CEDR
Conférence Européenne
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Directors of Roads

ICARUS

Improve the uptake of Climate change Adaptation in the decision-making processes of Road aUthoritieS

Guidelines on using performance metrics to make the case for adaptation

Deliverable D2.2 Version 1.0

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Summary

While the significance of resilience and climate change adaptation is well understood, practical implementation remains a challenge. Integrating climate change adaptation into decision-making processes can be complex, often resulting in a gap between knowledge and action. To bridge this gap, it is essential to determine how resilience and adaptation options can be effectively expressed to facilitate decision-making.

This document serves as a guideline for National Road Administrations (NRAs) on using performance metrics to make the case for adaptation. Within this document we explore the link between Key Performance Indicators (KPIs) and benefits and co-benefits of adaptation, ultimately to describe how to operationalise these within a decision-making context. By effectively expressing and evaluating adaptation strategies based on the existing decision-making context at NRA's, decision-makers at the NRAs can optimize their efforts to build resilience and foster a more sustainable and resilient future.

The decision-making process at NRAs is multidimensional and is done via different steering mechanisms; sometimes decisions are made via guidelines and design standards (often at asset scale), whereas other decisions are made via Key Performance Indicators (which are described mostly at a network scale). The challenge of implementing climate change adaptation options within these decision-making processes of NRAs is complex due to the existence of a tactical gap:

- It is not well understood how changes in guidelines and standards lead to different performance in terms of KPIs.
- The effect of climate hazards and climate change on KPIs is not well understood, further complicated by external factors like societal changes.
- There is limited understanding of how the effectiveness of adaptation options can be measured in terms of performance and changes in KPIs.

This is further complicated by boundary conditions (related to temporal and spatial scope, capacity, and data availability) which need to be clarified and specified before decisions can be made.

This guideline provides recommendations to overcome this tactical gap. Central theme in these recommendations is the differentiation between benefits and co-benefits that link to the decision-making context of NRAs and KPIs in particular. The metrics used for KPIs, policies and other indicators are often not suitable for assessments of adaptation options, and thus need to be converted to a more applicable metric to be used in evaluation of adaptation options. That is why this guideline recommends the use of benefits and co-benefits rather than KPIs.

Climate change adaptation options often yield co-benefits that extend beyond their primary benefits, positively impacting multiple sectors and stakeholders or society and the world in general. Understanding and valuing these co-benefits is essential to maximize the efficiency and effectiveness of climate change adaptation strategies. Since many NRAs are not allowed to invest for objectives beyond their service level agreement, it is key to link all co-benefits to existing policies and KPIs.

The key recommendations of the report are outlined below.

1. Key recommendations for influencing decision-making at NRAs:
    - Have a clear understanding of steering mechanisms which play a role in the NRAs and what are the key decision criteria NRAs use.

- Develop an approach to link the input-based (often asset-focused) indicators with the output-based (often network-based) KPIs by quantifying these.
- Identify dose-effect relationships for adaptation options.
- Consider effective communication across the different levels of steering mechanisms and decision-making due to the differences in metrics for estimating performance of the road.

2. Key recommendations for using performance metrics for making the case for climate adaptation:
    - For making the translation from KPIs to, and use of, benefits and co-benefits:
        i. Identify the relevant decision criteria for the NRA, based on the list of KPIs, other policies and other indicators
        ii. Translate these criteria to benefits and co-benefits.
        iii. Identify a feasible metric that can be used to assess and quantify the benefits and co-benefits.
    - To make most use of KPIs in the context of climate adaptation, it is recommended to adjust the KPI thresholds:
        i. To ensure that unforeseen and/or extreme events such as climate hazards are adequately included in the performance measurement. When climate hazards are not expressed in the KPIs, the rational for climate change adaptation is difficult to make.
        ii. To ensure for an appropriate spatial scale, often at connection level (or even to the asset level for critical assets).
        iii. To consider KPIs for specific seasons.
3. Key recommendations for gaining insight in the value of adaptation options:
    - The application of valuation methods will always be associated with some uncertainty. The accuracy of applying a measure should be determined based on the level of detail needed to be sufficiently informative in the specific context and the number of available resources. This trade-off between needed level of detail and resources used should always be considered carefully.
    - It is generally recommended to consider the magnitude/importance of the expected benefits. Whether a benefit is considered significant or not should go into the consideration given to the level of detail needed. Benefits that are expected to influence decision-making should in general require more scrutiny than benefits that are expected to influence decision making to a lesser extent.
    - Carefully consider what the relevant baseline should be, before starting to assess the expected benefits. Choosing the right baseline scenario will be vital in terms of not only the results, but eventually also the context in which these are applied.
4. Key recommendations for making the case for adaptation; three approaches are recommended to facilitate the decision making:
    - Approach 1 involves gaining insight into the effects of climate hazards on road performance by analysing trends in KPIs and their correlation with climate threats. This understanding helps determine the need for adaptation and future performance changes.
    - Approaches 2a and 2b focus on changing guidelines and standards to incorporate climate adaptation. The former aims to maintain current performance, while the latter involves optimising performance by evaluating costs, benefits, and co-benefits associated with guideline changes.
    - Approach 3 addresses the need for adaptation on a project-specific basis, considering factors such as political concerns, past climate events, and stakeholder involvement. Applying approach 3 can also serve as a basis for optimising guidelines through approach 2b.

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1 INTRODUCTION

1.1 Background and key challenges

In today's rapidly changing world, there is a growing recognition of the need to assess resilience for gaining insight in climate change adaptation options. The assessment of resilience has become crucial in addressing the challenges posed by climate change. Fortunately, in the past decade many frameworks have been developed to facilitate this assessment process.

While the significance of resilience and climate change adaptation is well understood, practical implementation remains a challenge. Integrating climate change adaptation into decision-making processes can be complex, often resulting in a gap between knowledge and action. To bridge this gap, it is essential to determine how resilience and adaptation options can be effectively expressed to facilitate decision-making.

Moreover, establishing a connection between resilience and the various steering mechanisms at different management levels of National Road Authorities is crucial. By aligning resilience strategies with existing governance structures, policies, and regulations, decision-makers can ensure that resilience and climate change adaptation are not treated as standalone concepts but as an integral part of sustainable development.

A key challenge in promoting resilience and adaptation is the identification and assessment of multi-benefits. Climate change adaptation options often yield co-benefits that extend beyond their primary objectives, positively impacting multiple sectors and stakeholders or society and the world in general. Understanding and valuing these co-benefits is essential to maximize the efficiency and effectiveness of climate change adaptation strategies.

Furthermore, evaluating adaptation options based on costs, benefits, and performance is of paramount importance. By conducting comprehensive assessments, decision-makers can make informed choices regarding the most viable and effective measures to enhance resilience. This optimization process ensures that available resources are utilized efficiently, resulting in resilient road networks, connections and assets that are better equipped to withstand future shocks and stressors.

This is what this ICARUS guideline is about. Resilience assessments play a vital role in addressing the challenges posed by climate change. By effectively expressing resilience and adaptation strategies, aligned with steering mechanisms as well as benefits and co-benefits, decision-makers at the NRA's can optimize their efforts to build resilience and foster a more sustainable and resilient future.

1.2 Objective of this guideline

Main objective of this guideline is to provide recommendations on how to effectively build the decision-making case for adaptation. Key in this regard is the link that is established between the performance metrics for the road services that road authorities use and the evaluation of adaptation options. It is deemed crucial, that the same metrics should be used for adaptation as are being used for other decisions that the NRAs make.

Sub objectives are:

- To consider the decision-making process at NRAs and how this should be used and informed regarding adaptation.
- To consider the performance metrics that road authorities use and how these metrics can be used in the field of climate change adaptation by translating them to benefits and co-benefits.
- To provide an overview of valuation options of benefits and co-benefits.
- To provide recommendations for approaches to build the decision-making case.
- To provide recommendations for evaluating adaptation versus service levels that the NRA is thriving for, by considering optimum service levels while balancing cost for adaptation with the wider benefits.

1.3 Definitions

Below we list the most relevant terms for understanding the recommendations in this guideline.

Adaptation option	An adaptation measure that is taken to adjust the road network, connection or asset to be more resilient against climate change in order to achieve a certain performance in the future while acknowledging the effects of climate change. Several types of adaptation options are available, ranging from. structural to non-structural and including nature-based solutions.
Benefit	Benefits are the effects of an adaptation option by comparing the effect after taking an adaptation option with the situation without intervention (business as usual situation). A benefit is expressed in terms of a KPI. A co-benefit is a benefit that is not linked to a KPI.
Co-benefit	Co-benefits are the additional benefits that are achieved as a result of achieving the primary benefit (see Benefit).
Input steering	Input oriented steering mechanisms use guidelines/standards/regimes for design, maintenance and/or operation (hereafter called guidelines). The mechanism considers specific asset design, maintenance and/or operational requirements to achieve adequate performance of the road(network/connection).
KPI	Key Performance Indicators; the indicators with described metrics that road authorities use to measure the effectiveness and efficiency of their operations, processes, and services.
NRA	National Road Administration; the authority that manages the national road network.
Output steering	Output oriented steering mechanisms use KPIs to measure performance of the road. This mechanism guides decisions on the necessity of action (e.g. climate change adaptation) based on road performance against these indicators (KPIs). These indicators are focused on network scale performance.
Service level	A level of performance. Different types of service levels are discerned in this guideline. These are: Minimum service level: The level that the NRA/society/politics always requests as the service level that should always be met Optimum service level: This is the minimum viable service level; the level at which the costs of the intervention leads to the highest additional benefits, including co-benefits. Additional investments would lead to lower net (wider) benefits.

1.4 Reading guide

In Section 2 the context within which this guideline should be used is described. This links to the general framework for enhancing resilience at NRAs as well as to boundary conditions for decision making. Section 3 describes the decision-making process at NRAs, which is important to fully understand for ensuring that the decision case for adaptation is addressing the right decision information as well as stakeholders. Section 4 provides a description of performance metrics that are generally used for roads. It describes how the various KPIs and other policies can be used in the field of climate change adaptation and paves the ground for the next section 5 in which benefits and co-benefits are introduced for valuing the adaptation options. Finally, everything is being integrated in Section 6, in which 3 approaches are introduced for building the decision case for adaptation. This section also introduces the evaluation options that are available for balancing cost, (co-)benefits and performance of the adaptation options.

This guideline should be read in conjunction with the other reports of the ICARUS project. An overview of these reports and how they relate to the underlying guideline is provided in Section 2.1.

2 UNDERSTANDING THE CONTEXT

2.1 The ICARUS framework: climate change adaptation decision making

Road authorities play a crucial role in ensuring the resilience of transportation networks. Decision making at road authorities is closely linked to resilience assessments, which involve evaluating the road system's ability to withstand and recover from disruptive events or changes. By conducting resilience assessments, NRAs can identify the most vulnerable locations of the road network and the risks involved in these as a consequences of natural hazard events. These outcomes can be used in decisions regarding the prioritisation of locations and investments to the infrastructure asset, connection or network. It allows road authorities to prioritize investments, allocate budgets, and allocate resources more efficiently and effectively, ultimately leading to a more resilient transportation system.

However, effective decision-making at NRAs is more complex than just performing the resilience assessment and involves more steps than performing the current and future performance of the road. Decision-making should also include the translation of these resilience assessments to decision-making at NRAs as well as the appraisal of adaptation options to identify which ones are most suitable at what location/part of the network. The ICARUS framework consists of the main steps that NRAs need to take for implementing climate change adaptation in their processes. This chapter introduces the contours of the ICARUS framework and how the underlying guidelines fit within the framework.

2.1.1 The contours of the ICARUS framework

Within ICARUS we adopt 6 main steps for incorporation of climate change adaptation in the processes of the NRAs, based on an extensive research of state of the art and state of practice in the ICARUS baseline reports [16, 17, 18].

The first step is called framing and consists of understanding the decision-making process at NRAs, as well as the use of Key Performance Indicators, existing policies and wider benefits in that regard. Furthermore, other boundary conditions for decision making should be clear like the temporal and spatial scope, capacity and resources and data examination. And finally, a clear overview of all involved stakeholder should be present. By comprehensively understanding these aspects, road authorities can enhance their decision-making processes and effectively work towards implementation of adaptation options for enhancing the resilience of the road network.

In the second step, business as usual is being assessed to understand how resilient the road network is for natural hazards, both for the current and the future situation. Adaptation is not yet considered. Insight in the resilience without adaptation will form the base case and is key to understand what the (wider) benefits are of adaptation options.

In the third step adaptation options come at stake. Adaptation options, as well as their benefits and co-benefits, are being identified. Adaptation options are being combined and placed on a timeline, in order to build adaptation strategies. The future resilience with use of these adaptation strategies is being assessed and benefits and wider benefits are being valued in such a way that this aligns with the decision-making process of the NRAs.

