macroeconomic, technology stock turnover, and land-use models, to simple spreadsheet models.

policy is complemented by targeted actions and a supportive investment climate' (*ibid.*: 50). In the absence of these conditions the required prices would be higher.

There is of course considerable uncertainty in developing a target-consistent cost of carbon. The cost of attaining a given target depends on assumptions about future technological developments such as large-scale carbon capture and storage. However, it has been argued that the uncertainty associated with estimates of the target-consistent cost of carbon is less pronounced than that associated with the social cost of carbon. This is based on the belief that uncertainty about MACs is less than that concerning marginal damage costs (DECC, 2009). A caveat to this argument is that, with the target-consistent approach, the uncertainty regarding the impact of emissions has been partly subsumed into the decision to set a particular target (Smith & Braathen, 2015). In other words, one can be more certain about the cost of achieving a particular target than about the ultimate damage created by carbon emissions. However, the target-consistent price will be also be affected by uncertainty as to whether the target set is appropriate.

The carbon price in the long term

Once the carbon price has been set at an appropriate level, it is generally accepted that it should increase in real terms into the future. It is sometimes recommended that the carbon price increase over time in line with the discount rate (for example, Quinet, 2013). This is derived from the application of Hotelling's rule, which is concerned with the optimum trend in prices that maximises the rents for the owner of a non-renewable natural resource. Others have suggested that the rule wrongly assumes that perfectly competitive markets exist, and they therefore argue that the price of carbon, as well as its trend, should be derived from the long-term strategies and reference scenarios (Meunier & Quinet, 2015).

Market valuation

The third approach to setting the carbon price used in CBA is the market value of emissions allowances in a carbon trading scheme. The traded value of emissions allowances reflects the quantity constraint on emissions that is set by the amount of allowances issued, and its interaction with demand from firms (Smith & Braathen, 2015).

The current ETS price was less than €10 per tonne from late 2011 until early 2018. It increased during 2018 to around €20 at time of writing (October, 2018). Future allowance prices are dependent on policy decisions about the cap, and the related scarcity value of allowances. Forecasting such variables, which depend on policy decisions, is difficult both in principle and in practice (*ibid.*).

The European Commission guidance on CBA rejected the EU ETS price and suggested unit costs of GHG emissions across the EU in 2010 of between €10 and €40 per tonne of CO_2. It also argued that between €0.5 and €2 should be added each year, to align with Hotelling's rule (Sartori *et al.*, 2014). These costs were taken from a 2006 review by the Stockholm Environment Institute, as reported in the European Investment Bank climate strategy (EIB, 2013). The costs were based on research on damage costs and target-consistent costs.

It is argued by Smith and Brathen that a trading price for carbon will not generally reflect the social cost of carbon:

> The only situation in which the carbon allowance price would reflect the social cost of carbon is if the quantity constraint set by the number of allowances issued had happened to coincide with the point where aggregate marginal abatement cost coincided with the social cost of carbon (Smith and Braathen, 2015: 24).

This has not occurred in practise. Indeed the ETS has been an extremely weak instrument in generating a positive price of carbon. Nonetheless Smith and Brathen argue that there are situations in which it might be appropriate to use the carbon price from an emission trading regime in project appraisal. This could arise where the emissions concerned fall within the scope of a trading system. In this context a project will not lead to an overall change in emissions assuming emissions are capped within the emissions trading system. If a particular project results in a saving of emissions this will free up allowances that can be used elsewhere. The value to the country of the emissions saved is the carbon allowance price.

This logic implies that for emissions in Ireland that fall under the EU ETS, for example, electricity consumption in public infrastructure, there is a case for applying the EU ETS price in CBA. However, the price is not appropriate to emissions that fall outside the ETS. This is because the EU-ETS traded price is a financial cost to firms in compliance with the ETS, which does not reflect opportunity costs. One qualification to note in regard to the use of the ETS price for valuing emissions in the ETS sector is that it is both a national and EU strategic objective that electricity be decarbonised as a central element of moving to a low carbon economy and the ETS price does not provide a sufficient incentive for this transition. Given this, it is necessary to use other policy instruments to achieve decarbonisation of electricity.

3.5.3 Conclusion: Carbon Price—Choosing an Approach for Ireland

The third approach to carbon pricing, the ETS price, seems inappropriate to CBA as it does not reflect the opportunity costs associated with mitigation strategies. Historically it has been a low price, less than €10 since 2011, such that very few mitigation projects would pass a cost benefit test and receive funding.

