OECD Public Governance Working Papers

Integrating climate change in infrastructure project appraisal

A proposed methodology for Ireland

Funded by the European Union

OECD
BETTER POLICIES FOR BETTER LIVES

This document was produced with the financial assistance of the European Union. The views expressed herein can in no way be taken to reflect the official opinion of the European Union

Authorised for publication by Elsa Pilichowski, Director, Public Governance Directorate.

Photo credits: Cover picture © luciann.photography/Shutterstock.com

Integrating climate change in infrastructure project appraisal: A proposed methodology for Ireland

By Marco Percoco, Professor at Bocconi University and external consultant to the OECD,
and Ana Maria Ruiz Rivadeneira, Margaux Lelong and Ludovica Mager,
OECD Public Governance Directorate

Infrastructure plays a pivotal role in achieving climate neutrality and resilience. However, infrastructure is also vulnerable to certain risks, and poor management of infrastructure assets can lead to increased dependency on fossil fuels and lock in climate-related risks. For this reason, an infrastructure governance framework is needed that can direct public investments towards sustainability objectives.

To this end, the OECD has provided technical support to the Government of Ireland to strengthen climate-related and environmental considerations in public infrastructure decision making (i.e. strategic planning, project appraisal, budgeting). Building on the Irish Public Spending Code and on standardised criteria based on international good practices, this working paper develops a new methodological approach to assessing the climate-related impacts of infrastructure and integrate climate-related risk and uncertainty in the appraisal of infrastructure projects.

Keywords: Public investment, environment, climate, adaptation, mitigation, infrastructure.
JEL Codes: H54, O18, O44, Q56.

Acknowledgements

This paper was written by Marco Percoco, professor at Bocconi University, Ana Maria Ruiz Rivadeneira, policy analyst at the Infrastructure and Public Procurement Division (IPP), Margaux Lelong, policy analyst at the Public Management and Budgeting Division (PMB), Ludovica Mager, consultant at the IPP Division, and Raffaele Della Croce, Senior Policy Analyst at the IPP Division. Comments and inputs were provided by Norihiko Yamano, economist at the OECD Directorate for Science, Technology and Innovation (STI), Lazaros Dimitriadis, policy officer from DG Reform at the European Commission, and by public officials from the Irish Department of Public Expenditure, NDP Delivery and Reform, the Department of Transport, and the Flood Risk Management Unit within the Office of Public Works. Most notably, Cillian Moran, Ken Cleary, Frank Newman, Laura Kevany, Kevin Meaney, James Reddy, James Connolly, Patrick Moran, Brian Hogan, Kyle Moore, Kevin Threadgold, and Mark Adamson.

This paper is part of a broader project aimed at strengthening the Irish government's capacity to take into consideration environmental aspects in the public investment decision-making to facilitate a socially inclusive, green, and digital transition. The action was funded by the European Union via the Technical Support Instrument, and implemented by the OECD, in co-operation with the Directorate-General for Structural Reform Support of the European Commission.

Table of contents

Acknowledgements 4

Executive summary 7

1 A methodological approach to assessing the climate-related impact of infrastructure investments 9

1.1. Methodologies for assessing the environmental and climate impact of infrastructure projects: Analysing costs and benefits of different methodological options 9
1.2. Proposed appraisal criteria and guidance for prioritisation 10
1.3. Phase 1: The carbon footprint of the construction phase 11
1.4. Phase 2: Carbon footprint of the operation phase 18
1.5. General evaluation: Cost-benefit analysis 20

2 A methodological approach to consider and value climate uncertainty and risks into planning and maintenance of infrastructure 22

2.1. Methodologies for assessing climate risk and to appraise the adequacy of proposed investments in terms of climate resilience: Analysing costs and benefits of different methodological options 22
2.2. Proposed appraisal criteria and guidance for prioritisation 24

3 Integration of the methodology in the Irish project appraisal framework 30

3.1. Integration of appraisal criteria in the project cycle 30
3.2. Appraisal 33
3.3. Prioritisation 35

Annex A. Carbon footprint methodologies 37

References 40

FIGURES

Figure 1.1. Simplified Project Cycle 11
Figure 1.2. How to calculate emissions using the I-O model 12
Figure 2.1. Illustration of the concept of risk as an integration of danger, exposure, and vulnerability 25
Figure 2.2. Examples of adaptation measures for energy infrastructure 28

TABLES

Table 1.1. Sectors in the Irish Input-Output Table 13
Table 1.2. Carbon emissions by sectors in Ireland 15
Table 1.3. Shadow price of carbon 2019-2050 (per tonne of CO2e) for the Non-ETS and ETS sectors 16
Table 1.4. I-O multipliers and emission factors (estimated) 17
Table 1.5. Selected parameters of carbon cost from transport 19
Table 1.6. Benefits and Costs 20
Table 1.7. Parameters for the cost-benefit analysis 20
Table 2.1. Vulnerability analysis 26
Table 2.2. Risk assessment 27
Table 3.1. Planning, appraisal and budgeting of infrastructure projects in Ireland 31
Table 3.2. Climate proofing and project cycle in Ireland 32
Table 3.3. Example of items scores for prioritisation 35
Table 3.4. Scoring structure 36

BOX

Box 1.1. An example of monetisation of CO2 emissions in the construction phase 17

Executive summary

Improving the environmental performance of infrastructure assets and services is key to achieve climate neutrality and resilience objectives. Infrastructure assets and services do not only contribute to greenhouse gas emissions, but they are also susceptible to changing climate conditions and extreme weather events. Poor planning and management can further increase vulnerability to climate risks and dependency on fossil fuels. For this reason, environmental costs and benefits need to be adequately assessed for new and existing infrastructure assets.

Strengthening existing tools and procedures for project appraisal to integrate environmental considerations is a major precondition to improve the environmental performance of infrastructure assets. In particular, developing standardised methodologies to include climate change mitigation and adaptation considerations during project appraisal could better inform the decision-making process.

The OECD has provided technical support to the Irish Government to strengthen climate-related and environmental considerations in public infrastructure decision making (i.e. strategic planning, project appraisal, budgeting). The action was funded by the European Union via the Technical Support Instrument, and implemented by the OECD, in co-operation with the Directorate-General for Structural Reform Support of the European Commission. The initiative produced two papers that propose a series of recommendations and new methodological approaches to integrate considerations relevant for carbon mitigation and climate adaptation in the appraisal process set out in the Irish Public Spending Code (PSC)[1].

Building on the Irish framework and on standardised criteria based on international good practices (see the policy paper "Strengthening environmental considerations in public investment in Ireland: Assessment and recommendations"), this working paper develops a methodological approach to assessing the climate-related impacts of infrastructure and integrating climate-related risk and uncertainty in the appraisal of infrastructure projects.

A new methodological approach for assessing the environmental impact of infrastructure investments

While environmental and climate-related considerations are explicitly considered in the Irish appraisal framework, the type and quantity of information varies and needs to be given a more relevant role in the decision-making process. To address some of the challenges previously highlighted, the working paper proposes a new methodological approach for assessing a project's contribution to climate change mitigation and adaptation.

[1] In March 2023, the Minister for Public Expenditure, NDP Delivery and Reform announced a package of reforms aimed at enhancing project delivery for the National Development Plan. Under these reforms, the Public Spending Code, which sets the appraisal guidelines for Exchequer funded capital projects will be removed and replaced by a set of Infrastructure Guidelines, to be published in 2023.

Carbon mitigation

This paper presents a framework based on the integration of cost-benefit analysis (CBA) and multi-criteria analysis (MCA) to evaluate and prioritize investments on the basis of their outputs, costs, and contribution to the mitigation strategy of Ireland. The methodology follows a simplified project cycle covering the planning, construction and operation phases and consists of two main steps:

1. Extending the assessment of greenhouse gas (GHG) emissions to include direct, indirect, and induced emissions from capital and operating expenditure;
2. Embedding the information on total emissions in the framework of CBA (or other evaluation tools).

The evaluation of the carbon footprint is conducted in two phases: the carbon footprint of the construction phase and the carbon footprint of the operating phase. The marginal impact of the project in terms of carbon emissions is calculated as the difference between a project's absolute emissions and baseline emissions (defined as the emissions generated by the system in the status quo situation).

The proposed methodology uses an input-output framework for assessing the impact of capital and operating expenditures for large-scale and complex projects. The input-output model is driven by demand; that is, consumption generates production through a set of intersectoral multipliers corresponding to the sectoral allocation of intermediate inputs. Once the change in production is estimated, it is possible to calculate emissions by using sectoral emission factors. After the total emissions produced by the project have been calculated, they can be evaluated in monetary terms by using the set costs of carbon. For small-scale and simple projects, a direct estimation of emissions by sponsoring authorities could be envisioned.

Climate adaptation

The proposed methodological approach to assessing the resilience of infrastructure investments to climate change takes into account vulnerability analysis, impact analysis, and adaptation strategies.

The aim of the vulnerability analysis is to identify the most relevant climate and environmental hazards in terms of potential impacts on the investment. To this end, the analyst is required to assess:

- The sensitivity of the project (in terms of on-site assets, inputs, outputs, access and transport links) to specific climate hazards;
- The exposure of the investment project to such events.

The aim of the impact analysis phase is to assess the potential damages generated by given hazards (the ones that have been ranked at high-medium vulnerability during the vulnerability analysis) and consists of two different moments:

1) An assessment of the likelihood of an event to occur;
2) An assessment of the impact of the extreme event in terms of asset damages, safety and health, environment, cultural heritage, social, financial, reputation.

A risk assessment matrix will allow projects to be classified as low, medium, high, or extreme. For projects ranked from “medium” to “extreme”, strategies and measures for adaptation should be identified.

1 A methodological approach to assessing the climate-related impact of infrastructure investments

1.1. Methodologies for assessing the environmental and climate impact of infrastructure projects: Analysing costs and benefits of different methodological options

Infrastructure investments generate impacts over a considerable time horizon. One of the main challenges of economic policy – especially for public investments in infrastructure - is the foresight of future scenarios. For many decades, at least since the New Deal in the United States, a major concern has been the ability to forecast demand, i.e. the estimation of the number of future users and the assessment of the potential to cover (explicit and/or implicit) costs with the benefits generated. More recently, policy making has become more sensitive to the long run outcomes of human behaviours and economic activities, so that the appraisal of specific measures now faces the challenge of integrating the interaction of a specific project with these long run objectives, including climate change and the environmental issues.