The fourth step builds the decision case for adaptation. By comparing the resilience for the business as usual with the resilience including adaptation one gains understanding of the benefits and co-benefits of adaptation strategies that can be evaluated with relevant evaluation methodologies. This step is key in providing the necessary information to decision makers while using the appropriate

methods and metrics, allowing them to consider the decision case integrally with other decisions that need to be made.

Here comes the fifth step at stake, in which the implementation of the decided strategies in practice needs to take place. By following the previous steps all relevant pre-processing has been done. However, now it needs to be ensured that all the valuable work will actually be implemented in practice.

The last step consists of monitoring of the results of adaptation. How is the performance of the road network developing towards the future? And does this link to the performance that was expected during the resilience assessments and appraisal of adaptation strategies? A proper monitoring enables evaluation of the performance and may lead to further steering of plans towards the future. Also, it further eases the decision case for adaptation, as it provides the metrics for the evaluation of adaptation strategies. This entails a feedback loop from this last step to the very beginning of the framework and all intermediate steps.

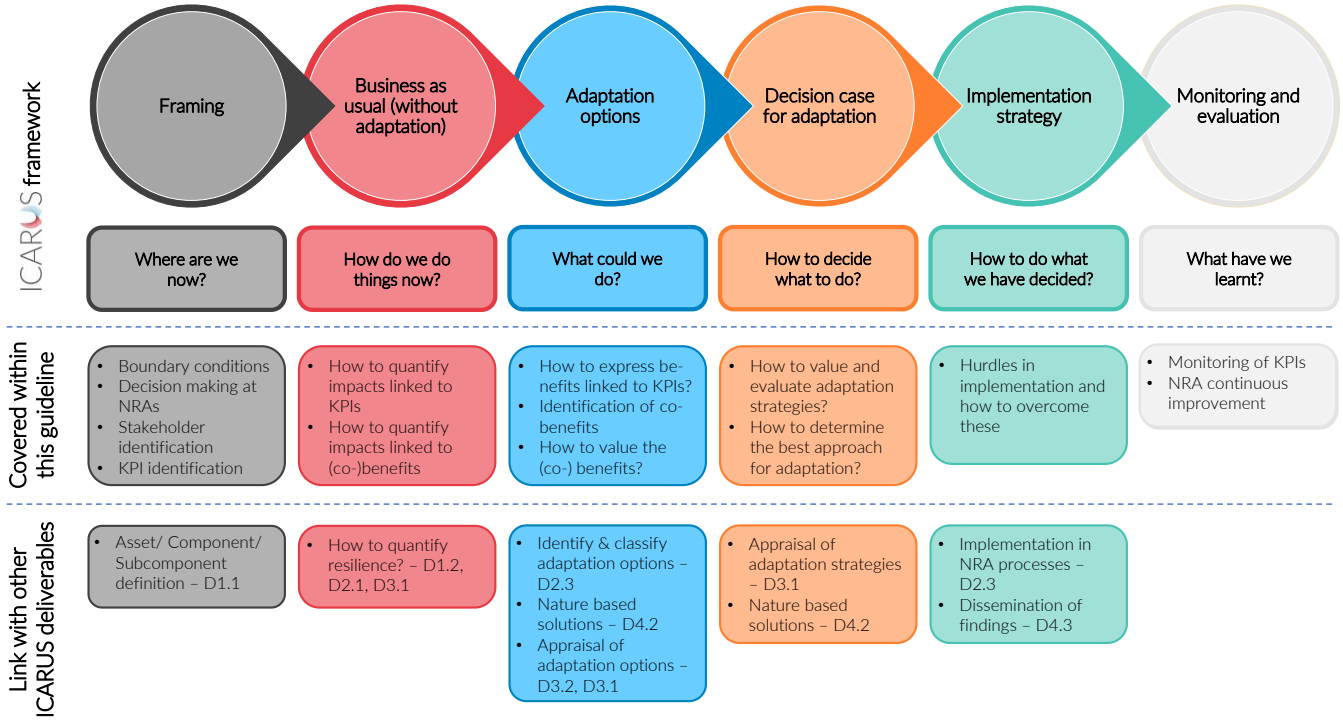

Figure 2-1 Overview of the steps in the ICARUS framework regarding decision-making and implementation of climate adaptation at NRAs, as well as how these steps are addressed in the underlying guidelines and other ICARUS deliverables.

2.1.2 This guideline D2.2 in relation to the ICARUS framework

Central idea of this guideline is that it is a prerequisite for enabling climate change adaptation decision making, to build the decision case along the same criteria that the NRA uses for all other decisions that are being made. This means that the use of requirements that are linked to the road network and how these can and should be addressed in the decision-making case for adaptation form a red line in this guideline. These requirements are expressed in the Key Performance Indicators that NRAs use for measuring the performance as well as policies in place that influence the decision-making process. It is key to understand how these criteria for decision making can be used to express the resilience of the roads and forthcoming also to express the benefits and co-benefits of adaptation options. Subsequently, the benefits and co-benefits can be valued and combined with the cost, allowing

evaluation of the available options and preparation of the decision-making case. This also allows for optimizing the performance by balancing (wider) benefits with the costs of implementation.

2.2 Boundary conditions for decision-making

When developing adaptation plans to increase resilience of the road at either asset, connection or network level, the first framing step is to identify the boundary conditions for the NRAs. Besides a clear identification of stakeholders within the NRA this also includes the following categories:

- Temporal and spatial scope: e.g. what is the time horizon the NRA aims to make the decision on and what is the spatial extent?
- Data examination: e.g. the quality and accuracy of the data should be validated to determine which approaches can be used to perform resilience assessments and approach for the appraisal of adaptation options.
- Capacity and resources within and outside the NRA e.g. what is the proposed budget, and are all human resources available and is all expertise in-house?

2.2.1 Temporal and spatial scope

Climate risk will change over time by its nature, not least as the global response to the climate crisis is uncertain. Resilience strategies must consider not only the impact of the risk itself but also how it may evolve over time and the spatial extent that is affected. A resilience approach could be based on a wide range of adaptation actions with both short- and long-term plans. Therefore, a strategy is needed to demonstrate the short- and long-term effects of climate adaptation and how the planning should account for uncertainty.

Sometimes it makes sense to invest in short-term adaptation options to solve problems in the longer-term. For example, in the current situation, certain assets, connections or parts of the network might not be affected very much with significant repair or investments, but when is known that in the future these locations become more vulnerable to a hazardous event or experience larger consequences as a result of an event, it might be more efficient to invest with limited resources in these locations now to prevent future problems. Also, planning in time gives the advantage of being able to execute adaptation strategies in a flexible manner and potential Decision-Making under Deep Uncertainty (DMDU) strategies.

To identify the spatial and temporal scope the recommended steps to take are:

- With the decision-makers at the NRA on strategic, tactical and operational level determine to what time horizon decisions are currently being considered (e.g. adaptation towards 2050, 2080, 2100 etc.) and what this time horizon is based on e.g. functional life span, economic life span. Here, a distinction should be made between yet to be constructed assets and corridors or upgrading existing assets, connections and network.
- When deciding on the time horizon also take the spatial scope into account. For example, investments at asset level will influence network performance, but when is known that investments are taken at connection level, this in turn influences whether changes at asset level are still preferred.
  Decide jointly on the scale to focus on. Is the ambition to increase the resilience/performance of the full network or does the NRA have a specific focus region for climate adaptation. To identify which assets and connections are most affected and how this influences the network performance, it is necessary to perform a resilience assessment for the current and future situation. How resilience assessments can be performed is explained in D2.1 as well as

information on climate change effects (D1.1) and how these propagate to infrastructure failure (D1.2)

Challenges: When performing these steps, several hurdles may arise. These can be related to the different life spans of part of the network and the typical investment schedule. Therefore, it is essential to discuss with all relevant stakeholders the time horizon because this also defines the approach at later stages of the resilience assessment and identification of adaptation options.

2.2.2 Data examination/quality of data

Implementing climate change adaptation options for road infrastructure requires data, which is a first critical step in performing a resilience assessment, because it may determine or limit the approach to perform the resilience assessment or evaluation of adaptation measures.

Information gathering occupies a large portion of time in the project schedule since it is a process of knowing where to collect data, how to collect data, involve all relevant stakeholders, and how to interpret the data collected. As an initial step in data collection, it is essential to know where the specific data can be obtained for each of the steps as described in Section 0. For this to take place successfully, all stakeholders that manage and maintain the data should be involved. These include data-providers, and experts at NRAs that are in the lead of performing the analyses e.g. performing the resilience assessment, identification of adaptation and the appraisal of adaptation options.

Also, when data are available, the quality might not be sufficient due to inconsistency or missing data. It is beneficial:

- To have a clear overview of where data are available with corresponding formats and short descriptions. In this way, it is properly disclosed which data exists and which is lacking. Even with vast amounts of available data, not being able to understand or rely on the retrieved information defeats the purpose of data collection. As prerequisite it is necessary to have an understanding of the spatial and temporal scope (Section 2.2.1).
- That data managers provide explanations on provided data. This can include interpretation of legends, scope, limitations, and how the data came about. This results in the data to be dependable: the user needs to know that the provided data set is complete and concise. If this is not the case, data sets may need to be cleaned up and/ or completed to be able to be used. Through such explanation, the information can be conveyed effectively to the users and may also provide plan on how to properly manipulate the data.

When data are not sufficiently maintained or available this influences the decision-making process, so that it identifies the uncertainties in the approaches involved and thus how certain decisions can be made. It inherently influences the approach for identifying the most appropriate climate adaptation plan. At the same time, it is not necessary to have the perfect dataset. This may turn out to be very challenging and time consuming, thus limiting resources that can also be used to come to an advice where decisions are made while considering uncertainty (see Deliverable 2.1 with the sections describing Decision-Making under Deep Uncertainty approaches).

2.2.3 Capacity and resources

When temporal and spatial scope (Section 2.2.1) are known, and is known what are the relevant stakeholders within the NRA at the different levels of decision making (Section 3.1), it is necessary to define the approach to build the business case for adaptation. For this, a thorough understanding of expertise needed is required and whether this expertise is available within the NRA, whether these people are involved or whether external support is required.

Relevant expertise includes, but is not limited to:

- Decision-makers at strategic, tactical and operational level that are able to define/understand the KPIs and co-benefits at network level, connection level and asset level. This is necessary when the performance of the road is evaluated.
- Experts that can perform a resilience assessment. This includes experts with an economic background as well.
- People that know what adaptation options are and how to identify which options are best suited. For example, people with experience in cost-benefit analyses for adaptation options, know how to apply bow-tie methodology and/or decision-making under deep uncertainty.
- People with an economic background for performing the appraisal of adaptation options.

An overview of the expertise required should be obtained by defining the capacity and resources that are available and needed. During a group conversation with all stakeholders involved (within and outside the NRA) identify what the steps are to take in the resilience assessment (Baseline report Deliverable 2.1, and this guideline). For each step then identify the time and expertise needed. Check within the group of stakeholders whether this expertise is represented sufficiently and if other people should be involved.

The proper execution of resilience assessment and implementation of climate adaptation needs expertise from very different disciplines and people at different decision-levels of the NRA.
We recommend having a core group of experts working for a large part of their time on the execution of the framework supplemented with a smaller sounding group of members that can reflect and execute if necessary. We further recommend that this group of stakeholders make agreements on the timeline, budget and scope of execution. Regular meetings and milestones should be identified in collaboration with each other (Links to Section 2.2.1 Temporal and spatial scope and Section 3.3 NRA decision criteria).

It is recommended there is an overview of external experts who know NRA processes, and who can be involved if knowledge and capacity lacks within the NRA, to prevent knowledge gaps and ensure better implementation. It is necessary though there is enough knowledge and capacity in this working field within the NRA to be able to manage and guide the work done by external experts, in order to prevent unwanted and unnecessary dependance on external parties. For ensuring implementation, it is also recommended to involve NRA staff who will be involved in the planning and execution of the adaptation measures, as they will understand the practical issues around implementation.

3 DECISION MAKING AT NRAS

This Section describes the components that influence the decision-making at national road authorities. For this, the NRA should have a clear understanding of the key decision criteria they use and how these are applied in practice, as well as the stakeholders involved at a strategic, tactical, and operational level.

3.1 Management Levels within the NRA

In the (asset) management of infrastructure there normally are three levels of organisation that have different responsibilities in the operations and management (Table 3-1).

- Strategic level
- Tactical level
- Operational level

The strategic level is mainly concerned with the setting of (national) targets for the performance of the network and connection level and possibly assets, with often a focus on network level. The strategic level is also responsible for the monitoring of (large scale) external factors that can influence the demands on the road network e.g. socio-economic growth, population growth and consequential increase in number of cars. These aspects need to be translated into future policies and long-term budgets. The strategic level is in control of the overall budget that is available for the maintenance, upkeep and expansion of the network, and should develop policies outlining how budgets can be assigned in the most efficient manner. Therefore, the strategic levels should make significant changes to budget assignments when these are deemed insufficient to cover identified future changes like climate change.