The choice between the remaining two approaches is difficult as both have strengths and weaknesses. The target-consistent approach to assessing the social benefit of climate-change policy measures sits uncomfortably with the approach to evaluating other environmental costs and benefits. This is because the emissions reduction targets may have greater or lesser credibility. The target-consistent cost approach shifts CBA towards cost-effectiveness of achieving a given reduction in emissions, rather than an assessment of overall net social benefits (Smith & Braathen, 2015).

However, the Paris Agreement, supported with almost unanimity by the world's governments, might be seen as establishing symbolic political and ethical approval for pathways and by extension a target-consistent cost approach to setting the price of carbon. To deal with uncertainty, strict design criteria and robust modelling assumptions are needed to underpin the MAC though will not eliminate it. An appropriate range of plausible scenarios, qualitative approaches, probabilistic methods and triangulation of various model results are some of the key analytical techniques that are commonly used in response to uncertainty in mitigation and transition studies. The framing conditions should also reflect the need to limit temperature increase to at least 2^{o} C or lower, preferably 1.5^{o} C.

While these models are being refined and developed, countries are applying higher carbon prices than in the past and certainly much higher than market valuations. The OECD survey of the 23 richer OECD nations and the EU documented the average carbon process for a number of appraisal years in different sectors. The average was $38 in the appraisal year 2014 for energy investments, rising to $153 for 2050 (Smith & Braathen, 2015).

The UK has adopted a target-consistent target price for CBA. The UK carbon price is based initially on the MAC of achieving the UK target for emission reductions domestically in the UK; this was estimated for 2020. In the longer term, the UK approach is based on the assumption that there would eventually be a comprehensive system of international trading of carbon allowances, as there is currently in the EU ETS. This would lead to a global price of carbon. Analysis by the UK Department of Energy and Climate Change (DECC, 2009) estimated the global price of carbon that would be consistent with various goals for stabilising GHG concentrations in the atmosphere. On this basis, carbon prices were recommended for the years 2030 to 2050.[20] From 2030 it was recommended that a single carbon price be adopted (i.e. the same price for emissions covered by the ETS and other emissions) while up to then separate ETS and non-ETS prices were recommended. The current cost is set at a central value of €75/tCO_2e (2017 € values) in the 2018 impact year (for non-ETS emissions), rising to €259/tCO_2e in the impact year of 2050 (DBEIS, 2012). Prices beyond 2050 were estimated using a linear relationship between annual changes in global emissions and the recommended carbon values

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[20] For the years between 2020 and 2030, annual prices are set on the basis of linear increases between the beginning and end year.

over the 2030 to 2050 period (DECC, 2011). The central value for carbon rises to €347 in 2100.[21]

A target-consistent approach for Ireland

If Ireland were to adopt a target-consistent approach to setting carbon prices for CBA, the question arises as to what is the relevant target on which to base it. In the short term, Ireland has an EU target of reducing emissions, in sectors not covered by the ETS, by 20 per cent by 2020 relative to 1990. The MAC of achieving this target has been estimated to be very high. However, it is not expected that Ireland will achieve this target by domestic reductions alone; the gap between the actual and target level of emissions will be covered through the purchase of carbon allowances.

For 2030, Ireland's EU climate target is to secure a 30 per cent reduction in emissions in sectors outside the ETS relative to 2005. As with the 2020 targets, there is provision for the sale and purchase of carbon allowances between member states. In addition there is limited scope to achieve credit towards the target by using ETS allowances that would normally have been auctioned and through changes in land use.

A study by Glynn *et al*. (2018) estimated the marginal abatement cost of reducing Ireland's emissions to follow pathways that would be consistent with the goals of the Paris Agreement. This research identified global carbon budgets in line with the Paris Agreement and calculated corresponding carbon budgets for Ireland based on Ireland's global population share. For scenarios based on limiting warming to two degrees, CO_2 abatement costs were estimated at €75/tonne in 2020, and by 2025 the range is from €96/tonne to €640/tonne. By 2050, the range is €362/tonne to €3308/tonne. For carbon budgets consistent with the 1.5 degree warming, the estimated abatement costs range from €965/tonne to €3080/tonne in 2020, and rise to more than €8,100/tonne by 2050. These estimates reach very high levels. This study takes account of Ireland's high level of emissions in agriculture and it is assumed that there are limited opportunities to achieve reductions in that sector. This, in turn, results in a particularly high cost burden on the energy sector to achieve the target reduction in emissions.