The evaluation of a single project with respect to the development trajectory or to the national climate adaptation strategy has not been addressed explicitly in the literature. In the policy paper "Strengthening environmental considerations in public investment management in Ireland: assessment and recommendations", the OECD Secretariat provides a discussion of the main evaluation tools in Ireland and an overview of current practices in a selection of OECD countries. As for the methodological approach to project appraisal, Ireland sticks to standard practices, namely **cost-benefit analysis (CBA), cost-effectiveness analysis (CEA), and multi-criteria analysis (MCA)**.

The contribution of a single investment project to environmental outcomes and greenhouse gas emissions can be assessed through either CBA, CEA or MCA, with some differences in the outputs depending on the method of analysis.

CBA assumes an explicit functional form of the social welfare function for the evaluation of an investment. The result provides an evaluation of the impact of the project on social welfare. This is complex in practice, as it requires strong assumptions for the validity of the shadow prices used to monetise benefits and costs, including greenhouse gas (GHG) emissions or the impacts on the environment in general. Despite the limitation concerning the assumptions on the social welfare function, the CBA has the advantage of producing a clear indication regarding the contribution of an action (or a project) to social welfare. Furthermore, climate and environmental impacts form part of the analysis, as factors in the social welfare function. Their relative weight is defined by the respective shadow prices and magnitude of the impacts.

CEA provides information in the form of outcome-to-cost ratios of a given project. This methodology is more flexible, as it does not require assumptions about the social welfare function or prices. However, if alternative projects have several outcomes, comparing the optimal project from a social perspective is difficult using CEA, especially in the case of climate and environmental impacts, when several types of pollutants and impacts are considered. For this reason, the prioritization of projects may be more difficult.

Finally, the MCA ranks projects on the basis of their outcomes without assigning shadow prices, but weights that reflect the importance of the outcome considered. This information is processed by means of mathematical algorithms that generate the ranking of alternatives. The procedure is extremely flexible, as it does not require the set of assumptions needed by CBA to monetise impacts and condense information into one single indicator, namely the change in social welfare. More importantly, it allows for the explicit consideration of wider economic effects, usually not accounted for in standard CBA (e.g. fiscal or demographic impacts), as well as standard climate and environmental impacts. In contrast to CEA, the MCA generates a clear ranking of investment alternatives. However, the flexibility of MCA in terms of assumptions may also be a disadvantage, as the methodology, contrary to CBA, does not have a direct interpretation in terms of welfare economics.

Ireland has a well-structured planning and appraisal framework[2]. Environmental and climate considerations are explicitly taken into account, although the type of information used varies and needs to be made more evident in the decision-making process. The integration of environmental and economic considerations should not be limited to the appraisal process, but they should rather be given a more prominent role in the planning phase[3]. This will help fully exploit eventual spillovers among projects and optimize infrastructure design.

To this end, this chapter presents a framework based on the integration between CBA and MCA in order to evaluate and prioritize investments on the basis of their outputs, costs, and contribution to the mitigation strategy of Ireland.

1.2. Proposed appraisal criteria and guidance for prioritisation

Climate change and its impacts are a key issue of the 21st century, and infrastructure is both a contributor to global warming and a victim of climate change. There are different external costs associated with global warming, such as sea level rise, higher health costs, damage to buildings and materials, biodiversity loss, water management issues, more and more frequent weather extreme events and crop failures. Climate change costs are complex to estimate due to their long-term life span and their global coverage.

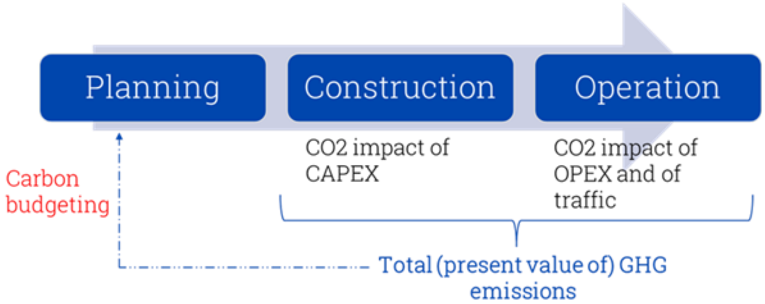
The aim of this document is to present **a methodology for the evaluation of carbon emissions of a given project and its interactions with the environment.** To this end, we follow a **simplified project cycle** covering the planning, construction, and operation phase.

The assessment of the carbon neutrality of the project (in terms of GHG emissions) will be conducted with respect to the construction and the operation phases, and the information produced could then be used in the planning phase, through carbon budgeting (see Figure 1.1).

[2] For a more detailed analysis see section 1 and 2 in "Strengthening environmental considerations in public investment management in Ireland: assessment and recommendations".

[3] In this paper, we refer to the "planning of specific infrastructure projects" and not to the definition of long-term strategies.

Figure 1.1. Simplified Project Cycle



The proposed approach is coherent with the "Technical guidance on the climate proofing of infrastructure in the period 2021-2027" of the European Commission (2021[1]), as we propose a methodology that consists in a first, quantitative, evaluation phase of the carbon footprint of the project and in a second, more qualitative, related to the resilience of the infrastructure itself, and largely relies on the procedures already used by the Irish Government. Furthermore, in chapter 3, an integration between the project cycle, as defined in the Public Spending Code, and the activities proposed under the climate mitigation objective is made explicit.

In what follows, we will consider two phases for the evaluation of the carbon footprint:

- Phase 1: the carbon footprint of the construction phase.
- Phase 2: the carbon footprint of the operating phase.

1.3. Phase 1: The carbon footprint of the construction phase

Evaluating the carbon footprint of the construction phase implies the evaluation of the carbon emissions potential of the capital expenditure (CAPEX), i.e. of the investment properly defined. Often, this phase is neglected when external costs and benefits are calculated in project appraisal. Notably, the document of the European Investment Bank Project Carbon Footprint Methodologies – "Methodologies for the assessment of project greenhouse gas emissions and emission variations", (2023[2]), proposes the quantification of carbon-equivalent emissions by considering the entire life of the project, so that three layers of emissions are considered:

a) **Scope 1**: Direct GHG emissions, that is fuel combustion, process/activity, fugitive emissions generated by the project;
b) **Scope 2**: Indirect GHG emissions, that is electricity, heating, cooling used by the infrastructure manager or the service operator;
c) **Scope 3**: Indirect GHG emissions, that is upstream and downstream Scope 1 and 2 emissions from a facility 100% dedicated to the project activity that would not otherwise exist and did not exist prior to the project's inception.

The marginal impact of the project in terms of carbon emissions is calculated as the difference between projects absolute emissions and baseline emissions (defined as the emissions generated by the system in the *status quo* situation):

$$\textit{Project marginal emissions} = \textit{Project absolute emissions} - \textit{Baseline emissions}$$

Cost-benefit analysis requires that only direct effects of the project are considered for appraisal or, in other words, that only projects with negligible indirect effects can be evaluated by means of a CBA. However, in the policy framework we are considering, it is important to quantify the wider environmental effects of the project. This means the direct, indirect and induced effects of three different moments of the investment:

a) The construction phase;
b) The impact of operation and maintenance expenditure;
c) The impact of the demand.

This indication may seem trivial, however, two novelties are embedded in this approach:

Usually, the environmental and climate effects of investment projects are estimated only with respect to the externalities produced or avoided by the demand satisfied by the project. In the proposed framework, instead, also the impact of capital and operating expenditures is considered as a source of reduction or production of externalities. In other words, we propose to account also for the externalities generated during the construction phase.

Environmental effects of demand are considered not only in terms of existing direct demand, but also in terms of indirect and induced demand. However, the precise quantification of the impact along the three cases is subject to the availability of information or models.

The proposed approach - presented below - follows a simple **Input-Output (I-O) framework** to assess the impact of capital and operating expenditures. This model has the advantage of simplicity, however, sponsoring authorities may have different and more precise information regarding the climate emissions and the general environmental impacts of the construction and operating phase for a given project, and may want to use it directly.

As a general guideline, the Input-Output framework proposed is preferable for large-scale and complex projects (especially, in terms of technological complexity) - such as airports -, as they normally encompass a wide range of factors and chains to be considered for the evaluation of emissions. To ease the application of this framework, the central government can develop a central-level guidance and a ready-to-use calculator, containing all the technical parameters and values to be used by sponsoring authorities in the estimation. This will help ensure coherence and will also make the framework more practicable by public administrations.

For small-scale and simple projects where information on emission estimates may be available more readily at different tiers (e.g. an urban sewage system), a direct estimation of emissions by sponsoring authorities could be envisioned. However, in order to verify the robustness and reliability of the assumptions and procedures used, the central government should audit the results, also for the sake of comparability and consistency across projects.

The Input-Output model is driven by demand, that is consumption generates production through a set of intersectoral multiplies corresponding to the sectoral allocation of intermediate inputs. Once the change in production is estimated, it is possible to calculate emissions by using sectoral emission factors, as sketched in Figure 1.2[4].

Figure 1.2. How to calculate emissions using the I-O model

$$\begin{matrix} \textit{Change in demand generated} \\ \textit{by the investment} \end{matrix} \xrightarrow{\textit{I–O multipliers}} \textit{Change in production} \xrightarrow{\substack{\textit{Emission} \\ \textit{factors}}} \textit{Total emissions}$$

Analytically and with specific reference to the case of CO2, let us consider the following formulation:

$$\boldsymbol{CO_2X = CO_2(I - A)^{-1}F}$$

[4] For a thorough introduction to I-O models, cfr. https://researchrepository.wvu.edu/cgi/viewcontent.cgi?article=1006&context=rri-web-book

Where CO2 is a diagonal $n \times n$ matrix of carbon intensity by sector, X is an $n \times 1$ output vector, $(\boldsymbol{I}-\boldsymbol{A})^{-1}$ is the usual Leontief inverse of inter-sectoral multipliers, F is a $n \times 1$ output vector of final demand. Carbon intensity by sector is defined as kilograms of CO2 per millions of euros of output[5].

Let us consider a project generating a shift in the aggregated demand equal to ΔF, then the change in the emission of CO2 can be calculated as:

$$\boldsymbol{CO_2}\Delta\boldsymbol{X} = \boldsymbol{CO_2}(\boldsymbol{I}-\boldsymbol{A})^{-1}\Delta\boldsymbol{F}$$

It should be noted that the previous equation implicitly assumes that the baseline emissions are unchanged and that carbon intensities do not change.

The World Input-Output database contains both the I-O table and the matrix of CO2 intensities for Ireland for the period 2000-2016[6]. Table 1.1 summarises the sectors considered in the database. Table 1.2 reports carbon intensities across sectors in Ireland, for 2016.