The main responsibility at the tactical level is to "translate" the national targets to guidelines, standards and regimes that can be used for design, construction, maintenance and operation, in order to ensure that the national targets are met. The tactical level is also responsible for the inventory of external factors that influence the performance of the road network e.g. climate change, increase in extreme rainfall, increased road drainage demand.
In practice, every NRA will have a different organisation and corresponding responsibilities for the tactical level, but generally it may have the following typical focal areas. They often have a role in the prioritisation of interventions on the (sub)network and associated assets and are responsible for their share of the budget of the (sub)network. The tactical level also often plays a role in the provision of information to the strategic level on the actual performance of the network and the budget that is required in the medium term for planned interventions for expansion of the network, replacement of assets and the budget required for operation and maintenance. Furthermore, the tactical level plays a role in assessing and reporting on regional developments and ambitions that can affect the requirements of the (regional) network.

The operational level is responsible for operating and maintaining the individual assets and connections. This is not only limited to the road (or stretches of roads) but also includes structures (flyovers, bridges, culverts, etc) that are essential for the good performance of the road.

Table 3-1. Description of the different management levels and their role within the NRAs including description of their main responsibilities and activities.

	Strategic	Tactical		Operational
Primary focus	Setting of overall goals and performance targets at **network level**, with possible involvement in sub-division to connection level or critical assets	Linking strategic goals to operational plans; Translation of key objectives at strategic level to practical guidelines (design/maintenance/operation) at the operational level Setting priorities for renovations and expansions at the **network, corridor and connection levels** Combining strategic goals with regional ambitions		Routine, preventive maintenance. Corrective maintenance and other interventions in case of emergencies at **connection and asset level**.
Organisational level for the road sector	Ministry and/or NRA senior management	Every NRA will have different organisation/ responsibilities for tactical level, but generally it may have these typical focal areas	NRA and higher management regional services	Regional/District services
Asset responsibilities	Owner		Manager	Operator
Asset level	Entire network and corridors		Corridors, connections	Connections, assets (structures, road segments)
Planning horizon	Long-term		Medium-term	Annual
Steering mechanisms	Output; KPIs, Service Level Agreements (SLA)		Process, output; KPI	Input; Guidelines and manuals
Budget responsibility	Securing of national or network level budgets, both for expansion, rehabilitation and operation and maintenance.		Drafting of budget requirements between (regional) assets and connections	Drafting of regional/district budget requirements for rehabilitation, operation, maintenance and annual planning for assets and connections
Typical KPIs	• Availability of national network • Number of collisions or (fatal) incidents at national level • Planned and unplanned interruptions of national network	• Availability of regional network • Number of collisions or (fatal) incidents at regional level • Planned and unplanned interruptions of regional network		• Percentage of network maintained • Response time in case of incidents • Unplanned interruptions/incidents
Activities	• Translating national policies and priorities to long-term developments of the network. • Planning network capacity by matching network performance with demand from society (capacity and availability) now and in the long-term. Setting safety standards for road users and network	• Translating the strategic goals to operational requirements via design and maintenance guidelines/standards • Translating network performance to interventions on an operational, tactical and strategic level		• (Planning and implementing of) regular operation and maintenance activities • Daily inspections and monitoring • Ad-hoc interventions in case of emergencies
Reporting	• Annual performance of the national network • Major unplanned incidents on the network • Bottlenecks in the network • Planned investments and rehabilitations • Implemented investments and rehabilitations	Depending on exact role at the NRA: • Annual performance of the regional network • Major unplanned incidents on the regional network • Bottlenecks in the regional network • Conditions of assets, connections and regional corridors • Planned investments and rehabilitations • Implemented investments and rehabilitations • Regional ambitions that require an intervention at the regional roads network		• Planned maintenance actions conducted • Unplanned maintenance actions and other interventions conducted • Incident reporting; cause, effect, duration • Condition of assets (structures, connections)

3.2 Decision-making based on different steering mechanisms

National Road Authorities (NRAs) utilise various mechanisms to make decisions, which are linked to road performance. When these different mechanisms are not properly aligned/connected this can pose challenges in building a case for climate adaptation. Understanding these mechanisms is crucial when implementing and advocating for adaptation options. This section provides recommendations for better decision making by providing an overview of the different steering mechanisms at NRAs. This is followed by an explanation of the hurdles associated with each mechanism. This information will serve as a baseline for Section 6, which will outline how the case for adaptation can be made.

3.2.1 Different steering mechanisms for road authorities

NRAs employ two general types of steering mechanisms:

1. Output oriented steering mechanisms using Key Performance Indicators (KPIs) to measure performance of the road (network): This mechanism, indicated by the yellow star with a number 1 in the top left corner of Figure 3-1, is often determined by road owners or policy makers. The KPIs typically focus on a network scale and are used to measure the performance of the network. This mechanism, referred to hereafter as the output-based steering mechanism, guides decisions on the necessity of action (e.g. climate adaptation) based on road performance against these indicators (KPIs).
2. Input and process oriented steering mechanisms based on guidelines/standards/regimes for design, maintenance or operation (hereafter called guidelines): This mechanism, reflected by the yellow star with number 2 in Figure 3-1, operates from a more bottom-up approach. The mechanism, hereafter referred to as the input-based steering mechanism, considers specific object design, maintenance and/or operational requirements to achieve adequate performance of the road(network).

Steering at the NRA can be done through the one or the other, a combination or none of these options. Both steering mechanisms work differently across different management levels within NRAs and are further detailed in the following sections.

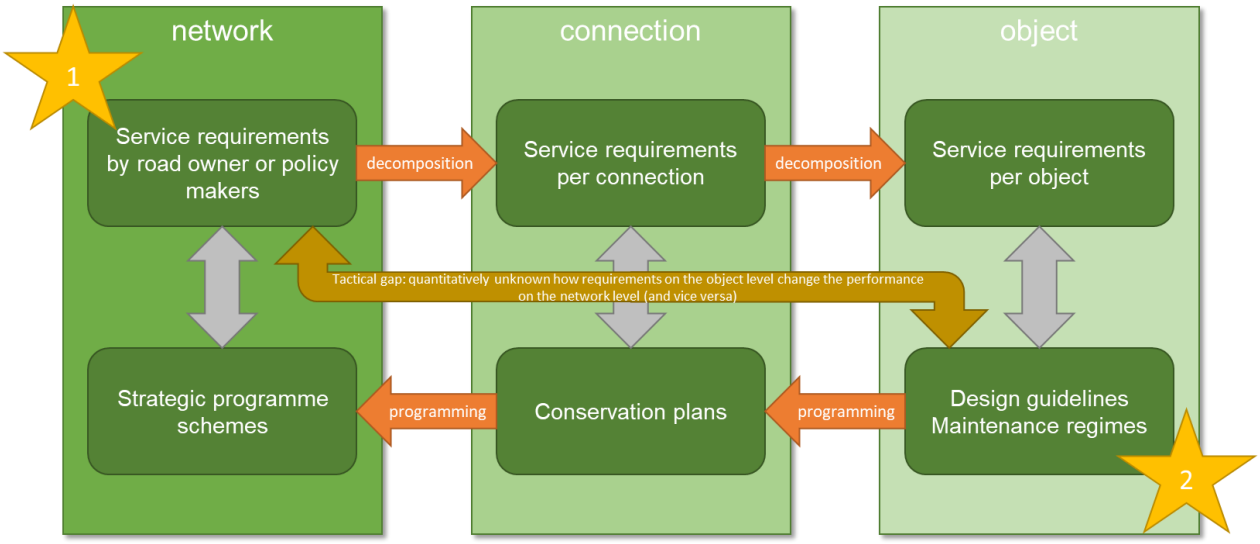

Figure 3-1 Line of sight for resilience across different levels (Adapted from Baseline report 2.1) showing the output steering starting at number 1 and input steering starting at number 2.

Steering based on output: KPI approach

The output-based approach (Figure 3-1, starting at yellow star 1) consists of the evaluation of the network performance based on the defined Key Performance Indicators (KPIs)which are used to monitor and report about the performance of the road network and its assets. In most cases KPIs are formulated for the road at network level. These are subsequently translated to service requirements per connection and per asset (Figure 3-1). However, a sub-division of the KPIs to the connection or even the asset level is not common practice. In principle it would be possible and preferrable to make this sub-division, because it would result in design guidelines and maintenance regimes that match the KPIs and set goals within these, that can subsequently be monitored.
The KPIs are often set by the NRA at the strategic management level. The different KPIs used will be further described and elaborated in the Section 4.1. The performance indicators are influenced by other factors, such as European and national policies and regulations such as environment, (carbon and/or final particle) emissions, and safety. These are further described in Section 4.1.3.

Steering based on inputs: building on guidelines

An input-based steering mechanism (Figure 3-1, starting at yellow star 2) assumes that pre-defined performance levels can be obtained when assets (i.e. roads, structures, etc) are constructed, maintained or operated according to specific criteria. As such the measuring of the actual performance is not an intrinsic part of the steering mechanism. However, there still remains some form of evaluation necessary to measure actual performance in order to verify that the prescribed activities and design criteria indeed achieve the required performance of the asset.

Performance targets (output) are usually set at the strategic level, whilst the drafting of the guidelines and manuals (input) can be done at the strategic or tactical level. The input steering mechanisms are then usually used at operational levels and in the design of standard structures.

Examples of input-based steering via guidelines are based on specification of design criteria or maintenance regimes that are deemed necessary to achieve an expected performance:

- The return periods for extreme situations that the road should be capable to withstand. The design criteria define for example the dimensions of drainage, storm water run-off, bridges, and/or culverts.
- The maintenance regime in activities and frequency per year and per location. For example, the frequency of the mowing of verges, cleaning the stormwater runoff system or removing the rocks in a rockfall ditch next to the road.
- Design characteristics of the road. For example, the type of vegetation next to the road, the maximum slope of embankments, minimum strength of materials or structural details to be used.

3.2.2 Tactical gap: hurdles in connecting different steering mechanisms

In practice, the steering at NRAs involves a combination of both input-based and output-based approaches and herein lies the challenge for building a case for climate adaptation. Based on the earlier CEDR study WATer management for road authorities in the face of climate Change (WATCH, 5) three reasons could be identified why the steering mechanisms used by NRAs complicate the decision-making process for implementing climate change adaptation options. These include:

1. The lack of understanding in quantifying input-based indicators to output-based KPIs;
2. The lack of knowledge on how climate hazards and climate change relate to KPIs, which is further complicated by other external factors such as societal changes; and
3. Limited understanding of how the effectiveness of adaptation options can be measured in terms of performance and changes in KPIs.

This tactical gap is further complicated by the fact that the metrics used at a network level to measure performance (KPIs) are different from the metrics used at the asset level for design and maintenance. Figure 3-2 provides an overview of these three main challenges that are further elaborated in the text below the figure.

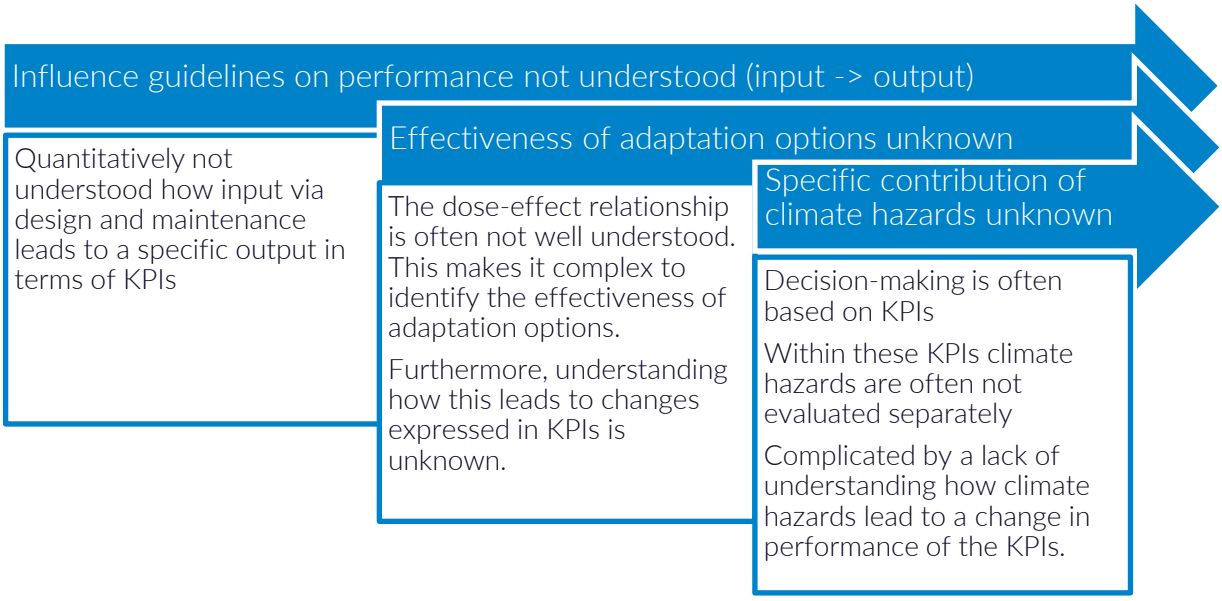

Figure 3-2 Description of the tactical gap and hurdles in linking the input and output-based steering mechanism.