In considering the carbon price for Ireland that would be consistent with support for the Paris Agreement, it is not necessarily the case that Ireland would meet its commitments solely through domestic reductions. If there were a binding global cap on emissions consistent with the Paris Agreement, accompanied by a comprehensive and effective international trading regime, the global price of carbon in such a regime would represent the marginal abatement cost of reducing

[21] The carbon prices in the text have been converted into euro terms using the 2017 exchange rate. The prices in sterling terms are: £66 for 2018, £227 for 2050 and £304 for 2050.

emissions globally. If Ireland could in part achieve its commitments to the Paris Agreement through purchases of allowances, then the global price of carbon would be a suitable target-consistent carbon price for Ireland.

Ireland's current long-term targets on climate change are outlined in the National Mitigation Plan, as follows:

- an aggregate reduction in carbon dioxide (CO_2) emissions of at least 80 per cent (compared to 1990 levels) by 2050 across the electricity generation, built environment and transport sectors, and

- in parallel, an approach to carbon neutrality in the agriculture and land-use sector, including forestry, which does not compromise capacity for sustainable food production (DCCAE, 2017: 13).

This means that it is energy-related emissions that are to be capped, while there is some ambiguity about what is the vision for emissions from agriculture in the long term. A carbon price consistent with these targets could be based on the MAC of reducing energy-related emissions by 80 per cent by 2050, although this leaves unresolved the question of agricultural emissions. There is also a need to review the long-term target of reducing CO_2 emissions by 80 per cent by 2050 in light of the commitment in the Paris Agreement to limit global warming to well below two degrees. The analysis of emissions pathways consistent with the Paris Agreement for Ireland by Glynn *et al*. (2018) above envisaged larger emission reductions than this.

It is proposed that Ireland use a target-consistent approach to setting carbon prices for CBA. For emissions covered by the ETS, it is logical to continue using the ETS price, although there are significant reservations about its adequacy. Further research is required to establish an appropriate target-consistent carbon price for emissions outside the ETS sector. The targets set out in the National Mitigation Plan provide a basis for developing a target-consistent carbon price for Ireland, but there is a case for reviewing the targets to ensure they are adequate in the light of the ambitious goals of the Paris Agreement. Pending the completion of analysis for Ireland, the UK target-consistent carbon prices could be used. On this basis, an appropriate level for the carbon price is €77/tCO2e (2017 € values) in the 2018 impact year, rising to €259/tCO2e in the impact year of 2050, followed by ongoing increases in subsequent decades.

3.6 Dealing with Uncertainty

Cost-benefit analysis, in particular, *ex ante* CBA, must deal with both risks and uncertainty. Risk arises where cost and benefits are not known with certainty but there is a probability distribution. With uncertainty, there is no known probability distribution. The OECD suggests that, for risk, expected value or expected utility approaches can be used, with corresponding assumptions about whether the decision-maker is risk-neutral or risk-adverse. When working with uncertainty, it suggests that, at a minimum, CBA requires a sensitivity analysis, with assumptions regarding likely minima and maxima. Both risk and uncertainty are heightened as time-frames lengthen and when systemic and global changes in the climate and environment are taken into consideration.

In general, CBAs have a poor record in forecasting. Flyvberg's work shows that CBA studies on infrastructure investments tend to underestimate costs (Flyvbjerg, 2009) while Morgenroth identifies clear optimism biases as demand and benefits are often over-stated (Morgenroth, 2011). An *ex post* assessment of 20 roads projects at the Norwegian Public Roads Administration noted that the actual results for net present values in Norway varied by +708 per cent to −169 per cent against the original CBA study conducted *ex ante* (Odeck, 2012). From a separate field outside CBA, it is known that energy and emissions forecasting is frequently inaccurate even on short time-scales (O'Mahony, 2014), particularly through under-estimates of private transport demand and related fuel consumption.

Some have argued that the long-term problem of climate change has been at the vanguard of the evolution of techniques to characterise and respond to uncertainty (Fisher *et al.*, 2007). Different fields employ different methods for a variety of purposes, and it is the objective of any given analysis that should dictate the choice of method (O'Mahony, 2014). Key analytical techniques used are: a range of plausible scenarios, qualitative approaches, transdisciplinary integrated foresight studies, probabilistic methods such as Monte Carlo simulation, and triangulation of various model results. These techniques could have potential not just in mitigation and transition studies, macroeconomic foresight and population scenarios, but, more pertinently, in responding to uncertainty in CBA such as in long-term demand and cost and benefit flows.