Table 1.1. Sectors in the Irish Input-Output Table

Code	Description
A01	Crop and animal production, hunting and related service activities
A02	Forestry and logging
A03	Fishing and aquaculture
B	Mining and quarrying
C10-C12	Manufacture of food products, beverages and tobacco products
C13-C15	Manufacture of textiles, wearing apparel and leather products
C16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
C17	Manufacture of paper and paper products
C18	Printing and reproduction of recorded media
C19	Manufacture of coke and refined petroleum products
C20	Manufacture of chemicals and chemical products
C21	Manufacture of basic pharmaceutical products and pharmaceutical preparations
C22	Manufacture of rubber and plastic products
C23	Manufacture of other non-metallic mineral products
C24	Manufacture of basic metals
C25	Manufacture of fabricated metal products, except machinery and equipment
C26	Manufacture of computer, electronic and optical products
C27	Manufacture of electrical equipment
C28	Manufacture of machinery and equipment n.e.c.
C29	Manufacture of motor vehicles, trailers and semi-trailers
C30	Manufacture of other transport equipment

[5] Note that the expenditure on capital goods and consumption products do not include trade and transport margins. These margins should be considered when implementing the I-O model. The allocation of trade and distribution margins that may well generate environmental impacts should be allocated to final expenditure in the case of a closed I-O table or should be split between domestic and Rest of the World sectors in the case of an open I-O table.

[6] Cfr. European Commission, Joint Research Centre, Román, M., Corsatea, T., Amores, A., et al., World input-output database environmental accounts: update 2000-2016, Publications Office, 2019, https://data.europa.eu/doi/10.2760/024036

C31_C32	Manufacture of furniture; other manufacturing
C33	Repair and installation of machinery and equipment
D35	Electricity, gas, steam and air conditioning supply
E36	Water collection, treatment and supply
E37-E39	Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services
F	Construction
G45	Wholesale and retail trade and repair of motor vehicles and motorcycles
G46	Wholesale trade, except of motor vehicles and motorcycles
G47	Retail trade, except of motor vehicles and motorcycles
H49	Land transport and transport via pipelines
H50	Water transport
H51	Air transport
H52	Warehousing and support activities for transportation
H53	Postal and courier activities
I	Accommodation and food service activities
J58	Publishing activities
J59_J60	Motion picture, video and television programme production, sound recording and music publishing activities; programming and broadcasting activities
J61	Telecommunications
J62_J63	Computer programming, consultancy and related activities; information service activities
K64	Financial service activities, except insurance and pension funding
K65	Insurance, reinsurance and pension funding, except compulsory social security
K66	Activities auxiliary to financial services and insurance activities
L68	Real estate activities
M69_M70	Legal and accounting activities; activities of head offices; management consultancy activities
M71	Architectural and engineering activities; technical testing and analysis
M72	Scientific research and development
M73	Advertising and market research
M74_M75	Other professional, scientific and technical activities; veterinary activities
N	Administrative and support service activities
O84	Public administration and defence; compulsory social security
P85	Education
Q	Human health and social work activities
R_S	Other service activities
T	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use
U	Activities of extraterritorial organizations and bodies
FC_HH	Final consumption expenditure by households

Source: (Corsatea et al., 2019[3])

Table 1.2. Carbon emissions by sectors in Ireland

Sector Code	CO2 (in ktonne)
A01	1 032 761
A02	0,347
A03	106,881
B	302,005
C10-C12	906,06
C13-C15	10,02
C16	65,871
C17	8,044
C18	8,044
C19	313,253
C20	143,865
C21	212,888
C22	73,126
C23	3 136,337
C24	1 186,832
C25	151,897
C26	97,824
C27	16,505
C28	57,71
C29	6,166
C30	5,396
C31_C32	88,893
C33	13,807
D35	11 844,35
E36	19,121
E37-E39	182,789
F	470,145
G45	112,907
G46	871,985
G47	540,565
H49	2 651,674
H50	217,671
H51	10 665,65
H52	138,307
H53	31,322
I	143,821
J58	44,069
J59_J60	12,292
J61	87,506
J62_J63	81,096
K64	72,672
K65	41,438
K66	3,401
L68	9,319
M69_M70	29,324
M71	12,506
M72	7,284
M73	6,588
M74_M75	3,642

N	63,619
O84	252,968
P85	183,241
Q	116,747
R_S	70,528
T	0
U	0
FC_HH	12 170,48

Source: (Corsatea et al., 2019[3])

As stated above, the quantification and monetisation of environmental and climate impacts for the construction and operating phases require the availability of a considerable amount of data and information in the use of a model to estimate emissions. To this end, **we propose the use of an Input-Output model for Ireland that estimates emissions from expenditure** (for investment and for operation and maintenance expenditure).

A desirable feature of the input-output model - also in the version extended to consider environmental outputs - is that it generates direct, indirect and induced effects of demand changes. This is the type of information needed for the assessment of a project.

Once total emissions produced by the project have been calculated, they can be evaluated in monetary terms by using the cost of carbon set by the Irish Government. Table 1.3 presents the current cost of carbon estimated by the Government of Ireland and included in the corresponding supplementary guidance of the Public Spending Code. These values are considerably below the suggested values by the European Commission in the Economic Appraisal Vademecum (2021[4]). As a reference, in 2020, the cost is set at EUR 80 by the European Commission and at EUR 800 in 2050. This difference may significantly alter the evaluation and prioritization of projects in Ireland.

The proposed procedure consists in three steps:

a) Classify operational and capital expenditure allocating expenditures across the sectors of the I-O table (see Table 1.1);
b) Calculate the intersectoral multiplies and the associated emission factors;
c) Calculate emissions from production generated by capital and operational expenditure and eventually monetize them.

Table 1.3. Shadow price of carbon 2019-2050 (per tonne of CO2e) for the Non-ETS and ETS sectors

Year	Carbon price for Non-ETS sectors (in EUR)	Carbon price for ETS sectors in EUR)
2019	20	23.6
2020	32	23.6
2021	39	23.6
2022	46	23.6
2023	52	23.6
2024	59	23.6
2025	66	23.6
2026	73	24.7
2027	80	26.9
2028	86	29.1
2029	93	31.3
2030	100	33.5
2031	105	35.2

2032	110	36.9
2033	116	38.6
2034	122	40.3
2035	128	42
2036	134	43.6
2037	141	45.2
2038	148	46.8
2039	155	48.4
2040	163	50
2041	171	53.8
2042	180	57.6
2043	189	61.4
2044	198	65.2
2045	208	69
2046	218	72.8
2047	229	76.6
2048	241	80.4
2049	253	84.2
2050	265	88

Source: (Department of Public Expenditure, NDP Delivery and Reform, 2019[5])

Box 1.1. An example of monetisation of CO2 emissions in the construction phase

Let us consider the construction of a motorway with total capital expenditure equal to EUR 96 million, to be spent in one year. In order to estimate CO2 emissions from the construction phase, we need to have the sectoral breakdown of such expenditure. As from the project, the breakdown is the following:

- Cost allocated to the construction sector: 50 million
- Cost allocated to the energy sector: 30 million
- Cost allocated to the banking sector: 16 million.

The analyst has estimated the I-O multipliers by calculating the inverse matrix **(I-A)**$^{-1}$ and emission factors by sectors, which are reported in Table 1.4. The Table also shows the procedure to calculate costs from the total estimated emissions, and that follows the aforementioned steps.

Table 1.4. I-O multipliers and emission factors (estimated)

Sector	Expenditure (in million EUR)	I-O multipliers	Production generated (in million EUR)	Emission factors (in kg/EUR)	Total emission (in ton)	Cost at 80 EUR/ton (in EUR)
Construction	50	2.2	110	0.5	25 000	2 000 000
Energy	30	2.4	72	0.2	6 000	480 000
Banking	16	1.6	25.6	0.1	1 600	128 000
Total	**96**		**207.6**		**32 600**	**2 608 000**

Note: Emission factors as well as multipliers are purely indicative

1.4. Phase 2: Carbon footprint of the operation phase

During the operation phase, the analyst has to estimate the carbon emissions of two different items:

a) Operating expenditure (OPEX).
b) Externalities generated by demand.

Regarding the carbon footprint of OPEX, the methodology proposed in the previous section should be applied.

Regarding the externalities generated by the demand, with specific reference to the carbon footprint, specific models depending on the sector of the investment should be applied. For example, in the energy sector, a measure of carbon avoided thanks to the new investment (e.g. in renewable energy production plants) should be evaluated and then monetized by using the values in Table 1.3.

The case of transport investment is perhaps more intriguing from a methodological perspective, as it entails the quantification of carbon avoided from traffic deviation and any change in its composition (i.e. changes to vehicle types). The greenhouse gas emission costs are calculated using a bottom-up approach, which combines the information on the GHG pollution of vehicles with the cost of CO2. The values of GHG emissions are converted to CO2 equivalents and added up across sectors. This approach uses the emission-related data coming from the environment: GHG emissions factors per vehicle type, vehicle performance data, and climate change costs per tonne of CO2 equivalent.

The first phase consists of the collection of data on GHG emissions by vehicle type. In case data are not available, it is possible to multiply the emission factors of a means of transport by the km travelled, by the type of vehicle considered. With regards to aviation, water vapour, sulphate and soot must be considered as well.

Secondly, during the calculation phase, GHG emissions need to be summed up. Since the impacts of GHGs differ depending on their lifespan and impact power, to compare them the 100-year Global Warming Potential (GWP) is used. It is a time-related factor that adopts CO2 as its basis, standardizing it to 1. Indeed, GHGs emissions are converted to CO2 equivalent using the GWP.

Two main methods are used to assess the climate change costs for air transportation:

1) The calculation of emissions through GWP factors as Emission Weighting Factors (EWF): results demonstrate that the total climate impact caused by aviation is 1.3-1.4 times stronger than the impact of CO2 emissions alone;
2) The use of the Radiative Forcing Index (RFI), i.e. a time-related indicator that represents the ratio of the total radiative force caused by aviation at a precise moment divided by the radiative force of the CO2 released by aviation at that same moment. Conclusions indicate that the total climate impact of aviation is 2-4 times more powerful than the impact of the single CO2 coming from the same mode of transport.