One of the main bottlenecks is the challenge of **linking the design criteria and maintenance standards described in guidelines (input-based approach) with the Key Performance Indicators (KPIs)** used in the output-based approach. While it is generally easy to qualitatively understand how changes in design and maintenance can affect road performance. For example, a higher requested return period in design criteria would likely increase road availability and safety, as it can withstand more extreme events. However, quantifying the exact impact in terms of percentage increase in availability or reduction in casualties, injuries, or incidents is not well understood.

This bottleneck is further complicated when evaluating adaptation options. Adaptation options need to be assessed and translated into performance metrics, but when the influence of design and maintenance regimes on road performance in terms of KPIs is not well understood, the effects of adaptation options linked to design and maintenance will also not be easily quantified in terms of KPIs. Additionally, the **lack of knowledge on the quantification of effectiveness of adaptation options** further complicates this process. While it may be possible to assess the changes in road infrastructure strength, stability of embankments, or flood depth that can be withstood for some adaptation options, it is not straightforward for many other options, and clear dose-effect relationships are lacking. These dose-effect relationships describe how changes in maintenance and design influence the performance of the road, which to some extent is reflected in the KPIs. For example, it may be unclear how increased maintenance will impact the number of incidents, how increased cross slope of the road will affect the risk of pluvial flooding, or what the consequences are on availability of the road when a Nature Based Solution for stabilizing an embankment to prevent a landslides is applied. Therefore, the quantitative understanding of the effectiveness of adaptation options in terms of KPIs is limited, and clear dose-effect relationships need to be specified. Different appraisal methods are explained in Section 5.

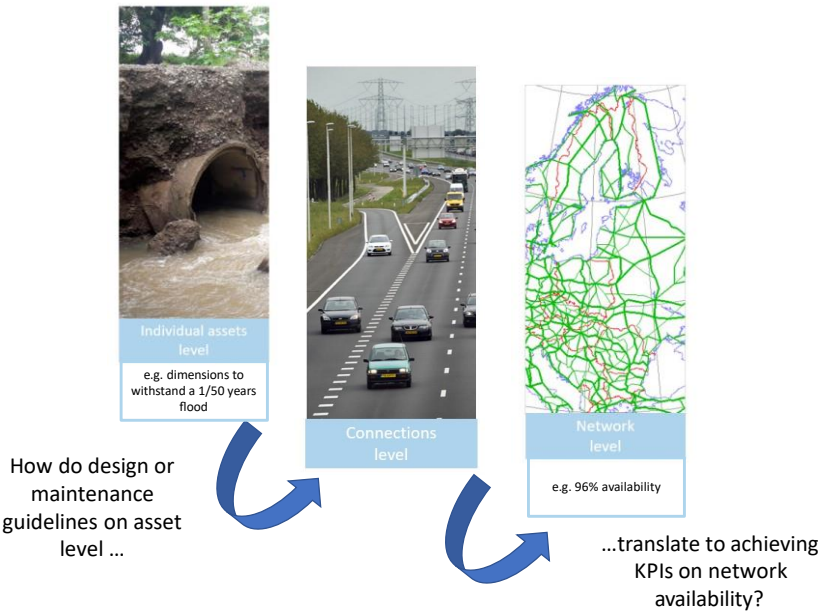

Figure 3-3 Hurdle 1 of tactical gap "linking guidelines to KPIs"

The final bottleneck is introduced when **estimating performance while considering the effects of climate change**. This is because the performance of the road, as measured by the output-based KPIs, is influenced not only by climate change, but also by other factors such as societal changes, current maintenance practices, and geo-political policies. For example, a decrease in availability may be caused by climate-induced events, but could also be due to backlog maintenance or cyber threats. Similarly, a decrease in safety may be influenced by older cars on the road or changes in traffic volumes due to societal changes.

3.3 NRA decision criteria

It is essential to understand the key decision criteria that the NRA normally use. These key decision criteria will be used to evaluate the adaptation options and ultimately build the business case for implementation. By connecting to the decision makers (at strategic, tactical and operational levels) at both the NRA as well as the road owner (when the NRA does not own the road), an understanding of the main driver for making decisions is required. This will be different for different NRAs and may also be different for different decisions within one NRA. A non-exhaustive list of options is provided below:

- Service driven decision criteria - The NRA strives to always reach a certain minimum or target service level, for the minimum cost. This implies that the service of the road is well described and that a minimum service level is determined. This would be a minimum service level that would need to be achieved, whatever the costs. If this is the NRA decision criterion, the performance of the roads will be measured (via Key Performance Indicators, see Section 4.1), and decisions will be made on achieving the minimum targets of the service-driven decision criteria. The guidelines for design, maintenance and operation (input steering, see previous section) will need to be developed such that the required service will be met. Specific reference is made to approach 1 (see Section 6.1) for making the case for adaptation as this approach aims for gaining an understanding in how climate threats lead to a performance, measured via the KPIs.
- Budget driven decision criteria – When this is the case, the NRA strives for the highest possible service within the budget available for managing the road network, possibly divided over different processes like maintenance, renewal and construction. If this is the NRA decision criterion, the performance of the road will be measured, and decisions will be based on providing the highest

possible service with cost of adaptation options that fit within the available budget. The guidelines for design, maintenance and operation (input steering, see previous section) are ideally followed, but budget restrictions may lead to other decisions than based on these guidelines.

- Optimum service - The NRA may strive for providing optimum road service to society, by balancing costs and benefits. If costs are high, the provided service will be lower and vice versa. The point of attention is whether co-benefits (see section 5) can or cannot be included in the determination of the optimum service level. If this is the NRA decision criterion, the decisions on investments for the road infrastructure will be made purely based on the most optimum adaptation strategy (i.e. the strategy with the highest service with the lowest cost). Specific reference is made to approaches 2b and 3 (see section 6.1) for making the case for adaptation as these approaches aim for an optimized performance of the road.
- Policy driven decision criteria – The NRA may have policies in place that direct the decision-making process, while not necessarily being explicitly mentioned in the performance indicators of the road. It makes sense to link decision making to these policies, to enhance the chance for approval of adaptation plans, by considering co-benefits (see section 4.2 and more specifically section 5). These policies for instance link to the following aspects:
    - Biodiversity: policies to thrive for increasing biodiversity
    - Carbon: policies to thrive for lowering carbon emissions of for capturing carbon
    - Climate change adaptation: policies to thrive for climate resiliency within a certain time horizon.
    - Environmental partnership: policies to be an NRA that participates in environmental stakeholder processes.
    - Inclusion: policies to include equity principles in the decision-making process

The first three options described above link to service levels that the NRA strives for. These can be linked to input and output steering which is described in Section 3.2.
It is essential to have a common understanding and insight in the rationale behind the decision-making process of the NRA. This should be clear in an early stage of developing climate change adaptation plans. The decision criteria influence how the performance of the roads is best measured and how adaptation options best can be evaluated.

It may prove to be difficult to get a full understanding of the rationale of the decision-making process, as other factors can steer decisions, such as political pressure or image (discussed in more detail in Section 6.3). It is important to gain insight into such priorities, as they can be beneficially in making the decision case and/or for implementing the decision-making case.

3.4 Key recommendations for influencing the decision making at NRAs

Decision-making at NRAs is complex because decisions are made at different management levels, with different responsibilities, decision-making often is being done via different steering mechanisms, and is further complicated by boundary conditions (related to temporal and spatial scope, capacity, and data availability) which need to be clarified and specified before decisions can be made.

Based on the findings in this Section we can make the following key recommendations.

1. Have a clear understanding of steering mechanisms which play a role in the NRAs and what are the key decision criteria NRAs use. To do this it is essential to have identified the key players at NRAs and create a common understanding of the processes at which decision making is

done. It may prove to be difficult to get a full understanding of the rationale of the decision-making process. Other factors like political pressure or image may also steer decisions. It is important to gain insight in this since it may influence the output-based steering mechanism based on KPIs.

2. When is identified that both input- as output-based steering occurs at the NRAs we recommend developing an approach to **link the input-based (often asset-focused) indicators with the output-based (often network-based) KPIs** by quantifying these. As requirement for this is that the key expertise is available and involved from the different management levels as well as the experts involved in performing resilience assessments.
3. **Identify dose-effect relationships for adaptation options**. This is related to recommendation 2. Currently a quantitative understanding of the effectiveness of adaptation options in terms of KPIs is limited, and there is a need to develop clear dose-effect relationships in order to better understand actions required. We recommend quantifying those with ongoing research and review of experiences in other parts of the world. Although often some research is done this is mostly location specific and more generalised dose-effect relations should be researched. NRAs can conduct pilots with tested and innovative solutions to weather related hazards to develop country specific experiences to adapt climate adaptation options to the local circumstances.
4. Due to the differences in metrics for estimating performance of the road, it is recommended that NRAs consider **effective communication** across the different levels of steering mechanisms and decision-making.

Table 3-2. Overview of recommendations and which management level they apply to..

Recommendation	Strategic	Tactical	Operational
1		X	
2	X		X
3			X
4	X	X	X

4 PERFORMANCE OF ROADS

4.1 Key Performance Indicators

4.1.1 Definition and objective of KPIs

Key Performance Indicators, or KPIs, are normally established via strategic decisions and captured in formal documents. KPIs are metrics that road authorities use to measure the effectiveness and efficiency of their operations, processes, and services. In general, KPIs will be chosen such that they link to the main objectives that the NRA strives for (or is ought to strive for by the road owner / policy makers).

KPIs can be used for many reasons. Related to climate change adaptation and road resilience the following objectives can be measured using KPIs:

- Measure Performance: KPIs help road authorities to measure and track their performance in areas, such as safety, service to road users and road maintenance. By setting clear performance targets and tracking progress towards those targets, road authorities can identify areas of improvement and take corrective action if necessary.
- Monitor Trends: KPIs can help road authorities to monitor trends over time, such as changes in disruptions or incidents, road conditions and traffic volume. By identifying trends, road authorities can anticipate potential issues and adjust their strategies accordingly.

KPIs can assist road authorities in making informed decisions regarding resource allocation, such as where to allocate budgets, equipment, and personnel. KPIs can also help road authorities prioritise tasks based on their level of importance and impact.

4.1.2 Use of KPIs within different institutional development levels

The specific KPIs that road authorities use depends on various factors. Bles et al. [4] have introduced the “Critical Infrastructure Development Pyramid” as a framework that provides insight in the different requirements that road authorities will ask, for various institutional development levels of the road authorities and/or countries. The framework is based on Abraham Maslow’s hierarchy of needs theory [24]. This theory suggests that human beings have a set of needs that must be fulfilled in a hierarchical order of 5 levels. The idea is that these human needs can dictate an individual’s behaviour. This theory can be applied to transport infrastructure development to identify the primary needs of road users and ensure that infrastructure development is aligned with those needs.

The following is an explanation of how Maslow’s hierarchy of needs theory can be applied to transport infrastructure development:

- Primary needs: The primary need for road users is the availability of the road and the ability to transport people and goods from one place to another.
- Safety needs: The next step in the pyramid is the safety of road users. This includes measures to reduce the risk of collisions and ensure the safety of road users.
- Social acceptance: The third level in the pyramid is social acceptance. This involves ensuring that the infrastructure is functional and convenient to use, at least under normal circumstances, while also minimising negative impacts on the surroundings. This requires a balanced view from road operators and owners, whilst also considering the interests of non-road users.

- Esteem: Esteem comes into stake when infrastructure users trust the system. This is achieved when the system becomes safe, reliable, predictable and comfortable even under stressful situations. At this stage, road operators and owners apply a more balanced view, considering the opportunities and impacts on the surroundings of the road network.
- Self-actualization: This is the highest level of the pyramid. At this stage, road authorities are fully aware of all levels of the pyramid and act in a professional manner while interacting with all stakeholders in the environment. They are also aware that the system they are operating is not static and will need to adapt in the future to increase resilience, requiring them to consider principles of decision-making under deep uncertainty to account for climate change, socio-economic, technical and juridical developments.