4. Implications for Ireland's Approach to Cost-Benefit Analysis

4.1 Introduction

Cost-benefit analysis (CBA) cannot resolve all of the policy, strategy and analytical dimensions of transition. Other tools are required for these purposes, but CBA is a key tool for appraisal of investment. Once the analytical and strategic work is complete, and a project investment has been identified, CBA may be useful for exploring value for money.

However, CBA cannot stand outside of the need to integrate the environmental into the economic (OECD, 2018), or to embed transition and sustainability throughout public policy, including the critical dimension of public investment. The report of the Global Commission on the Economy and Climate (2016) is clear that shifting public investment and addressing price distortions of carbon are key to tackling a number of interrelated goals: reigniting and sustaining growth, transitioning to low-carbon development, delivering on sustainable development and reducing climate risk. Failing to adequately account for the cost of emissions/benefits of avoided emissions will bias public investment away from government policy commitments towards low-carbon transition and sustainability, and towards what has been referred to as 'brown-growth', or carbon-intensive development (World Bank, 2013).

It is clear that delivering on transition requires changes to CBA or *within CBA*, as CBA is central to consideration of public investment and has been a key technique in analysing Irish mitigation policy for a number of years, including the recent National Mitigation Plan (NMP) (DCCAE, 2017). Where CBA is required by the PSC for appraisal of public investment, this appraisal process should be aligned with the transition to a low-carbon economy. This will be enhanced by implementing a series of updates to CBA—what we have termed the *CBA Sustainability Package.*

In parallel, it is evident that there is a need for other analytical and strategic policy approaches to support transition or changes *beyond CBA*, which we discuss in Chapter 5.

4.2 Four Proposed Changes in CBA: A CBA Sustainability Package

The analytical components in CBA—including the time horizon, the social discount rate (SDR), the ranges of costs and benefits, and the monetised valuations such as carbon prices—must be considered as a whole and not in piecemeal fashion. The issues are interlinked and methodological choices in one area necessarily affect the others. The changes within CBA proposed here are thus put forward as a *CBA Sustainability Package*.

4.2.1 The Time Horizon

The current approach to the time horizon with Irish CBA is linked to the economically useful life of the project (DPER, 2012). The Department of Transport, Tourism and Sport recommends that road and rail projects be appraised over a 30-year period (DTTAS, 2016). That guidance also recommends a residual value calculation based on the value at the terminus year. Two methods are outlined for this. First, the residual value may be taken as equal to the original capital cost where maintenance and renewal in the first 30 years are sufficient to ensure the infrastructure will provide an identical level of service in the period beyond the first 30 years. Second, the net present value of the benefits and costs of the infrastructure may be valued over a residual period beyond the first 30 years.

In addition, project appraisal guidelines for national roads are published by Transport Infrastructure Ireland. These propose that the residual period should cover up to a maximum of an additional 30 years in situations where the asset lifespan significantly exceeds 30 years. This implies that costs and benefits are appraised over a total period of up to 60 years (i.e. a 30-year appraisal period plus a 30-year residual period). The guidelines point out that, where a 5 per cent discount rate is used on a project with a 100-year lifespan, 95 per cent of the benefits will be accounted for in the first 60 years. It infers from this that ‘there is little to be gained by accounting for any benefits beyond 60 years from opening’ (TII, 2016: 21). However if a lower discount rate is adopted then adopting a time horizon beyond 60 years will make a difference.

Some other countries have adopted longer time-frames. The approach in France accounts for impacts of projects to 2070, and residual impacts to 2140. In Norway a 40-year appraisal period is used for transport projects, but 75 years for rail, while the net benefits may also be valued for a further residual period (see Section 3.3).

Best practice internationally would seem to be embodied in the French approach—to support demand-forecasting and accounting for all costs and benefits up to 2070, and long-term residuals including GHG emissions out to 2140—and in the Dutch approach, using scenarios and sensitivity analysis to address uncertainty.