Since each GHG has a specific residence time, it is necessary to use a factor to compare them that considers the lifetime. If not, the estimation would be overvalued in terms of climate impact. This is particularly relevant for emissions from aviation. Therefore, it is preferred to use the EWF instead of the RFI, because the latter does not account for the lifetime. Furthermore, aviation emissions can have not only a heating effect, but also a cooling one, and consequently a comparative factor is needed between all the GHGs that considers their wide heterogeneity. The lifetime of GHGs must be included to more accurately quantify transport-induced climate change. Considering only the short-term effects of GHGs and not the long-term ones would imply an underestimation of the total economic cost of transport on climate change.

Table 1.5 reports the specific parameters of carbon cost associated to specific vehicles. Further parameters can be found in the Handbook published by the European Commission (2020[6])(e.g. aviation, euro 4 vs euro 5 cars etc.). However, those parameters have been estimated on the basis of carbon cost reported in the Economic Appraisal Vademecum 2021-2027 (2021[4]), which is considerably higher than the cost proposed by the Irish government[7].This implies that using parameters in Table 1.3 and parameters in Table 1.5 for the same project may generate inconsistencies. To avoid such issues, the Irish government would need to either use European Commission cost of carbon or to estimate specific parameters, as the ones reported in Table 1.5 are coherent with Irish estimates of carbon costs.

Table 1.5. Selected parameters of carbon cost from transport

	Total costs EU28	Average costs	
Passenger transport	**EUR Billion**	**EUR -cent per pkm**	**EUR -cent per vkm**
Passenger car	55.56	1.18	1.90
Passenger car – petrol	32.02	1.22	1.97
Passenger car – diesel	23.54	1.12	1.80
Motorcycle	1.47	0.89	0.94
Bus	0.84	0.47	8.83
Coach	1.61	0.44	8.66
Total passenger road	**59.49**		
Passenger train diesel	0.22	0.34	20.1
Total passenger transport	**59.71**		
Freight transport	**EUR Billion**	**EUR -cent per tkm**	**EUR -cent per vkm**
LCV	13.17	3.98	2.75
LCV – petrol	0.71	3.76	2.56
LCV – diesel	12.45	3.99	2.77
HGV	9.63	0.53	6.48
Total freight road	**22.79**		
Freight train diesel	0.24	0.25	112.4

Source: (van Essen et al., 2020[6])

At this point of the presentation of the proposed methodology, a clarification regarding the treatment of direct, indirect and induced effects should be made. More in particular, we envisage the possibility to evaluate such effects in two distinct moments with distinct methodologies:

a) During the construction and the maintenance phase;
b) During the operation phase.

Concerning phase a) direct, indirect and induced effects are related to expenditures and can be calculated by means of the Input-Output model (or through direct estimation by the sponsoring authorities), as referenced above. As for phase b), the possibility to calculate external effects from direct, indirect and induced demand depends on the type of model adopted to forecast demand itself. For instance, in the transport sector, transport models capable to make such predictions are widely used.

[7] See endnote 6.

1.5. General evaluation: Cost-benefit analysis

At the final stage of the assessment, a full cost-benefit analysis should be conducted. It consists in calculating the **Net Present Value (NPV) of future net benefits**. It approximates the change in social welfare with[8]:

$$NPV = \sum_{t=0}^{N} \frac{B_t - C_t}{(1+r)^t}$$

Where B and C stand for benefit and cost respectively, *r* is the social discount rate, *t* is the time indicator and N is the time horizon.

In terms of benefit and cost, Table 1.6 summarizes their treatment in the Net Present Value formula.

Table 1.6. Benefits and Costs

Item	Inclusion in the CBA	Notes
CAPEX	Yes	They have to be valued by using conversion factors.
Carbon emissions from CAPEX	Yes	They have to be valued with the methodology described in section 3
OPEX	Yes	They have to be valued by using conversion factors.
Carbon emissions from OPEX	Yes	They have to be valued with the methodology described in section 3
Residual value	Yes	The residual value is calculated as the present value at time N of the net benefits in remaining year, until the end of life of the project.
Revenues	No	
Externalities	Yes	They are related to demand and consider acoustic and environmental pollution, congestion, well-to-tank emissions, habitat damages, accidents. As for transport, they should be evaluating by using parameters suggested in the EU Handbook on External Cost of Transportation

In terms of parameters, the Irish guidelines differ significantly with respect to the European Commission guidelines, as reported in Table 1.7.

Table 1.7. Parameters for the cost-benefit analysis

Parameters for CBA	European Union	Ireland
Discount rate	3%	4%
Shadow price of public funds		130%
Shadow price of labour	62-80%	80-100%
Shadow price of carbon	2020 – 20 euro/tCO2	Non-ETS Emissions 2019 – 20 euro/tCO2

Source: (Department of Transport, October 2021[7]; Commission, 2021[4])

Other issues to be considered when conducting the cost-benefit analysis are the following:

a) The project should be undertaken, from the point of view of welfare analysis, only if NPV>0, which implies a concrete definition of the baseline scenario, implicit in the “0”- case;

[8] For a general introduction to cost-benefit analysis, please refer to G. Atkinson, N.A. Braathen, B. Groom and S. Mourato (2018), “Cost-Benefit Analysis and the Environment. Further Development and Policy Use”, OECD.

b) Although this chapter often makes reference to carbon emissions, other types of external costs/benefits need to be taken into account, such as the value of pollutants produced or avoided, the change in biodiversity, the number of lives saved or lost[9];
c) Carbon emissions and externalities related to demand generated by the project account for one half[10]. The rule of half is particularly relevant for the framework proposed in this working paper, as it provides indications related to the welfare impact of additional demand;
d) Assess mitigation policies through sensitivity analysis of the CBA. This would require considering different mitigation options (e.g. installing solar panels) by altering the related costs and observing the benefits generated. The focus is on assessing the relative change in the NPV: NPV with solar panels vs. NPV without solar panels.

To summarise, the proposed methodology to assess the contribution of the project to climate mitigation consists in: a) extending the assessment of GHG emissions to include direct, indirect, and induced emissions from capital and operating expenditure; b) embedding the information on total emissions in the framework of cost-benefit analysis (or other evaluation tools). The extended version of the total emission indicator should then be part of the business case report, as it will be discussed in chapter 3.

[9] Specific parameters for external costs and benefits can be found in European Commission (2014), Guide to cost-benefit analysis of investment projects, DG Regional and Urban Policy.

[10] See, e.g. Department of Transport, "Common Appraisal Framework for Transport Project and Programmes", October 2021 Update, pp. 63-64.

2 A methodological approach to consider and value climate uncertainty and risks into planning and maintenance of infrastructure

2.1. Methodologies for assessing climate risk and to appraise the adequacy of proposed investments in terms of climate resilience: Analysing costs and benefits of different methodological options

Major climate risks to infrastructures are of two types. On one side, climate change is likely to exacerbate the frequency and intensity of extreme weather events that are likely to cause damages to existent infrastructure assets (e.g. heat waves, cold snaps, heavy rainfalls or snowfalls, ice or hailstorms, storm surges, and tornadoes). Evidence of such effects is clear from the growing number of extreme climate events on a global scale and the consequent impacts observed in recent decades (AghaKouchak et al., 2020[8]; Fisher and Knutti, 2015[9]; Pall et al., 2011[10]). On the other side, infrastructures are affected by changing climate conditions more broadly, for example, raises in the mean temperatures and changes in the mean discharge of rivers.

The impacts originating from these climate-induced threats vary according to the climate process considered and the characteristics of the specific infrastructure asset. In general terms, such impacts can be divided in direct and indirect. Direct impacts include physical damage or destruction, for example, ruptures of pipelines, collapses, or structural subsidence of the artefacts. Indirect impacts concern the alteration of the functions performed by the infrastructure itself and their decreasing level of service. Moreover, all these impacts usually translate into costs in the forms of necessary safety measures, costs for the restoration, replacement, reconstruction of the affected infrastructural components, and/or in economic losses due to the reduction of the functionality of the infrastructure, and therefore of the provision of the related services (Kreibich et al., 2014[11]). For this reason, it is increasingly important to start considering climate-related risks in the planning, design, and implementation of all infrastructure projects. For critical infrastructures, this is even more urgent given the larger extent of potential losses for society.

The economic and social development of a country can in turn influence climate risk impacts, for example, by promoting the construction of infrastructural works or their expansion in certain areas, thus affecting the spatial and temporal distribution of infrastructures on the territory. Moreover, countries are increasingly committed to climate change mitigation and adaptation strategies, which often include the uptake of new technological solutions to reduce the emissions impacts of infrastructure projects and increase their resilience to changing climate conditions and extreme events.

The socio-economic dynamics linked to the adjustment process towards a low-carbon and more environmentally sustainable economy can also generate transition risks, especially in the absence of analytical processes capable of assessing the exposure of the socio-economic system to these risks and the consequent strategies to anticipate them and convert them into development opportunities.

The design of infrastructures should be informed by the assessment of the climate hazards that they must be able to withstand during their life cycle (Croce et al., 2018[12]). Traditionally, historical data have been used to inform analysis of the potential likelihood and severity of impacts, but historical records need to be complemented with climate projections to understand how trends might change and create risks for new and existing infrastructure assets the (OECD, n.d.[13]). For example, the definition of climate hazard maps used for infrastructure design is generally based on statistical processing of the annual extreme values conducted in the hypothesis of stationarity of the climate. Since climate change modifies the intensity and frequency of climatic events, especially extreme ones, the hypothesis of stationarity of the climate is no longer valid; consequently, the climatic hazards to be considered for the design must be adequately re-evaluated, to ensure that the structures retain the required degree of reliability over time. In brief, gathering of reliable climate data, definition of climate scenarios and identification of reference parameters are the key ingredients to promote climate-resilient infrastructure projects. Authoritative national and sectoral climate risk assessments – as those developed in Ireland – can also provide data and a framework for the more detailed assessments necessary for specific infrastructure investments.

The market is progressively establishing regulations in the climate field (Climate Risk and Climate Disclosure), which are already in use by large organizations and which in some cases are becoming mandatory for large companies (e.g. the EU Taxonomy Regulation). These standards should gradually be extended to smaller entities, organizations and companies and public bodies, according to principles of progressivity and materiality. This will help trigger the same incentive mechanisms both in the private and in the public sector.

The integration of the climate risks and opportunities (deriving from it) in the various stages of decision-making and in management processes is a necessary condition to ensure climate adaptation, with potential benefits at all levels (e.g. managerial and operational).