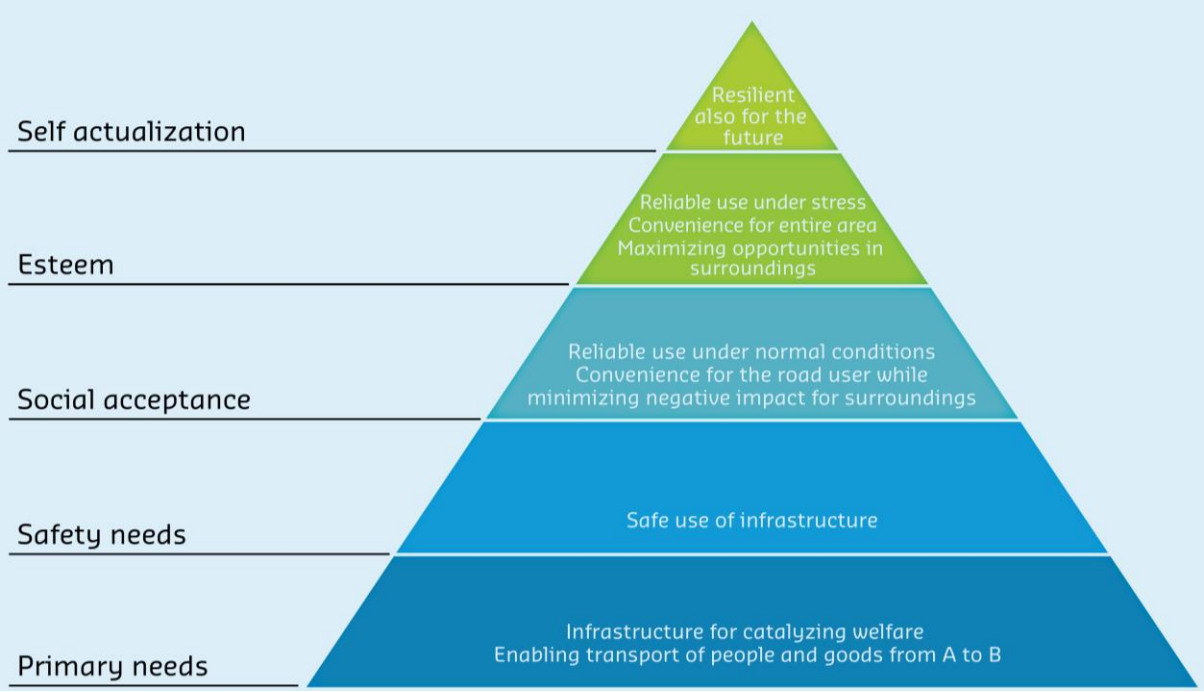

Figure 4-1 The critical infrastructure development pyramid as proposed by Bles et al. (2019)

Following the rational of this pyramid, depending on the maturity level of road authorities, different KPIs are likely to exist. Most, if not all European road authorities will have KPIs based on the first two layers of the pyramid, linked to availability and safety. Furthermore, many road authorities will consider effects on the surroundings of the roads as well. However, when it comes to climate change, the KPIs may vary. Climate change generally brings extreme weather or extreme climate events. These will only be captured when KPIs are also developed for the fourth level in the pyramid. If KPIs are only developed for the primary and safety needs, it may be the case that extreme situations are not monitored, not allowing the NRA to monitor trends. In other words, to act upon trends and predicted changes (including climate and societal changes) KPIs should also be formulated for the top levels of the pyramid. This means that KPIs that measure the impact of disruptions for the users and society in general need to be formulated.

4.1.3 Examples of KPIs

It has become clear that every road authority has their own system of monitoring performance. Also, some NRAs will distinguish between Key Performance Indicators and Performance Indicators in terms of importance linked to the different indicators. That is a decision that each NRA makes themselves. In

this guideline we provide an overview of generally available KPIs related to the performance of road connections and networks. This is based on literature review and NRA reports [27, 15, 14, 21]. There are also other KPIs being used by NRAs, however Table 4-1 only shows KPIs that can potentially be used to measure impact from climate change and adaptation measures to climate change. This overview can also be used to assist in establishing new KPIs that can be of help regarding decision making for interventions for climate change adaptation and resilience enhancement.

Table 4-1 List of possible Key Performance Indicators that can be used by NRAs

Key Performance Indicator	Metric	Possible unit	Affected directly by climate hazards	Possibly affected by climate adaptation
Road system condition	Condition?	Skid resistance Rutting Texture Maintenance status Number, degree, extent of defects	Yes	Yes
Availability, Or sometimes referred to as fast and reliable journeys	Delay	Vehicle Loss hours; sometimes categorised by unplanned and planned closures An average delay per vehicle distance	Yes	Yes
	Network availability	% of time and length in a year that a road or part of a road is closed; sometimes categorized by unplanned and planned closures Average speed	Yes	Yes
	Travel time	Average travel time to relevant points of interest Journey time reliability	Yes	Yes
	Social inclusion	Average travel time to basic everyday activities	Yes	Yes
	Incident clearance	Average time needed to re-open a (part of) the road after an incident happened	No	Yes
Safety	Killed or seriously injured	Number of casualties Number of injuries	Yes	Yes
	Incidents	Number of collisions	Yes	Yes
	infrastructure safety,	% distance driven over roads with a safety rating above an agreed threshold % road network length of roads with a safety rating above an agreed threshold	Yes	Yes
	emergency response	Average time needed for first responders to be at the location of an incident	No	Yes
	in time preparedness for extreme weather	percentage of time and length for which the road was prepared in time for the extreme weather	Yes	Yes

Key Performance Indicator	Metric	Possible unit	Affected directly by climate hazards	Possibly affected by climate adaptation
Environmental effects	Noise	Clear in time reporting Mitigation of noise critical areas	No	Yes
	Biodiversity	% increase in biodiversity	Yes	Yes
	Greenhouse gas reduction	% reduction from a baseline of corporate NRA % reduction from a baseline of road users	No	Yes
	Air quality	% or number in compliance with requirements7	No	Yes
	Water quality	% or number in compliance with requirements	Yes	Yes
Road user needs	Road user satisfaction	% above threshold Average satisfaction Number of complaints	Yes?	Yes
	Roadworks information	% in time communication	No	Yes
Resilient road network	Pavement condition	% of road network above a threshold	Yes	Yes

It has been identified that it is difficult to measure the safety of road networks. That is the reason why the European Union has performed research in the Baseline project, to establish 8 KPIs related to safety [1]. The Baseline project underlined the difficulties to measure safety, since a safety rating methodology is not widely available. One subset of the proposed KPIs for safety relate to infrastructure and these KPIs have been integrated in Table 4-1 above[34]. Other KPIs for safety are also proposed by the Baseline project, but these do not have a relation with climate hazards and the road infrastructure itself and therefore have not been added (e.g. use of safety belt, protective equipment like helmets, alcohol or speeding). It is also noted that some NRAs use other metrics to measure safety, such as the pavement quality or reporting in time. These do not link to climate hazards and performance of the road and have therefore not been added to the table.

Note that the specific KPIs used by road authorities may vary depending on factors such as the size and complexity of their road network, the goals and priorities of the specific authority, and the availability of data and resources.

4.1.4 KPIs at different spatial scales

Generally, the KPIs that are used by NRAs are applied on the network level. As such the KPIs measure the performance of the entire road network. In some cases, the network has been split in regional networks for which the same or other KPIs can be used. We have not found specific examples where the KPIs have been re-formulated and applied (decomposed) to the connection level or the asset level. However, it is understood that in The Netherlands a pilot is being conducted where this re-formulation of KPIs to the connection level is being made, based on critical parameters such as the volume of traffic, economic importance and redundancy of the connection.
One advantage of having the KPIs available for network scale is that they will provide a good overview of the performance of the network. However, this comes with a downside that extreme events will be averaged out. If an extreme event severely affects one connection or asset, it is likely that this will not

be reflected in the annual KPI values of the entire network if the network has a large spatial scale. Having KPIs solely for the network level also doesn't provide insight in how specific connections or assets perform, nor does it provide trends on those spatial levels. This means that the KPIs at the network scale will not always be able to identify or recognize the effects of climate hazards.

4.1.5 Recommendations for use of KPIs in relation to climate change adaptation

When KPIs related to climate change are poorly defined, most of the costs and benefits due to adaptation options cannot be captured as direct benefits and will thus end up as co-benefits. This complicates the decision-making case significantly since it is easier to initiate and make the case when climate effects are linked to KPIs. To include the use of KPIs in relation to making the case for climate adaptation, the following recommendations are made:

- KPIs should be available for the connection and asset level. A sub-division to the connection level (or even to the asset level for critical assets) has the following advantages:
    - the effects of extreme weather or climate hazards is not averaged out, but will be more likely to be visible in the performance of the connection (or critical asset)
    - It will become visible which connections (and assets) will be more vulnerable to weather events and climate change
- Ensure that unforeseen and/or extreme events such as climate hazards are adequately included in the performance measurement. This has the following advantages:
    - Trends in performance related to extreme weather or climate hazards can be evaluated
    - When climate-induced events are part of the KPI definition, the costs and benefits of adaptation options can be captured as direct benefits (the other way around: it will not be possible to make the case for adaptation by using KPIs, when the climate hazards are kept outside the performance assessment.
- Consider KPIs for specific seasons; try to not only have KPIs that are reflected by an annual representation of the entire network. When annual values are used, this would easily result in the impact of seasonal related extreme weather events (e.g. extreme rainfall related events like pluvial flooding or landslides, or drought and heat related events like wildfires) getting lost in the total representation of service of the road network.

4.2 Other indicators for evaluating performance

In this chapter an introduction to the use of Key Performance Indicators is provided. These KPIs are generally used by the strategic management level of an NRA. In many cases other criteria for decision making are also considered at the strategic level. As already described in Section 3.3, other policies may exist that are not reflected in the KPIs that the NRA is using. These are likely to be criteria that are linked to elements listed higher in the pyramid that was introduced in Figure 4-1 in Section 4.1.2. For some NRAs these will be described as KPIs and are listed in the example Table 4-1Table 4-1. For other NRAs, these will be available in separate policy documents. Examples of such policies are policies related to environmental effects such as noise, biodiversity, greenhouse gas reduction, air quality, water quality or soil quality.

Also, the operational level needs to make decisions and has tools for that purpose. An instrument that is frequently used for operational decision making are (corporate) risk matrices. These risk matrices provide insight into the acceptability of a combination of likelihood and impact. In many cases the impact will be classified by means of criteria. It is likely that the KPIs that the NRA are using, are linked to these impact criteria, but additional factors can be considered as well. For instance, in many cases

the impact in terms of politics or image is used for the decision making, while not necessarily reflected in the KPIs.

It is recommended to get a full overview of such policies and decision criteria, to select the relevant benefits and co-benefits for making the case for adaptation.

4.3 Summary and key recommendations for use of performance metrics for making the case for climate adaptation

To make the case for climate adaptation, it is key to understand and link to the existing decision-making context at NRAs. By working like that, the decision for climate adaptation may be evaluated in the same way as other decisions by the NRA.

The following decision information related to the performance of roads is found:

- Key Performance Indicators (Section 4.1): these are mainly used at the strategic level to measure the performance of the road network and to prioritise actions once needed. It was found that the type of KPIs used by an NRA is determined by the institutional development level of the NRA.
- Policies (Section 4.2): in many cases policies are in place with additional decision-making criteria that are not reflected in the KPIs.
- Other indicators (Section 4.2): the operational level uses tools for decision-making in which additional decision criteria are present.

To make most use of KPIs regarding climate adaptation, we provide specific recommendations for the use of KPIs:

- To adjust the KPI thresholds to the connection level (or even to the asset level for critical assets)
- To ensure that unforeseen and/or extreme events such as climate hazards are adequately included in the performance measurement.
- To consider KPIs for specific seasons.

We recommend using the decision information for gaining insight into the level of resilience of the road, both for the current and the future climate. This provides the base case for climate adaptation. As it has become clear that the metrics used for KPIs, policies and other indicators are in most cases not suitable for assessing resilience on an asset and connection scale, there is a clear need to make a translation to assessable metrics for measuring resilience and effectiveness of adaptation options. This is what we call the benefits and co-benefits. We distinguish between these two concepts by using the following rationale, where a benefit is linked to a KPI and a co-benefit is a benefit that is not linked to a KPI. This is further elaborated in Section 5.1.

For making the translation to, and use of, benefits and co-benefits we recommend the following:

- Identify the relevant decision criteria for the NRA, based on the list of KPIs, other policies and other indicators
- Translate these criteria to benefits and co-benefits. This is further elaborated in Section 5.1.
- Identify a feasible metric that can be used to assess and quantify the benefits and co-benefits, both for gaining insight into the resilience of the road, as well as to gain insight into the effects of adaptation (being a change of the resilience of the road). This is what we call the valuation and this is further elaborated in Section 5.2.

5 PERFORMANCE OF RESILIENCE ENHANCING ADAPTATION OPTIONS

5.1 Introduction to benefits and co-benefits

In Sections 3.3 and 4.1an introduction is provided to the decision-making criteria used by NRAs and how Key Performance Indicators are used in that respect. It has become clear that KPIs generally have different metrics when compared to the metrics that are used to measure the resilience of a road network, connection or asset, as well as the benefits of adaptation options. This leads to the conclusion that a translation is needed from the decision-making context (including the KPIs, other policies and other decision criteria) to an assessable metric for measuring resilience and effectiveness of adaptation options. This translation is done by applying the concepts of benefits and co-benefits.