A pragmatic approach that balances the need to capture long-term impacts with the challenge of managing the uncertainty of long-term estimates may be to adopt a time horizon of up to 60 years for infrastructure projects. Current Irish guidance allows for time periods of up to 60 years (comprising a 30-year appraisal period and a 30-year residual period) and this has applied to some major projects, such as the CBA of the Dublin metro. This should be supported by guidance on the carbon price beyond 2050. There are other situations relating to mitigation of climate change and protection of biodiversity where the relevant time period is much longer, with consequence for future generations. Investment planning needs to support the transition to a low-carbon economy that is sustainable in the long term. In some cases this will involve adopting a very long-term, multi-generational time horizon in CBA.

The incorporation of longer time-frames, as well as wider costs and benefits, makes CBA more complex. Consequently there may be a need to consider further training, supports and resourcing for practitioners, if deemed necessary.

4.2.2 The Social Discount Rate

Discounting is often identified as *the* issue in CBA when it comes to environment and climate change.

The rates for the social discount rate (SDR) in Ireland have varied from 5 per cent at 1984 to 2007 (social opportunity cost approach), 4 per cent from 2007 to 2015 (social rate of time preference approach) and 5 per cent from 2015 to 2018 (social rate of time preference).

This paper suggests that the SDR should be set in the range 2.6 to 3.9 and preferably at the lower end of that range, given the low rates of real returns on government bonds. In addition, dual discounting is proposed for GHG emissions and other enduring environmental damage, which in Ireland would be set at 1.7. This is based on a pure rate of time preference close to zero (0.1), which is line with the Stern Review and widely seen as the appropriate level to support transition. If dual discounting is not adopted, this reinforces the case for a general discount rate at the lower end of the proposed range. In addition, the use of declining discount rates is recommended so that some weight is placed on very long-term effects where these arise.

4.2.3 Costs and Benefits

Deciding the scope of cost and benefits included in CBA is subject to an analyst's judgement and deliberation among relevant actors. The identification and characterisation of the costs and benefits to be included, beyond the core technical parameters, could be enhanced by central guidance.

This National Mitigation Plan (NMP) reports the net present value of some of the measures in the NMP based on a CBA for the periods 2017 to 2020 and 2017 to 2030 (DCCAE, 2017). The analysis includes ‘direct spending’ and ‘taxes foregone’, and separately presents ‘exchequer receipts’. It is not clear what further costs and benefits are included.

At a minimum there should be greater consideration of ‘co-benefits’ in emissions mitigation and transition projects, including fuel savings and air pollution reduction, in addition to the cost of GHG emissions. The co-benefits of reducing GHG emissions can include prominent benefits for welfare through reductions in health impacts attributable to lower fossil-fuel combustion, the financial value of fuel savings and the enhanced environmental protection and nature conservation from some types of native afforestation. This is not an issue of double-counting because it involves accounting for other dimensions of costs and benefits outside of the cost of carbon, which are not fully internalised in the cost of carbon emissions alone.

It would also be useful to consider how the Total Economic Value (TEV) approach could be applied to Irish central CBA guidance. The experiences of using this in the UK should be actively reviewed.

As noted above, work to include a wider range of costs and benefits will likely mean that, to carry out effective CBA, more resources are required both centrally and in departments and agencies.

4.2.4 The Carbon Price

Efforts have been made in Ireland to include a shadow price of carbon in CBA since 2007, despite the difficulties experienced since the beginning of the recession in 2008. However, current shifts in the political priority on climate change offers an opportunity to bring CBA in Ireland into line with international practices, as part of the evolution of the institutional frameworks that is necessary for long-term low-carbon and sustainable transition.

Continuing with an EU ETS market price does not reflect an appropriate range of costs other than for emissions regulated by the ETS. It is probably at least an order of magnitude below an appropriate externality cost in the crucial near-term years of analysis when the undiscounted values arise. The report of the International High-Level Commission on Carbon Prices strongly recommended that, to make long-term decarbonisation happen, a rapid increase in the signal of the shadow cost of carbon to emitting firms and households is needed in the short term (High-Level Commission on Carbon Prices, 2017).

It is likely that, if such a framework (much higher carbon prices) were applied to Irish project and policy appraisal, a higher benefit to cost ratio would be generated on most mitigation projects that save emissions, in addition to greater costs estimated for emissions-producing projects. Such a move would be in line with the requirements of low-carbon transition commitments in both national and international policy and legislation. It would favour the alignment of current and capital expenditure with the requirements of transition rather than the status quo.