The concept of “risk” and “opportunity’” must permeate the various areas of the project cycle, at least for two main macro-categories:

- Risks associated with the transition to a low-impact economy (so-called **transition risk/ opportunity**), that may involve changes in policy, technology and market response. A typical example are the so-called *stranded assets* of which coal-fired power plants are a typical example.
- Risks associated with the physical impact of climate change (so-called **physical risk**) due to variations in the frequency and magnitude of extreme events (i.e. acute physical risk) and/or variations in average climatic variables, for example global average temperature increase (i.e. chronic physical risk). Typical examples are direct damage to assets and service interruptions.

In this perspective of integration, the risk-based approach contributes to improving the performance and stability of the services provided by the infrastructure, by managing the uncertainty inherent in possible future scenarios due to climate change. In this context, the typical climate, physical and transition risks must be analysed at the same time in the various states of the world.

The evaluation of specific risks and the general vulnerability of the project to climate change are qualitative in their nature, however, it is desirable to frame them into accepted scenarios. On this specific point, **we suggest the Irish government to undertake actions leading to the definition of sector- and location-specific risks as the ones that have produced maps of flood risks that should be considered as best practices in the area.**

Given the nature of climate risk, the strategic planning process should normally start from the identification of the reference scenarios from which management could identify and evaluate the short, medium and long-term risks and opportunities. Scenarios are descriptions of future states, hypothetical and plausible (i.e. they are not predictions). Normally, scenarios consider transition risks and physical risks and the interaction between them, the aim is to describe, in a nutshell, a result that can be achieved in a given time frame and a path to achieve the objective outlined.

It is also important to define a process for the identification and effective assessment of climate-related risks, or a robust *"Climate Risk and Vulnerability Assessment"*. This represents a key ingredient to adequately respond to the challenges posed by climate change. There are no standards on how to assess climate change risks and vulnerabilities, but normally the assessment builds upon:

- Information on current climate conditions and scenarios of future climate, including future slow on-set and extremes events;
- An analysis of other underlying factors and trends (ecosystem related, physical, technical, or socio-economic factors) that can influence climate risks;
- An assessment of potential impacts of climate extremes and climate change on potentially vulnerable sectors and/or assets.

Moreover, climate change risk and vulnerability assessments can leverage a wide range of approaches to gather information – from data and model-driven approaches (e.g. climate data and impact models) to more review or expert-based approaches (ClimateADAPT, n.d.[14]). Assessments and steps are normally performed in a participative manner with key stakeholders, including different government levels, academics and experts, NGOs, local communities and the private sector. Inclusive engagement is important to help managing the scale, complexity and uncertainty affecting the analysis of climate change risks (OECD, n.d.[13]).

The importance of this tool as a preparatory element to develop climate change adaptation strategies and plans is emphasized not only by the relevant scientific literature, but also within the European Community. The 2018 report by the European Environment Agency (EEA) presents a first systematic review on how the 33 EEA countries (including the 27 EU member states) have developed their national climate change impacts, vulnerability, and risks assessments, confirming how this instrument is mainly used to inform adaptation strategies at the national and sectoral level. Moreover, the assessment of risk and vulnerability related to climate change represent, for example, one of the steps that characterize the *Adaptation Support Tool* (AST) developed within the ClimateADAPT platform of the European Commission, or again within the framework of the so-called "EU Taxonomy Regulation" (2020[15]).

Also, the ISO-norm "Adaptation to climate change – Guidelines on vulnerability, impacts and risk assessment" provide guidance on how to conduct a sound risk assessment in the context of climate change and use it to inform adaptation strategies.

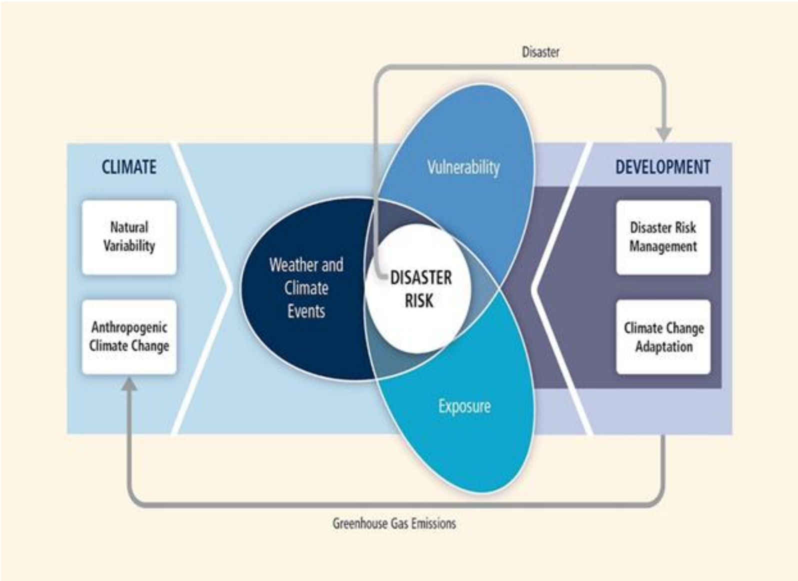
2.2. Proposed appraisal criteria and guidance for prioritisation

When referring to the benefits of climate change adaptation - in which infrastructure resilience is a key element - a "triple dividend" often emerges as a combination of three different categories of benefits: (i) the reduction of the damage generated by events related to climate change, (ii) the potential expansionary effect of investments in adaptation on the economic system, (iii) the additional social and/or environmental benefits that can derive from it.

Understanding and quantifying the risks associated with climate change is necessary in order to adequately plan and design prevention, mitigation and adaptation measures. These helps safeguard infrastructure and guarantee their functioning, as well as minimising their impact on the environment.

According to the methodology proposed by the IPCC (2014[16]), the impacts (risks) of climate change on infrastructures originate from the dynamic interactions between the dangers generated by climate phenomena, infrastructures' exposure to climate threats and their vulnerability (see Figure 2.1). Climate hazard represents the potential occurrence of a climate event likely to cause damage and loss to property, infrastructure, and more generally, to the provision of services. The exposure refers instead to the spatial distribution of infrastructures potentially subject to danger. Vulnerability expresses the degree to which an infrastructure is damaged when exposed to a threat.

Figure 2.1. Illustration of the concept of risk as an integration of danger, exposure, and vulnerability



Source: (Team, Pachauri and Meyer, 2014[16])

The quantification of hazards, exposure and vulnerability is subject to uncertainty, both in terms of magnitude and probability of occurrence, and each element is variable over time and space according to future climate and socio-economic changes. Obviously, different types of infrastructures are characterized by different levels of vulnerability to climate change (Forzieri et al., 2018[17]). Furthermore, as the impacts of climate change occur locally, individual infrastructures also have different exposure to climate hazards depending on their geographic location.

As mentioned above, climate and socio-economic processes affect the danger, exposure and vulnerability and, consequently, the resulting impacts. For example, the growing instability of the climate system as a result of natural and anthropogenic pressures, such as GHG emissions, amplifies climate variability and, ultimately, increases the frequency and severity of extreme climatic events (Fisher and Knutti, 2015[9]; Diffenbaugh et al., 2017[18]).Following Commission's notice "Technical guidance on the climate proofing of infrastructure in the period 2021-2027" (2021[1]), the assessment of the resilience of infrastructure investment should be conducted in two phases:

1) Phase 1: Vulnerability analysis.
2) Phase 2: Impact analysis and adaptation strategies.

2.2.1. Phase 1: Vulnerability Analysis

The aim of the vulnerability analysis is to identify the most relevant climate and environmental hazards in terms of potential impacts on the investment. To this end, the analyst is required to assess:

i. The sensitivity of the project (in terms of on-site assets, inputs, outputs, access and transport links) to specific climate hazards;
ii. The exposure of the investment project to such events.

For each hazard, Table 2.1 can be used to summarize the vulnerability of the project to specific hazards. For example, a natural hazard such as an earthquake in Ireland would be classified as “low” in the vulnerability analysis proposed. Indeed, the country generally has good infrastructure assets which can withstand seismic phenomena, and it is not an area subject to a high seismic risk.

Table 2.1. Vulnerability analysis

Vulnerability Analysis		Exposure		
		High	Medium	Low
Sensitivity	High	High vulnerability	High vulnerability	
	Medium	High vulnerability	Medium vulnerability	
	Low	Medium vulnerability	Low vulnerability	

Note: For the hazards that fall in the High-Medium vulnerability area, a further impact analysis should be conducted
Source: (European Commission, 2021[1])

In principle, if the exposure of a project to climate hazards is appropriately estimated, the impact of climate change on the value of the infrastructure is embedded in this measure. Therefore, benefits from adaptation strategies should be considered in terms of reduction of exposure and hence risks for the project. The correct definition of the vulnerability of projects should rely on a quantitative assessment of associated risks. In this respect, it would be useful to build a specific integrated model on the basis of the following procedure:

a) Construction of a detailed GIS-based map of critical infrastructures in Ireland;
b) Calculation (on the basis of an Integrated Assessment Model specific of Ireland) high resolution projections of hazards in terms of heat waves, cold waves, drought, wildfires, floods, storms;
c) Definition of parameters of sensitivity of infrastructures to climate hazards, with substantial sectorial heterogeneity;
d) Calculation of future exposure of infrastructures and the associated risk in terms of expected damages;
e) Identification of policy actions for risk reduction and quantification of expected costs;
f) Calculation of expected benefits from adaptation strategies in terms of reduction in expected damages.

With specific reference to point d), e), and f), it is worth underlining that adaptation solutions and strategies involved real costs and benefits. For example, for a highway running close to the coast, the risk of a flood to destroy the asset is relatively high. One solution could be to build a natural barrier made of trees. This investment will increase costs and reduce the NPV resulting from the CBA, however, it will also help reducing the probability of a negative event to occur, as well as the physical damages it might cause. This example should make it clear how important it is to assess the costs and benefits associated with adaptation solutions through CBA, comparing the relative change in the NPV values.

2.2.2. Phase 2: Impact Analysis and Adaptation Strategies

The aim of the impact analysis phase is to assess the potential damages generated by given hazards (the ones that have been ranked at High-Medium vulnerability in Phase 1) and consist in two different moments:

1. An assessment of the likelihood of an even to occur;
2. An assessment of the impact of the extreme event in terms of asset damages, safety and health, environment, cultural heritage, social, financial, reputation.