We distinguish between these two concepts by using the following rational:

- A benefit is directly linked to a KPI. For that purpose, the NRA needs to determine the benefits associated with achieving each KPI. For example, increased safety leads to fewer deaths on the road network.
- A co-benefit is a benefit that is not linked to a KPI. Co-benefits are the additional benefits that are achieved as a result of achieving the primary benefit. NRAs should identify the co-benefits associated with achieving each KPI, as much as possible linked to other policies that the NRA thrives for (see Section 4.2). For example, a co-benefit of increased safety is less demand on emergency services.

Based on national priorities, different European NRA's will set their own KPIs. This results in the fact that different NRAs will consider benefits and co-benefits differently (a benefit for one NRA may be a co-benefit for another NRA). This also links with the maturity level of the NRA. The higher the institutional development level of an NRA, the more co-benefits come at stake (or even become real benefits).

In general, it will be easier for an NRA to make the decision-making case when more positive effects of adaptation options are linked to KPIs (benefits). Co-benefits can aid in making the decision case, but always will need more explanation/reasoning to ensure that these are alco counted in the valuation of the performance of adaptation options.

Furthermore, it doesn't make sense to have a long list of co-benefits when:

- It proves to be impossible to quantify the effects of adaptation options to these co-benefits.
- The co-benefits are deemed unimportant; since it may take substantial effort to quantify the co-benefits (reference is made to Section 5.2) it doesn't make sense to do this if the added value to the decision case is deemed low.
- The co-benefits are not used in the decision-making process.

Since NRAs' benefits and co-benefits will be defined differently depending on the defined KPIs, the following section will simply refer to benefits. In addition, it is important to note that although the benefits by definition are framed as positive effects, it is possible that these might take the form of negative benefits in some cases. More specifically a negative benefit is the reduction/negative effect on one of the defined benefits. For example, reduced speed limits result in longer journey times but increased safety and journey time reliability.

The following section provides an overall guideline on how to incorporate benefits through quantification and valuation within decision-making contexts and resilience assessment. In continuation of this section 5.2 relates the overall guideline to some specific examples of benefits, likely to be associated with climate adaptation and resilience. The benefits included in section 5.2 are presented in Table 5-1, which includes a list of benefits, likely to be associated with options for climate adaptation and resilience. The list relates to KPIs listed in Table 4-1. The table provides a brief description of each benefit and potential means of quantification and valuation. Furthermore, indicators to assess the magnitude of impact are included. These are provided to allow for screening/assessments of the significance of each benefit in relation to the specific project.

Table 5-1 List of potential benefits associated with climate adaptation and increased climate resilience of road networks.

Benefit	Description	Quantification	Valuation	Indicator for magnitude of impact
Availability				
Travel time, leisure	Value of travel time for persons in their leisure time	Minutes of increase/decrease in travel time	Travel loss hours / value of travel time	Number of users of network and level of change
Travel time business	Value of travel time for businesses	Minutes of increase/decrease in travel time	Travel loss hours / value of travel time	Number of users of network and level of change
Reliability of travel time	The value of reliability of predicted travel time for users	Reliability of predicted travel time measured as e.g., percentage of average travel time of a road network	Value of reliability	Number of users of network and level of change
Availability of network	The value of being able to always access public services and critical infrastructure	-		
Availability: Connectivity and social inclusion	Connectivity and travel time to basic everyday activities	-	-	-
Durability		-	-	-
Replacement	Costs associated with wages, materials etc.	Hours worked, units of material, fuel machine hours etc	Wages, costs of materials, fuels, machinery, etc.	-
Upgrading	Costs associated with wages, materials etc.	Hours worked, units of material, fuel machine hours etc	Wages, costs of materials, fuels, machinery, etc.	-
Safety	Value of injuries/fatalities	Increase/decrease in the risk of injuries/fatalities	Value of statistical life	Number of users of the network and level of change
Health effects		-	-	-
Air pollution	Improved air quality from increased coverage of plants	Increase/decrease in the level of particle matter	Value of statistical life, quality adjusted life year	Number of affected individuals and level of change
Noise	Lowered noise levels from noise barriers of coverage from plants	Increase/decrease in the level of decibel	Value of statistical life, quality adjusted life year	Number of affected individuals and level of change
Job creation	Job creation from investment in climate adaptation/resilience	-	-	-
Ecosystem services	Value assigned to areas due to their aesthetics, opportunities for walking, socializing etc.	Increase/decrease in level of greening or ha of green areas	Stated/revealed preference methods	Number of users of the area, and level of change in provision of environmental good
Water quality	Value assigned to good quality of water, e.g., stemming from conta-minants from run-off	Increase/decrease in quality status, e.g., ecological status based on threshold values		Number of affected individuals and level of change.
Climate				
Embodied carbon	Emissions arising from construction materials, transport, and installation	Increase/decrease in the number of embodied carbon emissions	Social cost of carbon	Level of change in the number of embodied carbon emissions

Chapter 5 solely regards the question of how benefits can be quantified and valued. How to work with this in relation to the specific appraisal method is included in the following section 6.

5.2 Valuation of benefits and co-benefits

5.2.1 Benefits and co-benefits in relation to the application of KPIs

Valuation of costs and benefits in relation to decision making provides a convenient and potentially informative way of evaluating different options in decision making. The comparison of costs and benefits of undertaking adaptation options or resilience measures provides a transparent way of considering different alternatives. Still, it is important that such valuation measures are applied with some prudence and that associating losses and benefits with monetary values always will be associated with at least some uncertainty.

The following provides a stepwise generalised approach of valuation. More thorough guidelines on the subject exist and are recommended for further elaboration on the subject. For instance, the OECD have provided a thorough guideline (Atkinson et al. 2018) but often national guidelines are also available. Furthermore, in the following section the term 'benefit' is used to cover both benefits and co-benefits for simplicity, as the distinction between the two is irrelevant in relation to the valuation.

The first step in the process of applying valuation of benefits is to start out with a description of the relevant effects, expected to be associated with the interventions proposed by the project. It is necessary to consider both the spatial and temporal scope of these expected changes. What changes are expected to occur, what is it expected to impact and for how long are impacts expected to last? To meaningfully describe the expected changes, a baseline should be defined, against which the expected changes can be described. In most cases, the baseline should be defined as a *business-as-usual* scenario which incorporates expected future changes to the current situation, importantly in relation to climate change.

When the relevant project(s) have been defined and described, a straight-forward result of this, should be the considered associated benefits of the project. Note that this might also entail some negative benefits. In the case that there are (pre)defined KPIs, it will be possible to define the changes/results as either benefits or co-benefits. It is noted that while co-benefits are not directly linked to the KPIs of the road-network they could be used to build the decision-making case for adaptation and could be linked to defined performance indicators at lower levels.

In addition, benefits will often be defined as either tangible or intangible in relation to valuation, as illustrated in Figure 5-1. This is because for some benefits it is possible to observe prices in the market. Tangible benefits are values that we can elicit a value from based on the prices we observe in the market. For example, damage to infrastructure assets can be priced based on how they are booked in the accounts, or costs for repairs can be assessed in terms of the estimated value of that production.

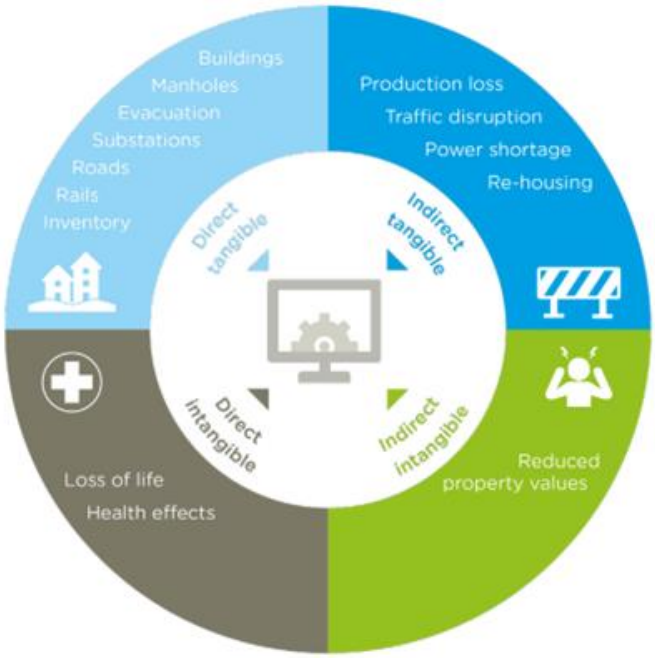

Figure 5-1: Illustration of the differentiation between direct and indirect tangible and intangible goods.

Intangible benefits are different from tangible benefits in the way that the monetary value of these is not possible to observe in existing markets. The fact that it is not possible to observe the market prices of a given benefit does, however, not mean that it does not have a value. For example, if one chose to take a leisure walk on a Sunday afternoon, one does not pay $10 to do so. Although the Sunday leisure walk is not paid for, the activity still has a value, assuming that it is a voluntary choice to go for a walk. The person who decides to go for a walk pays for that walk by choosing to go for a walk rather than other potential ways of spending the Sunday afternoon. Valuation of such activities or options can, for example, be valued by estimating the transportation costs of the leisure activity (e.g., cost of fare by bus or car) or simply by asking people about their willingness to pay (Atkinson et al. 2018). Valuing intangible assets thus revolves around figuring out the estimated value of such benefits as leisure walks.

5.2.2 Applying valuation in decision-making contexts

Applying valuation in decision-making contexts requires systematics and consideration to scope and objective to provide the intended transparency and relevance for decision-making. A four-step staged method is suggested to ensure a systematic approach for valuing the expected costs and benefits of a project. An overall description of the suggested approach is presented in section 5.2.1 and is further aligned with the description of valuing the identified benefits in section 5.2.2.

The first step basically entails what was briefly touched upon in the previous section 5.2.1. This involves defining a clear baseline against which the different alternative options are evaluated. The expected outcomes should be described, to identify the expected associated costs and benefits. The result of step one should be a complete list of expected costs and benefits, and depending on the defined KPIs, the benefits can be categorised as either benefits or co-benefits.

In step two, the identified benefits are assessed in terms of their relevance. This is due to the fact that while some changes might be expected to occur, they might not necessarily be of a magnitude to justify a thorough value assessment, but rather a qualitative one. Basically, the decision to include valuation

of a given effect comes down to a trade-off between the need for detail and available resources. It is suggested, in general, that tangible (or monetary) outcomes are included as these values are usually quite straight-forward to elicit. In relation to identified intangible outcomes, it is suggested to consider parameters defining for the magnitude of the outcome. For example, whether the level of change in the effect is significant and/or how many individuals that will be affected by the change.

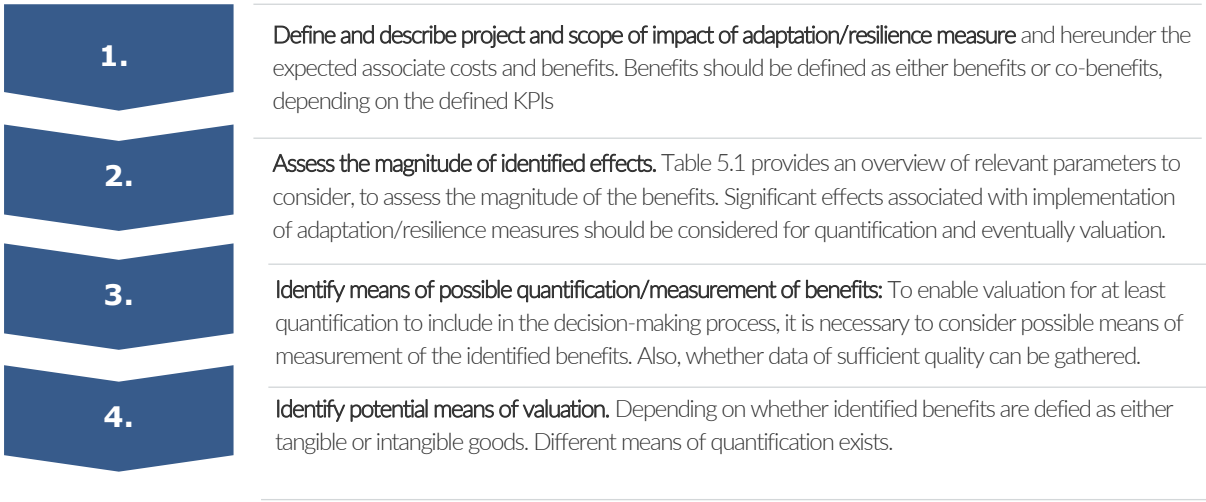

Figure 5-2: Summary of the four steps included in the overall approach suggested for valuation of benefits.

In step three the possible means of quantification/measurement and valuation of the benefits and co-benefits considered relevant in step 2 should be assessed. To enable valuation, it is first necessary to be able to measure or quantify the identified effects. This question primarily relates to intangible values, as it will most often be known in relation to tangible values (the unit of measurement of a product or service).

There is no generalised way of measuring intangible values, simply due to their various nature. For example, there is a significant difference between measuring the level of change from the increase in the size of a recreational area and that of noise reduction. The first mentioned could be measured by the number of additional visitors per year and the latter could be measured as the change in decibel in the nearby neighbourhood and its associated impact on health. A vital element in relation to step 3 is the availability of data, which will obviously affect the ability to measure the relevant changes.