It is necessary for CBA guidance in Ireland to move from setting the price of carbon according to the EU ETS price approach, to a target-consistent approach. In addition, there is a need to provide guidance on the carbon price for a longer time horizon beyond 2050 (the final year covered by the current guidance). Pending the completion of such analysis for Ireland, the UK target-consistent carbon prices could be used. On this basis, an appropriate level for the carbon price is €77/tCO2e (2017 € values) in the 2018 impact year, rising to €259/tCO2e in the impact year of 2050, followed by ongoing increases in subsequent decades.

5. Placing Cost Benefit Analysis in a Wider Context

5.1 A Realistic View of Analytical Techniques

This paper has argued that the implementation of a *CBA Sustainability Package* would align the appraisal process for public investment with strategies and policies for climate transition. However, international practice and academic research suggests that improving policy formulation and decision-making with for the climate transition will require further change in appraisal tools, techniques and methodologies. This chapter focuses on the way in which key characteristics of climate transition—systemacity, transformative change, wider economic, social and environmental impacts and the need for a longer time horizon—challenge conventional approaches to CBA and reinforce the need to explore other analytical and policy making approaches.

The Government has recently launched an ambitious and overarching policy initiative, Project 2040, incorporating both the new National Planning Framework (NPF) and National Development Plan (NDP) 2018-2027. Project Ireland 2040 seeks to achieve 10 strategic outcomes, reflecting the overarching themes of well-being, equality and opportunity and representing the 10 priorities of the NPF. The NDP sets out the investment priorities that will underpin the implementation of the NPF and contribute to the achievement of the 10 strategic outcomes. In this context, it is important to ask what type of analytical tools and approaches, including CBA, will be required to achieve these outcomes, particularly in terms of generating appropriate and ambitious policy options, project selection and prioritisation, and effective policy implementation.

Roelich (2015) argues that traditional CBA is limited by its failure to capture the value of investment in infrastructure resilience, and highlights the need to adopt methodologies that can quantify and/or monetise environmental and social outcomes. This suggests the need to identify a wider range of impacts associated with a project, even though it is accepted that it may not be possible to identity and/or monetise all potential costs and benefits.

In Section 4.2.3 it was suggested that it would be useful to consider how Total Economic Value (TEV) could be applied to Irish central CBA guidance and that the experiences of using this in the UK should be actively reviewed. The TEV approach seeks to represent a comprehensive economic valuation of marginal change in all environmental effects or the underlying ecosystem services. Although this approach is a useful framework for identifying environmental effects, it is limited in terms of its capacity to identify and estimate ecosystem impacts (costs and benefits) that are non-monetary, non-marginal and dynamic in character.

The OECD (2017) suggests that the overall value for money of an infrastructure investment should be carefully assessed using a combination of quantitative tools (such as CBA) and qualitative approaches that seek to establish the overall societal return on investment. It is recognised that this process is necessarily based on assumptions that are open to discussion; but, as long as these are transparently treated, the process is valuable (*ibid.*).

The European Bank for Reconstruction and Development, for example, has used a combination of conventional CBA and qualitative investigation to assess the impact of transition projects in Central and Eastern Europe. Similarly, the empirical analysis of the regional impact of major transport investments can be deepened by the use of case studies and greater engagement with key actors—businesses, government actors, academic institutes—whose strategies and future actions will be pivotal in harnessing the full potential of a particular investment (NESC Secretariat, 2017).

Continuing to develop a broader range of sophisticated tools and methodologies to support the evaluation and appraisal of environmental projects and policies is a worthwhile and necessary policy endeavour.

5.2 The Distinctive Character of the Climate Transition

5.2.1 Systemic versus Marginal Change

It is widely recognised that addressing climate change requires a transition to a new low-carbon economic and social system. The systemic nature of the transition has significant implications for policy analysis. Likewise, it has been argued that the systemic nature of infrastructure makes conventional CBA, which underpins project appraisal in the UK, a fundamentally weak tool for deciding how much (and arguably what kind of) infrastructure should be provided by the state (Helm, 2013). Helm put this point well:

> Infrastructure typically comes in systems, not discrete bits. Choosing what sort and level of infrastructure to supply is not a marginal decision. It is often about one system or another. Marginal analysis—as the core of cost-benefit analysis—has little to offer (*ibid.*: 290).

He proposes that individual infrastructure projects should be evaluated in terms of how their relative costs and benefits fit into, and support, broader strategic goals, rather than being evaluated as stand-alone projects.