Table 2.2. Risk assessment

Risk assessment		Impact of climate variables and hazards				
		Insignificant	Minor	Moderate	Major	Catastrophic
Likelihood	Rare	Low	Low	Medium	High	Extreme
	Unlikely	Low	Low	Medium	High	Extreme
	Moderate	Low	Medium	High	Extreme	Extreme
	Likely	Low	High	High	Extreme	Extreme
	Almost certain	High	High	Extreme	Extreme	Extreme

Source: (European Commission, 2021[1])

For projects ranked from "medium" to "extreme" impact for specific climate hazard, strategies for climate change adaptation should be identified. Adaptation measures should aim at bringing the expected negative effects at an acceptable level, and they might also allow taking advantage of any positive opportunities arising from climate change. Given the context-specific nature of climate adaptation, the measures to achieve this will vary widely. However, for infrastructure projects, they can be generally grouped into two categories:

- **Structural adaptation measures**: for example, the integration of nature-based solutions to enhance resilience and extend the lifespan of grey infrastructures, changing the composition of road surfaces to avoid deformation under high temperatures, building seawalls or using permeable paving surfaces to reduce run-off during heavy rainfalls.
- **Management (or non-structural) adaptation measures**: for example, review the timing of maintenance to account for changing patterns of energy demand and supply, investments in early warning systems or purchasing insurance to address financial consequences of climate variability. These measures can also include enhanced monitoring of existing assets to reduce the risk of failure as climate conditions change. Adaptive management approaches also include provisions to include flexibility from the outset to monitor and adjust to changing circumstances over the asset's lifetime.

Although actions should be project-specific, they may include:

- Capacity building and training of local and national institutions that are supposed to monitor climate-related risks and their impacts;
- Capacity building and training of the personnel operating the infrastructure assets on climate risks as well as on how to intervene in case of physical damages or service disruptions;
- Revision of maintenance schedules and updating of operational rules;
- Structural interventions to strengthen resilience and adaptative capacity of infrastructures, including by re-locating infrastructure assets in lower-risk areas;
- The identification of national and international best practices;
- Implementation of nature-based solutions (e.g. planting trees to mitigate CO_2 emissions and contain flood risks);
- Optimization of project technical design;
- Definition of disaster mitigation plans, including the creation of an emergency response team;
- Promotion of behavioural changes by users;
- Managing risks from a financial perspective by subscribing specific insurance contracts.

Figure 2.2. Examples of adaptation measures for energy infrastructure

	Climate impacts on infrastructure	Management measure	Structural Measure
Generation	– Inundation of coastal infrastructure, such as generation plants – Reduced efficiency of solar energy – Insufficient cooling water – Temperature of cooling water before and after use – Reduced output from hydropower generation	– Model climate impacts on existing and planned assets in collaboration with meteorological service – Revise maintenance schedules – Update hydropower operating rules	– Fortify coastal, off-shore and flood-prone infrastructure against flooding – Increase cooling system capacity for solar energy – Locate new facilities outside high-risk zones
Transmission and distribution	– Flooding of electricity substations – Damage to transmission lines from climate extremes	– Implement program for pruning and managing trees near transmission and distribution lines – Create disaster mitigation plans – Train emergency response teams for quick repair and restoration actions	– Adjust design criteria for transmission lines, e.g: – Increase transmission tower height – Bury distribution lines – Use stainless steel material to reduce corrosion from water damage
Consumption	– Change in energy demand patterns (e.g. increased demand for cooling and reduced demand for energy for heating)	– Undertake load forecasting using climate information – Promote behavioural change measures to reduce peak consumption	– Improve building and industrial energy efficiency

Source: (IEA, 2015[19])

When adaptation options have been identified, the next steps are to assess and prioritize the compilation of adaptation options based on a detailed description and criteria. CBA and MCA can prove useful for ranking and selecting the preferred measures. Moreover, the preferred list of adaptation options should be discussed with stakeholders, who should also agree on the values and criteria used for the prioritisation. This will help ensure their support in the implementation of the selected measures (ClimateADAPT, n.d.[20]). Criteria and considerations that might be used to inform the assessment and prioritization of adaptation actions are listed below:

- Identifying the risks the option addresses (i.e. each option may have an effect on or treat multiple risks) and by how much the option will likely reduce the risks;
- The time frame to implement the measures and when it shall become effective, reflecting identified risks and the range of urgency to act;
- Performance against general and wider objectives and avoidance of maladaptation[11].
- If the option is of incremental or transformative nature;
- Addressing direct and indirect effects of the option in economic and environmental terms (including effects on climate change mitigation) with an emphasis on potential benefits. Measures with multiple benefits should be preferred;

[11] Maladaptation refers to a situation when actions do not achieve their aims or cause side-effects that impede adaptation elsewhere or in the future.

- Address interplay of the adaptation option with different groups of society and map any groups that might not be covered by the adaptation option;
- The link to climate mitigation measures, as measures that contribute to climate change should not be implemented;
- An assessment of effectiveness and efficiency;
- Assessing costs and benefits to predict whether the benefits (e.g. avoided damage) of an option outweigh its costs, and by how much in relation to other alternatives (i.e. one can rank alternate options in terms of the cost-benefit ratio). All costs and benefits should be quantified where this is possible and meaningful, otherwise a qualitative assessment shall be delivered;
- Considering the barriers to implementation of adaptation actions including budget required, the need of a policy change or introduction of legislation, the expected level of acceptance to stakeholders as well as the extent of research and development needed.

3 Integration of the methodology in the Irish project appraisal framework

3.1. Integration of appraisal criteria in the project cycle

Prioritisation of investment projects in a transparent and consistent way is one of the most difficult tasks for governments and policy makers, as the process of ranking entails the identification of the relevant features and their relative weights.

In the case of Ireland, the different phases of infrastructure planning and appraisal are explicitly defined in the Public Spending Code (PSC)[12] as:

1. **Strategic Assessment and Preliminary Business Case**, in which there is an early evaluation of the problem to be addressed, the objectives to be reached, the desired outcomes, and preliminary approval indicating that the project is worth proceeding with to detailed design;
2. **Pre-tender - Detailed project brief and procurement strategy**, in which there is a formal approval of the project to proceed to tender;
3. **Post – tender - Final business case**, in which, in light of the tenders received, a project is worth proceeding with.

Despite the precision of the requirements of information and appraisals across phases requested by the PSC, the consideration on the interactions between the project and the environment vary considerably across sectors especially with respect to reference to planning documents and prioritization schemes.

In order to rule out such heterogeneity, the OECD Team has conducted extensive desk research and interviews with public officials from the Department of Transport, Office of Public Works and the Department of Public Expenditure, NDP Delivery and Reform on planning, budgeting and appraisal of infrastructure projects. The results of the analysis are reported in Table 3.1. Most notably, DPENDR defines general guidelines applicable to all sectors, while the Office of Public Works and Department of Transport have sector specific guidelines.

This chapter will leverage the Team's background research to discuss infrastructure planning and appraisal and propose a methodology for investments prioritisation that can fit into the existing Irish framework.

Our proposal is that prioritisation of projects should be conducted on the basis of a **scoring mechanism** ranking items on a 5-point scale across two areas: **an economic and an environmental area**. In

[12] See also Department of Public Expenditure, NDP Delivery and Reform (2012), Public Spending Code. A Guide to economic appraisal: carrying out a cost benefit analysis.

particular, projects will be ranked in the economic area according to the results of the cost-benefit analysis, total emissions of CO2 and impact of climate variables and extremes with scores reported in Table 3.4.

It should be noted that item scores are consistent with the assessment of the National Development Plan review[13].

Table 3.1. Planning, appraisal and budgeting of infrastructure projects in Ireland

	Office of Public Works	Department of Transport	Department of Public Expenditure, NDP Delivery and Reform
PLANNING			
Integration of the environment and climate in long-term planning	The potential impacts of climate change have been assessed nationally with regards to flood risk through the Catchment-based Flood Risk Assessment and Management (CFRAM) Programme and through subsequent national indicative flood mapping projects.	The Government set sectoral emissions ceilings for each sector, including the transport sector.	Project Ireland 2040 (PI2040) is the long-term overarching strategy for public investment in Ireland out to 2040. The National Planning Framework (NPF) and the National Development Plan (NDP) 2021 – 2030 combine to form Project Ireland 2040. PI2040 includes environmental and climate goals and objectives.
Existence of mechanisms to align project with policy objectives	The Flood Risk Schemes form part of the National Development Plan (NDP) and are integrated into statutory spatial plans at National (NDP), Regional, County / City and Local Area scale as appropriate. Flood risk management planning is aligned with the Ireland's National Biodiversity Plan, especially with the objectives of minimising the loss of biodiversity and ecosystem services through environmental assessments (i.e. SEA, EIA and AA) and of having policies and research in place to promote more catchment-wide and non-structural flood risk management measures.	In the development of individual transport projects - as outlined in the Public Spending Code and CAF - it is necessary to demonstrate the strategic context and projects' alignment with transport and wider policy objectives, including climate and environmental goals.	Each department is responsible for ensuring that project proposals align with national and supra-national policy objectives for the environment and climate.
Consideration of climate mitigation	The assessment of the emissions (i.e. carbon footprint) impact of public investment in FRS is now a standard requirement as part of the design and implementation process. However, as of currently, the emissions impact is not factored in the planning and prioritization of capital investment programmes.	The modelling undertaken for the GDA Transport Strategy considers the interim targets for 51% reduction in transport related emissions by 2030. Moreover, the TII has developed **a carbon emission too**l, which can measure the usage and embodied emissions of transport infrastructure.	
Consideration of climate adaptation	Flood relief schemes that are planned, or currently in construction or under design, will include a Scheme Climate Change Adaptation Plan. This will ensure that climate adaptation is embedded in the design process and help to ensure that the scheme is planned and designed so that it can be adapted to manage increased flood risk associated with the potential impacts of climate change. A pilot Scheme Adaptation Plan has been prepared for Midleton Flood Relief Scheme.	The development of the Transport Sectoral Adaptation Plan (SAP) included a strategic climate vulnerability screening and identified high-priority risks, medium-priority risks and low-priority risks for the transport sector as a whole. This involved collaboration with the Environmental Protection Agency (EPA), the Irish Centre for High-End Computing (ICHEC) and others.	There are no specific guidelines around climate change risk assessment

[13] See Department of Public Expenditure, NDP Delivery and Reform, "Climate and Environmental Assessment of NDP Review Spending Proposals".