The last step revolves around the actual valuation. The possibility of valuing the identified benefits/co-benefits will be highly dependent on the possible means of quantification/measure of the identified values, in step three. As previously mentioned, tangible goods will often be quite straight forward, as market prices can be used (e.g., €/kg). For intangible values, different methods have been applied in studies seeking to uncover people's *willingness to pay* (i.e., their valuation) (Atkinson et al. 2018). The most commonly applied methods are revealed preference studies and stated preference studies.

Revealed preference studies seek to elicit the value placed on specific goods, by observing how people act in other markets. Widely used in this context is the housing market, where statistical methods can be applied to elicit the values of specific characteristics of housing, e.g., green spaces or ocean views.

Stated preference methods are based on simply asking people about their willingness to pay for a specified good e.g., in a survey or interviews[1] (Atkinson et al. 2018 ; Navrud & Ready 2005).

However, while being the most precise way of valuing intangible benefits, both revealed and stated preferences studies are costly and time consuming to conduct. Therefore, benefit transfer (or value transfer) is a widely used method. A lot of scientific work has been done, to identify the primary sources of uncertainty and validate the use of the methods, especially with regard to its use in policy contexts. It is important to mention that the use of benefit transfer in general will be associated with more uncertainty than with primary studies. It is suggested to align with the most recently updated guides on the application of benefit transfer (Johnston et al. 2022).

In relation to valuation, especially of intangible goods, the risk of valuing overlapping effects (double counting) should be carefully considered. Thus, when choosing the means of valuation, consideration should be given to what effect we are assuming is being valued and whether these overlap with other included values. It is suggested to strictly consider guidelines on applying valuation methods of intangible values, to enable best practice and avoid largely misleading results.

Lastly, some identified effects will be unsuitable for monetary valuation either due to their complexity level or due to ethical reasons. A good example could be the availability of road networks to provide access to critical infrastructure and health care. For one thing, this is a rather complex task to value, and secondly, it is influenced by ethical considerations. Thus, it is likely to be more meaningful to associate this with quantified criteria or qualitative descriptions.

The following section includes a description of the benefits included in Figure 5-1 in section 5.1, including means of quantification and valuation. It is important to state that there could be various ways of quantifying and evaluating the benefits.

The section is structured so that tangible benefits are included first and following that valuation methods for the included intangible benefits.

5.2.3 Valuing identified benefits

Availability/lack of disturbances and delays: Persons and businesses

Effect/expected outcome	Change in travel time both under normal circumstances and in case of disruptions.
Parameter for assessing magnitude of effect	Level of change: how much is the travel time expected to change, and what is the number of users?
Possible means of measurement	Traffic models most likely means of producing estimates on the expected travel time, both with and without the presence of disruptive events.
Possible means of valuation	Estimates on value of travel time, cost savings approach

The increase in availability and/or the decrease of delays and disturbances of road networks is often considered one of the primary objectives of infrastructure investments. Road networks and connections constitute one of the backbones of economic activity by enabling movement of goods and people. Disruptions and delays can cause significant associated economic and social impacts.

For individuals, disruptions and delays will affect e.g., time spend on commuting to work or leisure time. Business could be affected e.g., by delaying business travel times, creating bottlenecks in the supply chain or inability to connect or deliver end products to users/consumers.

Due to the importance of the value of disruptions and delays to infrastructure decisions, such values are frequently produced on a national level. Such values are often referred to as the value of time.

The value of time is primarily being estimated by using the so-called stated preference methods. While stated preference methods is a widely accepted measure to apply in especially CBA in relation to decision making, it is important to state that results will often differ across especially income levels, primary travel motive, travel conditions and time. For that reason, it is generally recommended to use national measures and measures that are frequently being updated (Fosgerau et al 2007; Batley et al. 2017; De Jong & Kouwenhoven 2019).

Many countries in the EU have provided national level estimated on the value of travel time. In addition, meta-analyses on values of travel time been conducted with the intend of providing values applicable across the EU (Wardman et al. 2016). Applying estimates based on meta-analysis and of older data series should however be considered the second-best option, compared to national-specific updated numbers. Furthermore, the OECD International Transport Forum has provided materials on recommendations, application and related shortcomings of the use of value of travel time in relation to decision-making processes (International Transport Forum 2019).

Business related travels make up for a large part of the value of delays and disruptions of travel time. Business related travel is usually considered not to include commuting, but rather employees travelling in the course of their working day to meetings or other related activities. The value of business related travel time is sometimes included in national estimates on value of travel time, but this is not always the case. Instead, a common practice is to use a cost saving approach. For example, by using an estimate of the wage rate plus any other employment related costs as the value, under the assumption that an employee is unproductive on the journey and travels exclusively in the paid working time (International Transport Forum 2019).

The method suggested above for estimating the value of extended travel times for business, covers solely the additional costs of delays and disruptions of travel time. However, delays for business are likely to be far more far reaching. For example, will the sole value of travel time fail to include the cost of delays of movement of goods and services. Extending the value impact on businesses to their supply chain rests on the overall assumption that efficient movement of goods and services saves time, and therefore incurs a cost for businesses when extended. Extending the inclusion of business impacts to include the impacts on supply chains, requires a far more comprehensive approach in terms of enabling valuation.

Transportation Research Board (2012) presents an extensive review of methodologies to measure the direct and indirect economic impacts of disruptions to the goods movement system, including an analysis framework. The review summarizes the most important models used, categorized as either

supply chain models or economic impact models and suggests that the choice of models should be considered in relation to four determining factors:

- Duration of disruption
- Mode of transport
- Value of commodities being shipped
- Geographic area involved

Availability: Reliability of travel time

Effect/expected outcome	Change in the reliability of predicted travel time for users from e.g., adverse weather and fluctuating travel demand.
Parameter for assessing magnitude of effect	Level of change: how much is the travel time expected to change, and what is the number of users?
Possible means of measurement	Reliability of predicted travel time measured as the e.g., the percentage of average travel time of a road network
Possible means of valuation	*Value of reliability*

Reliability of travel is a measure of the consistency in the travel time of a road or road network, and therefore intended to reflect the additional time (buffer time) travellers need to allocate to compensate for unexpected delays. Reliability is affected by, for example, bottlenecks, weather, traffic incidents or fluctuations in travel demand.

Travel time reliability is usually measured as the buffer travellers need to add to the planned travel time in addition to the average travel time, measured as a percentage of the average travel time.

Example

If the average travel time is 30 minutes and travelers must plan for an additional 15 minutes as a buffer to secure on-time arrival the buffer index is

$$\frac{additional\ buffer\ of\ 15\ minutes}{average\ travel\ time\ of\ 30\ minutes} = \mathbf{0,5\ buffer\ index}$$

The value of reliability is an additional measure to value of travel time (as elaborated above). Value of reliability can be measured by using the same methodological means as for value of travel time; either stated or revealed preference studies to reveal value placed on having reliable transport connections (See for example Carrion-Madera & Levison 2010).

Availability of connections to critical infrastructure and public services

Effect/expected outcome	Change the risk of experiencing cut-offs from connections to critical infrastructure and public services
Parameter for assessing magnitude of effect	Level of change: size of the change in risk and number of individuals affected
Possible means of measurement	Formulation of criteria based on defined minimum service levels
Possible means of valuation	*NA*

In addition to the value of availability in terms of lack of delays and disturbances dealt with in the previous section, it is suggested here that there is an independent value associated with the availability of network connections. Both relating to connections to critical infrastructure and public services as well as everyday activities. Cut-offs from connections to critical infrastructure like health care, home care or food supplies can cause great human and economic losses. Furthermore, infrastructure to support availability of everyday activities furthermore have an independent value.

It is suggested that critical infrastructure is identified, including key connections to e.g., health care and related services, so that minimum service levels of these connections and areas can be defined. It would then be possible to define quantifiable requirements, for example, that hospitals should always be available at all times or that electricity fall outs should last no more than 12 hours.

Availability: Connectivity and social inclusion

Effect/expected outcome	Changes in the level of connectivity
Parameter for assessing magnitude of effect	Level of change in access for targeted groups
Possible means of measurement	Formulation of criteria based on defined minimum service levels
Possible means of valuation	*NA*

There are many ways in which transport can have an impact on people's lives, as transport choices are essential to a wide range of activities undertaken by individuals daily. Besides providing access to services and opportunities, transport has an important role to play in supporting or hindering social connectedness. Furthermore, transport has a multifaceted impact on social inclusion, thus reflecting an issue of equity aspects (Van Marle et al. 2022). Availability of transport connections/networks, facilitates social interaction and thereby also social inclusion. Transportation networks furthermore play an important role in terms of availability of employment and educational opportunities and of which a pivotal in terms of socio-economic status. In addition to this, studies suggest that groups with lower socio-economic status do not benefit

equally from infrastructure improvements and in turn are more vulnerable, when it comes to disruptions (Van de Walle & Mu 2011; Kilgarriff et al 2019).

Table 5-2: Example of positive and negative effects related to connectivity and social inclusion

Positive and negative effects of transport on physical health (Cooper et al. 2019)
Benefits of well-designed transport policy and infrastructure: ▪ Enables access to employment, education, shops, recreation, social support networks, health services etc. ▪ Access to places for recreational activities and opportunities to exercise
Negative impacts of poorly designed transport interventions ▪ Inequitable distribution of access to employment, education, shops, recreation, social support networks, health services, ▪ Collisions, noise, stress/anxiety, danger, loss

The effects of transport connectivity/availability on social equity and inclusion entails large complexity and is likely to vary significantly between communities/sites and temporal scales. Thus, monetary valuation might be misplaced in this case as it 1) poses a daunting task to try and valuate, 2) might end up reducing the complexity and importance of the issue to a single unit that is nevertheless difficult to comprehend and 3) likely still to be a subject of ethical concerns/disputes. Thus, for inclusion in decision-making context the benefit of social inclusion/equity might be better assessed by applying qualitative measures through the formulation of criteria based on defined minimum service levels.

Durability

Effect/expected outcome	Change in the effort associated with maintenance
Parameter for assessing magnitude of effect	Level of change: expected change in effort associated with the type of maintenance required – as either repair, replacement or upgrading
Possible means of measurement	Materials used and hours spend
Possible means of valuation	Market price of materials used, and wages paid

Maintenance associated with either repair, replacement or upgrading represents a cost (potentially significant) associated with road networks. Thus, can the potential improvement of durability of climate adaptation and resilience options be reflected as a benefit.

Including valuation of the benefit of increased durability of an asset would be based on the market prices associated with costs of maintenance. The benefit would thus occur as a decrease in the costs associated with the activities performed and materials used in relation to maintenance. For example, would such activities be possible to quantify in amounts like hours used by workers and the number of materials and machinery (incl. fuel) used. The associated costs with maintenance can then be estimated based on inclusion of the wages paid to the workers, cost of material use, cost of use of machinery etc.

Safety

Effect/expected outcome	Change in the safety level of using the road/road network
Parameter for assessing magnitude of effect	Level of change: expected change in the risk associated with using the road and the number of users
Possible means of measurement	Estimation of risk rates and the number of users
Possible means of valuation	Value of statistical life

Changes and adaptation of the features of roads and road networks might potentially cause changes in the safety level. Thus, when major adaptations/alterations are made, it should be considered whether these changes in features might change the safety level. Safety of roads is usually measured by the number of collisions which includes damages (to the road and vehicles), fatalities and injuries incurred in the traffic, or for a specific road/network. This implies that improved safety of road and road networks can be quantified as the reduction in the risk of a fatality of injury in the traffic.

Based on data and road characteristics it is possible to estimate safety levels, e.g., by the number of crashes, injuries and fatalities. Based on data on crashed, traffic volumes and characteristics etc. it is possible to estimate safety as well as what the expected changes from changing road characteristics might be, for example measured as a risk rate (US Department of Transportation 2017).

To valuate effects one commonly applied metric is the *value of statistical life* (VoSL)[2]. VoSL is a measure of the monetary value placed on a reduction in the risk of premature death (OECD, n.d.). Value of statistical life (VoSL) has for many years been considered the primary tool to economically assess health effects. The measure entails the value of experiencing an increase in the risk of death, or, in other words, the amount of money that people are willing to pay to see a reduction in the risk of fatal injury or illness.

VoSL is used in various settings e.g., to estimate the value places on increasing the safety level of roads or the value of lowered pollution levels in a neighbourhood. VoSL estimates have been elicited in different ways, but the most common way is through studies that ask people about their willingness to pay for a specific risk reduction in different settings (Atkinson et al. 2018).

There might be considerable difference in estimates of VoSL across populations and risk characteristics. Perceptions on risk might differ between the risk associated with traffic and air pollution, respectively, and societal and cultural perceptions of collective risk and the value of individuals lives might also differ substantially. Moreover, it is firmly documented that individuals respond quite differently to whether they asked to *accept payment for an increase in risk* or *asked to pay* for a reduction in a risk.