This suggests that the approach to evaluation of key climate-related projects—investing in renewable energy or major public transport schemes, for example—needs to consider how relative costs and benefits promote the overarching goal of systemic climate transition. To put it another way, we need to move from considering ‘whether a particular individual project is cost-effective’, in itself, towards exploring whether or not a project represents a cost-effective and efficient way of supporting our goal of transitioning to a low-carbon economy and society. Consequently, it is necessary to take account of the deepening interdependencies between sectors. The type and scale of the costs and benefits associated with systemic change are non-marginal, transformative and dynamic in character, which limits the appropriateness of standard CBA.

In Chapter 4, drawing on international research and practice, we suggest that applying a longer time frame than is currently used in Ireland would contribute to guiding appraisal, investment and policy towards the long-term thinking that is required for the low-carbon transition and sustainability. However, adopting a longer time horizon not only makes CBA more complex, but also increases the degree of uncertainty since it is much more difficult to predict long-term demand, technologies, costs and benefits.

A similar outcome is associated with the necessary but complex task of incorporating a much more extensive range of economic, social and environmental impacts into the appraisal of investment projects. As the range of possible such effects taken into account widens, the relevant data and cause-effect relationships become more uncertain and are subject to divergent understandings.

5.2.2 Uncertainty, Complexity and Ambiguity

Taken together, these characteristics of climate transition—systemacity, transformative change, a long time horizon, and a wide range of costs and benefits—greatly increase the degree of uncertainty and complexity. This has profound implications for policy analysis and evaluation.

Increased complexity and uncertainty ensure that environmental policy goals are characterised by greater ambiguity. Consequently, the goals, evidence and cause-effect relationships relevant to climate-change policy are the subject of conflicting meanings, contestation and diverse, but equally plausible, interpretations. These issues have already been explored, to some degree, in international thinking about infrastructure and the kinds of policy analysis that is required. While good information is still seen as key to good decision-making, it is recognised that it is generally contested or negotiated knowledge (de Bruijn & Leijten, 2008). In like manner, uncertainly and contestation about policy and technology is endemic in the area of climate transition and serves to undermine both predictive policy analysis and the search for an 'optimum policy' (NESC Secretariat, 2012; O'Donnell, 2012).

As complexity, uncertainty and ambiguity increase, it becomes less feasible to formulate expert advice in isolation from stakeholders, practitioners and political actors. The international research on the relationship between knowledge and expertise, on the one hand, and policy, on the other, shows that effective expert analytical work requires a careful combination of 'boundary work' and 'coordination', suited to the nature of the policy area being addressed (Bijker *et al.*, 2009). This includes identifying areas of analysis that can, to a degree, be effectively undertaken by those with technical expertise, and areas where involvement of various sets of stakeholders is necessary, as well as careful coordination between the two.

Engagement of stakeholders brings a wider range of evidence, knowledge and practice in to the formulation of policy and implementation. It also provides an opportunity to harness frontline innovation and experimentation. The International Transport Forum (ITF) of the OECD indicates that increased stakeholder engagement from the start of major transport projects provides insights and perspective that might otherwise be missed and also acts as a mechanism for tackling uncertainties and interdependencies (ITF, 2017).

Research on the governance of infrastructure policy suggests that the more actors are involved and the more contested is the evidence base, the more difficult and unrealistic it is to rely on rational strategies of decision-making (Hammerschmid and Wegrich, 2016). Consequently, contrary to a view often heard they argue that it is not possible or feasible to depoliticise policy-making in this key area:

> Complexity is inherent to infrastructure governance and will not cease with the application of more advanced tools of economic analysis or more rational planning cycles. Decision under conditions of complexity and uncertainty require political choices (*ibid.*: 36).

Consequently, the role of enhanced analysis and expert advice is not to depoliticise decision-making but rather to contribute to better policy formulation and implementation.

Drawing on extensive experience as both a researcher and practitioner in infrastructure evaluation, Rosewell (2010) demonstrates that the UK's overreliance on narrow technical analysis interacted with the political and planning system to limit effective decision making on major projects. She notes that the attempt to make objective technical economic analysis the key determinant of decisions on major infrastructure projects had the paradoxical effect of making decisions more political. She notes that 'Between political negotiation and technocratic decision making there is a big gap' (Rosewell, 2010: 51). She suggests that 'If models were only seen as exploratory and partial, it would be easier to use them as tools to play with rather than tools for answers and this would give much more potential for the processes to create consensus rather than creating divisions which can only be resolved by direct intervention' (*ibid.: 51)*.