	All existing flood relief schemes will also have a Scheme Climate Change Adaptation Plan prepared retrospectively to determine what future interventions or works would be required to maintain the standard of protection to communities that they currently enjoy. A pilot Plan has been prepared for the Mallow flood relief scheme in County Cork, and a national programme is now commencing to prepare such plans for the other schemes previously constructed around the country		
APPRAISAL			
Existence of criteria for conducting cost-benefit analysis	Standard CBA is widely adopted	Standard CBA and CEA are widely adopted	Standard CBA and CEA are widely adopted
Existence of other methods	Multi-criteria analysis is adopted	Multi-criteria analysis is adopted	Multi-criteria analysis is adopted
Existence of clear prioritization mechanisms	While there are no "clear" prioritisation mechanisms, guidelines and tools for project prioritization, but there are some priorities and hierarchies set out in the NIFTI. Moreover, the first tranche of the proposed flood relief schemes set out in the Flood Risk Management Plans were prioritised based on the number of properties at risk within the relevant community, and that would benefit from the scheme.		

Note: Based on the responses to the questionnaire provided by different Departments of the Irish Government.

Table 3.1 provides a general overview of the main elements and strategies developed by some of the departments more directly involved in infrastructure planning and appraisal in Ireland. Interestingly, there seems to be a clear gap in the explicit evaluation and prioritization of projects based on their interactions with the environment and climate.

Finally, Table 3.2 reports the integration among current project cycle in Ireland and the activities related to climate mitigation and climate adaptation.

Table 3.2. Climate proofing and project cycle in Ireland

PSC project lifecycle					
Strategic assessment	Preliminary Business case	Final Business case	Implementation	Review	Ex-post evaluation
Climate neutrality-mitigations					
• Link to climate policy	• Quantification of GHG emissions • Monetisation of GHG emissions • Economic analysis • Coordination with EIA process		• Implementation of mitigation measures in the construction and operation phase	• Verification of actual GHG emissions • Verification of the effectiveness of mitigation measures and setup of alternative measures	
Climate resilience - adaptation					
• Strategic climate vulnerability screening to identify potential risks from climate change impacts	• Screening in terms of exposure, sensitivity, vulnerability • Risk assessment and impact analysis of climate variable and extremes • Measures for adaptation • Coordination with EIA process		• Implementation of adaptation measures in the construction and operation phase	• Verification of actual GHG emissions • Verification of the effectiveness of adaptation measures and setup of alternative measures	

3.2. Appraisal

As shown in Table 3.2, we envisage the possibility to evaluate and prioritise the project in the preliminary and final business cases in terms of information:

- Quantification of GHG emissions;
- Monetisation of GHG emissions;
- Economic analysis;
- Coordination with EIA process;

The preliminary business case sets out the preliminary information base upon which a first decision is made (i.e. Approval Gate 1). Most notably, it should provide a first assessment of costs, benefits, affordability, deliverability, risks and sensitivities of the project and of alternative options. The preliminary business case report should include:

a) Confirmation of the strategic relevance of the proposal and detailed specification of the objective of the proposal;
b) Description of the short list of potential options to deliver the objectives set out;
c) Detailed demand analysis and description of underlying assumptions;
d) Options appraisal - including financial and economic appraisal, and sensitivity analysis;
e) Assessment of affordability within existing resources;
f) Risk assessment, allowance for optimism bias and full risk management strategy;
g) Proposed approach to procurement;
h) Proposed approaches to implementation and operation;
i) Assessment of delivery risk;
j) Plan for monitoring and evaluation, including key performance indicators;
k) Recommendation to the approving authority.

Contents sub d) and f) are of key relevance for the assessment of the project in terms of climate change mitigation and adaptation, so that our proposal is to complement the current practice in the drafting of the preliminary business case report with information covered in chapters 1 and 2 of this working paper that is:

i. An assessment of the GHG emissions of the project and related options within the preferred framework of cost-benefit analysis as well as separately in order to highlight information useful to assess the contribution of the project to the general climate change strategy of Ireland. Data should cover in principle both the investment and the operating phases.
ii. An assessment of the project and related options of the resilience with respect to climate change scenarios as well as to extreme events. The sponsoring agency should make effort to identify potential threat to the functionality of the project generated by changes in the climate and propose eventual mitigation actions in terms of training, capacity building, monitoring, use of best practices and standards, nature-based solutions, engineering solutions, technical design, risk management insurance.

Information related to climate mitigation (i.e. information *sub* i.) should be ideally embedded in the framework cost-benefit analysis of the project or eventually within the economic appraisal conducted with other methodologies (e.g. multi-criteria analysis). Differently from current practice, they should consider also the environmental and climate impacts of both capital and operating expenditure and the results should be discussed explicitly within the report and by the approving authority when making the decision at gate 1.

Information related to climate adaptation (i.e. information *sub* ii.) should be part of the risk analysis currently contained in preliminary business case report. However, in addition to current practice, long run environmental and climate risks should be identified and evaluated qualitatively by adopting the methodology proposed in chapter 2 of the present working paper and coherent with the climate proofing concept of the European Commission. This information should be made distinctive with respect to current risk analysis in terms of net benefits and cash flows volatility, ideally, in a separate section or sub-section of the report, to that the approving authority will be in the position to evaluate the strength of the project in terms of future climate scenarios and extreme events.

Mitigation and adaptation characteristics of the project should be in principle assessed in terms of counterfactual projects and scenarios. Often, the sponsoring authorities do not consider alternative projects as proper counterfactuals, but rather they assess the quality of the project under evaluation with respect to the *status quo*. This option is correct if all the socio-economic and environmental trend Ireland faces are properly considered. In other words, a decision rule in the form of "*positive present value of future net benefits*" implies that the future will maintain the same level of social welfare as the present. In cases of environmental deterioration, future welfare will be possibly lower, other things equal, and this need to be considered properly. As an extreme situation, a project generating a welfare loss might be considered as acceptable if this loss is lower than the trend loss the society will face in the future under the "do-nothing scenario".

The preliminary business case assesses the project in terms of consistency with national and regional planning policy, national public investment policy, specific sectoral policy, climate action policy. At this point, it should be evident that the type of information provided in evaluating project mitigation and resilience might be crucial to provide the approving authority with quantitative and qualitative information regarding the consistency with Irish climate action policy to make the decision at gate 1. In order to facilitate such decision, a slight expansion of the items the approving authority checks when reviewing the preliminary business case report might prove to be beneficial.

Currently, the approving authority checks the quality of the report in terms of:

1. Specificity of objectives;
2. Alignment with national policy;
3. Completeness of options appraisal;
4. Technical soundness of the options appraisal including assumptions, economic parameters, evidence base used, etc.;
5. Affordability;
6. The relative merit of the proposal in comparison to competing proposals;
7. Consideration of the range of potential costs and risks;
8. Consideration of the detailed delivery programme;
9. Assessment of procurement strategy and commercial arrangements including capacity of the promoter to delivery.

In order to highlight the consistency of the project with respect to climate objectives, a further item might be considered:

10. **Assessment of the climate adaptation and mitigation properties of the project and its consistency with climate action policy**.

To facilitate the assessment of the business case by the approving authority, the sponsoring authority may consider condensing and eventually replicating all climate and environment-related information in a separate section of the report. To this end, a further section with respect to sections a)-k) reported above should be included before k) Recommendation to the approving authority:

l) Climate and environmental performance of the project.

This section might also include information relevant for the Environmental Impact Assessment and constitute the documental evidence of the co-ordination between the project appraisal activity and EIA, envisaged in Table 3.2.

Finally, it should be noted that climate adaption and mitigation properties, as well as general environmental outcomes of the project, that is information contained in the aforementioned novel section l) of the report, should be revised and eventually updated in the final business case stage, at gate 3.

3.3. Prioritisation

Prioritisation of investment projects in a transparent and consistent way is one of the most difficult tasks for governments and policy makers, as the process of ranking entails the identification of the relevant features and their relative weights. **We propose that this activity is performed by the approving authority at the earliest stage possible prior to reaching approval (i.e. Approval Gate 1), although differences may emerge across sectors.**

In the medium run, we suggest prioritising projects on the basis of a scoring mechanism ranking items on a 5-point scale which would consider the environmental impact alongside the economic impact. The specific items and scores given in the prioritisation framework can be adapted considering government's priorities and key policy objectives.

In the proposed framework, climate change mitigation and the reduction of GHG emissions is considered of high priority. Therefore, projects will be ranked based on the economic impact (i.e. the results of the cost-benefit analysis), total emissions of CO2 and the impact of climate variables and extremes with the scores reported in Table 3.3 and Table 3.4.

It should be noted that item scores are consistent with the assessment of the National Development Plan review[14]. In the NDP review, scores were attributed ex-post, whereas, in the prioritisation activities, projects will be evaluated ex-ante, so that a final ranking of projects, highlighting priorities, will be available. Ideally, all Departments should be involved in the process and, even more importantly, Environmental Impact Assessment and Strategic Impact Assessment might be documents, along with the document by the Environmental Protection Agency "Ireland's Environment – An Integrated Assessment", needed to inform the scoring mechanism.

Table 3.3. Example of items scores for prioritisation

Score	Cost-benefit analysis	Evaluation of CO2 emissions	Impact of climate variables
-3	NPV or IRR very below average / 5th quintile / very positive	Very below average / 5th quintile	Extreme
-1	NPV or IRR below average / 4th quintile / positive	Below average / 4th quintile	High
0	NPV or IRR on average / 3rd quintile / marginally positive	On average / 3rd quintile	Medium
+1	NPV or IRR good / 2nd quintile / negative	Good / 2nd quintile	Low
+3	NPV or IRR excellent / 1st quintile / very negative	Excellent / 1st quintile	Null

[14] Department of Public Expenditure, NDP Delivery and Reform, "Climate and Environmental Assessment of NDP Review Spending Proposals".

Table 3.4. Scoring structure

Area	Item	Weight
Social welfare and climate	Cost-benefit analysis	0.5
	Total emissions of CO_2	0.25
	Impact of climate variables and extreme events	0.25

The final score of a project will be the weighted average of items' evaluation across the economic and environmental areas, so that a final ranking of projects can be generated, eventually for the sake of fiscal and carbon budgeting[15].

Furthermore, it should be noted that **the number of areas can be extended to other impacts**, such as demographic, economic (growth), fiscal, institutional, depending on the structure of social preferences of the Irish government. Also in this vein, **weights in the table are merely indicative and somewhat "neutral"**. They can be adapted to reflect specific policy objectives. In principle, social preferences should be elicited among policy makers (not necessarily political actors), preferably by means of anonymous questionnaires, and the results scrutinized by using a standard sensitivity analysis[16].

[15] See the document by Climate Change Advisory Council, "Carbon Budgeting Technical Report", October 2021.

[16] On these issues, see OECD (2008), Handbook on constructing composite indicators, OECD-JRC; G. Munda (2008), "Social Multi-Criteria Evaluation for a Sustainable Economy", Springer.