Similarly, in the international literature on the relationship between expert advice, knowledge and policy-making, it is recognised that denying the contested character of information tends to turn decision-making into a straight political fight in which the role of information is devalued rather than strengthened (de Bruijn & Leijten, 2008). These are important insights to consider in thinking about how we both improve the analytical work that can support the climate transition and at the same time strengthen the broader decision-making process for climate-change policy.

5.2.3 Evaluating, But also Generating Options to Address Climate Change

Increasing the pace and scale of climate transition will require a step-change in both the level of strategic ambition and the degree of policy innovation and experimentation. Despite its value in certain contexts, CBA is confined to assessing a given set of policy options. It is not an agenda-setting and option-generating device (O'Donnell, 2012; Richardson, 2000). But to address climate change, it seems necessary to animate networks of actors—public agencies, civil society organisations, firms and academic experts—with the capacity and expertise to engage in problem-solving deliberation and policy experimentation (NESC Secretariat, 2012).

It is accepted that achieving the ambitious goals of climate transition requires not only strong political commitment but also societal buy-in. This highlights that fostering more effective approaches to climate transition policy requires greater focus on how the relations between the analytical/technical, political and societal spheres are structured, institutionalised and conducted in Ireland and how they might be reconfigured and enhanced (NESC Secretariat, 2012; NESC, 2014).

Appendix 1: International Examples

This appendix describes developments in the approach to cost-benefit analysis used in France and the Netherlands. This paper has drawn on each of these in the discussion of the key areas of change.

France

The practice of CBA in general in France has been comprehensively upgraded in the context of the framing requirements of environmental factors, including ecological transition and climate change and greenhouse gas emissions. The recent guidance update (Quinet, 2013) was chaired by Emile Quinet, one of the authors of an influential paper on transport CBA (Meunier & Quinet, 2015).

Meunier and Quinet noted that the new guidance extended the time horizon from 50 to 140 years, and required that the value of the carbon price increase at a rate equal to the discount rate, following Hotelling's rule. Table A1 details these changes. These are significant changes to the practice of CBA, reflecting the need for orthodox economics to be radically updated to deal with 21st century challenges, as has been noted by the IPCC (Kolstad *et al.*, 2014). Meunier and Quinet noted that the value of carbon emissions had not changed by much, increasing by about a third in 20 years. However, with the modification to the time horizon and the discount rate now used in French CBA guidance, the net present value of carbon emissions increased by a factor of 20 between 1995 and 2014 (Meunier & Quinet, 2015).

Table A1: Net Present Value per tonne CO2 saved in different time horizons based on French CBA guidance

		1995 procedure	2004 procedure	2014 procedure (Quinet E. Report)
CO2 unit values by time period		74 €2000/ton	100€2000 /ton, +3%/year from 2010 on	100€2000/ton +5,8%/year from 2010 to 2030, Hotelling-like from 2013 on
NPV of 1 ton carbon/each year	50 year time horizon	910 €	3 900 €	6 100 €
	140 year time horizon	920 €	9 800 €	17 600 €

Source: Meunier and Quinet (2015).

The Netherlands

The Dutch CBA guidance (CPB/PBL, 2013) distinguishes three types of uncertainty: (i) knowledge uncertainty, (ii) policy uncertainty and (iii) uncertainty about future developments. Knowledge uncertainty refers to limitations on knowledge about how people respond to various policy interventions and uncertainties in valuation. This uncertainty can be described using sensitivity analysis; i.e. checking how the results vary when changes are made in key parameters; for example, the responsiveness of investment in renewable energy to the provision of an incentive. Policy uncertainty here refers to uncertainty in other policy measures outside the project in question. For example, investment in a transport project will be affected by future policy decisions on road pricing. Consideration of different policy scenarios is recommended for this type of uncertainty. Scenarios of possible future trends (such as different possible rates of economic growth) are recommended for dealing with the third type of uncertainty. The addition of a risk premium to the discount rate is also recommended to take account of macroeconomic uncertainty.

This guidance also points to the scope for mitigating the influence of uncertainty and risk by including flexible policy alternatives; for example, estimating the advantages of postponing the measure, considering the consequences of a phased introduction of the measure, or adapting the measure to different future circumstances.

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