Annex A. Carbon footprint methodologies

This Annex reports suggestions made in the document EIB Project Carbon Footprint Methodologies, "Methodologies for the assessment of project greenhouse gas emissions and emission variations", Version 11.2 with specific reference to the transport sector. Further details and also information regarding other sectors, such as energy production, can be found in the aforementioned document.

Road transport

A proprietary model, ERIAM, is used. This takes project input data in the form of traffic data and costs data and calculates the emissions without the project and emissions with the project for third-party use of the project infrastructure in the form of existing and induced traffic indirect emissions. Induced traffic is determined by the analyst on a case-by-case basis according to the project's circumstances, usually by applying an appropriate elasticity to the percentage change in expected time savings in the opening year.

The model has an assumed set of relationships relating to speed and fuel use, speed and traffic flow and fuel use and GHG emissions. The sector expert can select the relative ratio of diesel and gasoline vehicles in use and the type of vehicles considered light vehicle diesel and gasoline and heavy goods vehicle diesel.

Emissions from the project construction phase are not included.

Rail transport

A proprietary model, RAILMOD, is used. This takes project input data on rail line lengths and uses and calculates the avoided emissions, absolute emissions and baseline emissions.

Alternative modes that are considered are rail, high-speed rail, car (truck for freight), bus and plane. Modal shift is accounted for.

Emission factors for fuel types can be entered by the user into the model.

If the project is a rolling stock replacement, the project boundary is the fleet being replaced and the operation to which it is dedicated. Absolute emissions are those related to the operation carried out by these vehicles: the total yearly production in train-km for the replaced fleet is calculated. Based on this, on the average consumption (per car-km or train-km) of fossil fuel or of electric energy, and on the CO2 emission factor (grams of CO2 per litre of fossil fuel or per kWh), the total fleet emissions per year are calculated (scope 1 or 2 emissions).

For baseline emissions, either the replaced fleet is taken as a conservative assumption (if the old fleet can still be legally operated) or, in case sufficient information is available, any modal shift and induced traffic is calculated.

Emissions from the project construction phase are not included.

Urban transport

A proprietary model, URBMOD, is used to calculate emissions. This takes project input data from the promoter's traffic model and calculates absolute, baseline and relative emissions.

Absolute emissions are calculated as those stemming from the project's operation. The calculation of baseline emissions is based on the change in emissions for all other modes stemming from the reduction of the mileage of competing modes resulting from the shift in demand to the project. Relative emissions represent therefore the net change across the network as a result of the project. Reported emissions are the average over the entire project's economic life.

URBMOD appraises different urban public transport modes including electricity-based systems, such as suburban railways, metro and tramway lines, light rail systems and trolley/electric buses, as well as standard buses.

Default emission factors in URBMOD are based on COPERT/TREMOVE values for the urban cycle and are country specific

For electricity-based systems, the user enters a project's specific consumption rate in the model (kWh/km) which is then converted into GHG emissions (gCO2/kWh) through average electricity emission factors.

URBMOD is typically used for new infrastructure with significant impacts on service supply and demand. It is not used for asset renewal with marginal impact on supply and demand, for which a demand estimate based on a traffic model is normally not available.

For the type of operations where modal shift is limited, absolute emissions are calculated as those stemming from the project's operation, while baseline emissions are calculated in relation to a credible alternative consistent with the guiding principles set out in this methodology.

Emissions from the project construction phase are not included.

Other transport

Vessels

If the project is financing a new fleet of vessels, the project boundary is the financed vessels and the expected operations.

Absolute emissions of a new fleet/vessel are the average annual emissions of the vessel(s) included in the project. This estimation is based on expected annual fuel use per fuel type of the project vessel(s) (if available, otherwise averages will be used) and standard fuel emission factors. No absolute emissions are calculated for retrofit operations.

Relative emissions are calculated as the average per unit emissions savings between the project and the without project scenario over the economic life of the project, multiplied by the traffic in the project scenario. In competitive markets, the relative emissions are expected to be limited.

Ports

A detailed methodology for the calculation of the carbon footprint of a port project can be found in the Annex 5 "Ports and airports: carbon footprint calculation methodology" of the EIB's document.

Air

If the project is financing new aircraft, the project boundary is the financed aircraft and the operation to which they are dedicated. Absolute emissions are those related to the operation of these assets: the total yearly production in km is estimated based on the routes taken and number of trips per annum. Using this figure and the average occupancy of the plane in number of passengers, the emissions can be expressed by multiplying by the efficiency factor of the aircraft expressed in gCO2/pax*km.

Airports

A detailed methodology for the calculation of the carbon footprint of an airport can be found in “Annex 5: Ports and airports carbon footprint calculation methodology”.

E-mobility, including hybrids, full battery electric and hydrogen fuel cell vehicles, and its charging infrastructure

If the project is a fleet replacement, the project boundary is the fleet financed and the operation to which it is dedicated.

If the project is recharging or refueling infrastructure, the project boundary is the energy dispensed by the infrastructure to a fleet being served.

Absolute emissions are those related to the operation carried out by these fleets: the total yearly production in vehicle-km or vessel-km.

Based on the average consumption of electric energy or hydrogen (combined with any other (fossil) fuels consumption in case of hybrid vehicles), and on the CO2 emission factor (grams of CO2 per kWh or per kg of H2), the annual total fleet direct emissions are calculated (scope 1 or 2 emissions).

Average consumption is based on (industry) standards if no other information is available (e.g. WLTP for cars and vans and VECTO for heavy-duty vehicles). In case VECTO data are not (yet) available, a reasonable proxy is assumed.

CO2 emission factors for electricity consumption are based on the electricity emission factor for that country unless justified in line with guidance in paragraph 7. For hydrogen, as “grey” hydrogen is the dominant type of hydrogen, scope 2 emissions will need to be based on this type of hydrogen unless another source can be assumed over the lifetime of the vehicle (9.98 kg CO2-eq/kg H2).11

Baseline emissions are calculated in relation to a conventional fleet (internal combustion engines running on fossil fuels).

For all of the above: Emissions from the project construction phase are not included.

References

AghaKouchak, A. et al. (2020), "Climate Extremes and Compound Hazards in a Warming World", *Annual Review of Earth and Planetary Sciences*, Vol. 48, pp. 519-548, https://doi.org/10.1146/annurev-earth-071719-055228. [8]

ClimateADAPT (n.d.), *Adaptation Support Tool - Assesing adaptation options*, https://climate-adapt.eea.europa.eu/en/knowledge/tools/adaptation-support-tool/step-4-2 (accessed on January 2023). [20]

ClimateADAPT (n.d.), *Adaptation Support Tool - Assessing climate change risks and vulnerabilities*, https://climate-adapt.eea.europa.eu/en/knowledge/tools/adaptation-support-tool/step-2-0 (accessed on January 2023). [14]

Commission, E. (2021), "EU Vademecum 2021-2027", in *Economic Appraisal Vademecum 2021-2027 - General Principles and Sector Applications*, Publication Office of the European Union, https://doi.org/10.2776/182302. [4]

Corsatea, T. et al. (2019), *World Input-Output Database Environmental Accounts [EUR 29727 EN]*, Publications Office of the European Union, https://doi.org/10.2760/024036. [3]

Croce, P. et al. (2018), "The snow load in Europe and the climate change", *Climate Risk Managemnt*, Vol. 20, pp. 138-154, https://doi.org/10.1016/j.crm.2018.03.001. [12]

Department of Public Expenditure, NDP Delivery and Reform (2019), *Public Spending Code: Supplementary Guidance - Measuring & Valuing Changes in Greenhouse Gas Emissions in Economic Appraisals*, Government of Ireland, https://www.gov.ie/en/publication/public-spending-code/. [5]

Department of Transport (October 2021), *Common Appraisal Framework V4*, Government of Ireland, https://www.gov.ie/en/organisation-information/800ea3-common-appraisal-framework/. [7]

Diffenbaugh, N. et al. (2017), "Quantifying the influence of global warming on unprecedented extreme climate events", *Proceedings of the National Academy of Sciences of the United States of America (PNAS)*, Vol. 114/19, pp. 4881-4886, https://doi.org/10.1073/pnas.1618082114. [18]

European Commission (2021), *Technical guidance on the climate proofing of infrastructure in the period 2021-2027 - (2021/C 373/01)*, Official Journal of the European Union, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021XC0916(03) (accessed on 24 February 2023). [1]

European Investment Bank (2023), *EIB Project Carbon Footprint Methodologies - methdologies for the assessment of project greenhouse gas emissions and emission variations*, European Investment Bank, https://www.eib.org/en/publications/20220215-eib-project-carbon-footprint-methodologies. [2]

European Parliament and the Council of the European Union (2020), *Regulation (EU) 852/2020 on the establishment of a framework to facilitate sustainable investment*, Official Journal of the European Union, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32020R0852. [15]

Fisher, E. and R. Knutti (2015), "Anthropogenic contribution to global occurrence of heavy-precipitation and high-temperature extremes", *Nature Climate Change*, Vol. 5, pp. 560-564, https://doi.org/10.1038/nclimate2617. [9]

Forzieri, G. et al. (2018), "Escalating impacts of climate extremes on critical infrastructures in Europe", *Global Environmental Change*, Vol. 48, pp. 97-107, https://doi.org/10.1016/j.gloenvcha.2017.11.007. [17]

IEA (2015), *Making the energy sector more resilient to climate change*, International Energy Agency (IEA), https://www.iea.org/reports/making-the-energy-sector-more-resilient-to-climate-change. [19]

Kreibich, H. et al. (2014), "Costing natural hazards", *Nature Climate Change*, Vol. 4/5, pp. 303-306, https://doi.org/10.1038/nclimate2182. [11]

OECD (n.d.), *OECD Environment Policy Papers*, OECD Publishing, Paris, https://doi.org/10.1787/23097841. [13]

Pall, P. et al. (2011), "Anthropogenic greenhouse gas contribution to flood risk in England and Wales in autumn 2000", *Nature*, Vol. 470/7334, pp. 382-385, https://doi.org/10.1038/nature09762. [10]

Team, T., R. Pachauri and L. Meyer (eds.) (2014), *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Intergovernmental Panel on Climate Change (IPCC), https://www.ipcc.ch/report/ar5/syr/. [16]

van Essen, H. et al. (2020), *Handbook on the external costs of transport : version 2019 – 1.1*, Publications Office of the European Union, https://doi.org/10.2832/51388. [6]