Even though values are known to vary, the VoSL is a generally accepted measure, and most EU countries provide country-specific estimates on VoSL. Some examples are included in table 5-2 below.

[2] Measures of *quality adjusted life years* or *disability adjusted life years* can also be applied.

Table 5-3: Examples of national values of statistical life (Danish Economic Council, 2016)

Country	Value of Statistical life
Denmark	4.5 million Euro
Norway	3.8 million Euro
USA	7.2-9.7 million Euro
EU	5.2 million Euro

In addition, the OECD provides a dataset, including a publication of how VoSL estimates from across countries have been elicited, explanation for the variation across countries as well as advice and recommendations for using VoSL in environmental, health and transport decision-making settings (OECD, n.d.).

However, it is important to note that VoSL is not without controversy and criticism. Some critics argue that it places an economic value on human life that is insensitive to social justice considerations and the intrinsic value of human life. Others argue that the methods used to estimate VoSL are based on questionable assumptions and may not be applicable in all situations.

Info box 5-4: Example on the use of value of statistical life

Example

A specific road is currently associated with a fatality risk of 0.01 %. This means that if the road has 10 million annual users, it is estimated that there will be 1 fatality per year.

$$\mathbf{1,000,000 * 0.01\% = 1,000}$$

An initiative is undertaken to reduce the number of fatalities by 2% per year. That is a reduction in fatalities of 20 per year.

$$\mathbf{1,000 * 2\% = 20}$$

If the VoSL is estimated to a 5 million Euros, the value of the initiative is worth 100 million Euros in increased safety.

$$\mathbf{5\ million\ Euro * 20 = 100\ million\ Euro}$$

Health effects

Effect/expected outcome	Change in the level of noise, particular matter or mortality rates to affect mortality and morbidity
Parameter for assessing magnitude of effect	Level of change: expected magnitude of change, e.g., to surpass a specified threshold level, and the number of individuals affected.
Possible means of measurement	E.g., by threshold levels or by data on dose-response effects.
Possible means of valuation	Value of statistical life and estimates on *willingness to pay* through stated or revealed preference studies[3].

[3] For reference see: Anderson et al. (2018); Day et al. (2006); Lavine (2021)

Human health is greatly affected by the environment and in various ways. Effects on our health can be categorized as either an effect on our lives and as such with a *mortality effect*, effects on our physical health, a *morbidity effect* or an effect on *mental stresses and strains* to affect our mental health. Such effects on our health can be caused by changes in the physical environment (Münzel et al. 2014; GBD 2019). For example,

- Increased greening of the neighbourhood to improve air quality by reducing pollutants
- Lowered noise levels by increased green coverage of buildings to cause a reduction in stress levels for residents.

These effects are suggested to be some of the most important health related effects that could be affected by investments in changes to road infrastructure. Figure 5-3 suggests modes of quantification for each of the two examples of health-related effects.

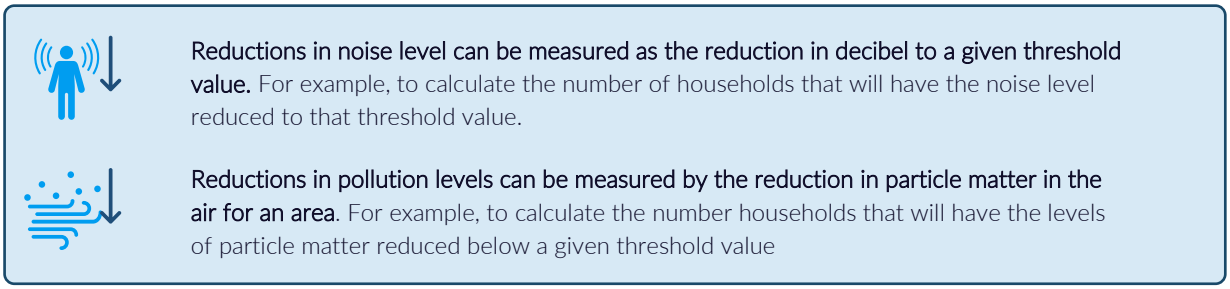

Figure 5-3: Figurative illustration of important health related effects.

As mentioned above, health effects relate to both mortality, morbidity and our mental health. It is thus suggested to consider the value for both mortality effects and morbidity effects, under the assumption that mental health can be considered a morbidity-related effect[4]. The differentiation between mortality and morbidity rests on the fact that there is a significant difference between increasing the risk of losing one's life and experiencing discomfort linked to decreases in health and illness.

The following two sections include descriptions of possible valuation methods for mortality and morbidity, respectively.

Valuing mortality

Health-related mortality effects associated with increased noise and pollution relate to the fact that they constitute stressors which, over time, could lead to premature death. For example, that increases in noise levels are connected to increased stress levels, blood pressure and cardiovascular diseases (WHOa, n.d.; WHOb, n.d.).

The inclusion of mortality related effect should be considered as relevant, especially when climate adaptation and resilience measures are expected to have significant effect on, in particular, noise, pollution or thermal comfort. Effects could for example be measured through application of threshold values of decibel, particular matter or degrees Celsius.

Valuing mortality in relation to health-related effects can be done by applying measures of value of statistical life (as elaborated on in previous section). Ideally national measures should be applied to ensure the most accuracy.

[4] This is a simplifying assumption. It is important to underline that the suggestion rests on the value of presenting a simplified assumption. Various health related measures for valuation exists, also including social value measures of both physical and mental health related issues. When such effects are expected to be of significant importance, valuation method and measure should be carefully applied in the correct context.

Valuing morbidity

Valuing the morbidity related effects of air pollution, noise pollution but also the urban heat island effect has been done using both revealed and stated preference methods[5]. Noise pollution is generally related to cardiovascular diseases, sleep disturbance, mental and cognitive disturbances. Valuation has predominantly been conducted using revealed preference methods, where the housing market have been used, to elicit the implicit prices paid to reduce the noise levels, so-called hedonic pricing method (Anderson et al. 2015).

Similarly, the effect on air pollution have also been valued in studies using the housing market (Lavine 2019; Gyo Kim et al. 2010). The studies include elicitation of the implicit price being paid in the housing market for reductions in the levels of air pollution. Most important health related issues are respiratory problems, cardiovascular diseases, cancer and so on.

In addition, the Canadian database Evri.ca provides a search engine of more than 5.300 economic valuation studies, including studies in relation to the impact of road networks on especially noise and pollution.

Job creation

Effect/expected outcome	To create and retain more (local) jobs
Parameter for assessing magnitude of effect	Level of change in the number of jobs.
Possible means of measurement	Number of *full-time equivalents* (*FTE's*)
Possible means of valuation	-

Job creation is usually considered an important factor in relation to investment projects in infrastructure., especially in terms of local job creation and retention. Job creation is a vital element to economic activity and growth, especially for local economies, employment opportunities and skill development. In addition, job creation can play an important role in terms of social and mental benefits, reducing inequality and promoting social inclusion and cohesion.

Considering job creation as a benefit and including that in decision-making appraisals rests on the assumption, that new job opportunities are created, and which would otherwise not exist. Or, at least, that the available job opportunities are improved. Moving employment from one place to another, might be considered a benefit at a local level but it is important to state that the overall societal benefit will be absent, unless employment comes from unemployment, or the new jobs are associated with improvements in working conditions. If jobs and economic activity is simply reallocated from one place to another, it will not as such, be a benefit.

[5]Quality *adjusted life year (QALY)* and *disability adjusted life years (DALY)* are also metric sometimes used in relation to measuring morbidity. For reference, see for example: Sassi & Hurst (2008).

As a general rule, it is not recommended to include job creation as a benefit in decision-making processes, unless careful consideration and scrutiny is given to the context and relevant factors for actual benefits to materialize. This could e.g., be the case in areas that have experienced high levels of unemployment. However, it is important to state, that job creation is not to be included in *cost-benefits analyses*. If a CBA is the primary appraisal method applied, it is recommended to include job creation as a qualitative description in addition.

If it is considered desirable to include job creation by a quantitative measure, this is most commonly done by estimates on the anticipated number of *full-time equivalents*[6] (FTEs). Usually, the estimated number of FTE's is split into the number of *direct* FTEs and *indirect* FTEs. The indirect FTEs is a result of additional jobs created from increasing the economic activity, e.g., in adjacent sectors or from increased spending in the local economy. This can be done by using so-called multiplier effects. Multipliers can often be found for specific sectors in national statistics of related publications.

Ecosystem services

Effect/expected outcome	Level of change of ecosystem services
Parameter for assessing magnitude of effect	Level of change: Change in the size, number or level of ecosystem services and the number of affected individuals/users.
Possible means of measurement	Size, quality indicators, level or the likes.
Possible means of valuation	Primary revealed or stated preference studies or benefit transfer.

Ecosystem services is an umbrella term for the various services ecosystems potentially can provide. Some of the most important mentions in relation to infrastructure and investments in climate adaptation and resilience, are the aesthetic and recreational value of green areas, parks, forests and green landscapes. Moreover, preservation of biodiversity and habitats are also often mentioned.

Considering these values might especially be relevant in relation to new investments, where green elements could play a role. Or in relation to new investments that might require removal of green landscapes or forests, and therefore causing a negative benefit impact. When larger areas are removed and/or disturbed this could give rise to potential value loss. Or similarly, in more urban areas, where greening is more sparse, even minor changes in the greening of built environments could yield positive values.

Valuation of ecosystem services thus covers a multitude of various values, that are in turn also highly dependent on the specific context.

Generally, valuation of ecosystem service-related values should be based on benefit transfer (or value transfer) of values elicited in primary revealed- or stated preference studies. Such studies can be sought

[6] A full time equivalent is a unit that represents the workload of one full-time employee.

out e.g., from databases like Evri.ca, which includes valuation studies on many different environmentally related values.

It is important to state, that benefit transfer generally is associated with more uncertainty than other forms of economic valuation. It is, however, a recognized method for application in settings where environmental goods potentially form an important part of a decision-making process, but consideration needs to be given to the trade-off between the detail level of information and resource use to add more detail.
Guides on best practice for benefit transfer however exist, and are continuously being updated as the field develops (Johnston et al. 2021)

Water quality

Effect/expected outcome	Adaptation/resilience measures to affect especially run-off to impact soil and water quality
Parameter for assessing magnitude of effect	Level of change in the impact of run-off and e.g., through monitorization of water flows and the movement of pollutants through a catchment area
Possible means of measurement	Data on water quality, e.g., threshold values for ecological status
Possible means of valuation	Estimates on *willingness to pay* where readily available and applicable estimates exists, otherwise a qualitative assessment of the measures.

Adaptation and/or resilience measures could be designed to address the negative impacts of run-off from roads. The negative impacts from run-off stems from various contaminants like heavy metals, oil and salts from the road. Therefore, run-off from roads can have a significant effect on water quality.

In cases where the effect of reducing the negative impacts of run-off is expected to be significant, the impact can be measured on data on water quality maybe in relation to specified threshold levels for quality assessment.Many European countries have quality standards on ecological quality of different kinds of surface waters.

Valuation studies have been conducted on the value of water quality, especially in relation to surface waters that often hold significant recreational value and biodiversity values. However, to apply measures based on stated or revealed preferences in a benefit transfer would still be highly site and context depended. Thus, it is suggested to apply qualitative assessments of water quality measures in decision-making, when sufficiently accurate applicable studies are lacking, and primary valuation is unfeasible.

Climate change

Effect/expected outcome	Changes in the level of emissions arising from construction materials, transport and installation .
Parameter for assessing magnitude of effect	Expected level of change in the substitution of materials as well as the number of materials substituted.
Possible means of measurement	Carbon accounting
Possible means of valuation	Social cost of carbon

Road infrastructure represents a major contributor to greenhouse gas (GHG) emissions, both through direct emissions from the construction, operation, and maintenance of assets, as well as indirect emissions resulting from their use. Additionally, infrastructure projects are typically spatially large, and they inevitably have impacts on land use. Thus, construction projects affect the climate directly through material consumption and construction activities, but also indirectly if carbon sinks and stocks are impacted. Similarly impacts of CO_2 emissions on society is indirectly causing damage to assets through weather animalities.

The extent of greenhouse gas (also known as 'carbon') emissions over the lifecycle of infrastructure is largely influenced by the choices made by asset owners, managers, designers, constructors, and suppliers of materials and products. Using NBSs instead of or in addition to conventional civil engineering solutions has the potential to decrease the negative climate impacts arising from construction projects. Using NBSs or other low-emission alternatives in relation to road infrastructure resilience measures therefore have the potential to reduce the emissions associated. How to account for this and eventually value it is described in the following sections.

Embodied carbon

The emissions associated with the design and transport stage (A1-A3 in Figure 5-4) is referred to as embodied carbon and make up for a large part of the environmental impact of product's environmental impact. Embodied carbon is the major defining factor in infrastructures CO_2e emissions and it's a core element when searching solutions for carbon neutral built environment. NBSs are usually a low-carbon option compared to heavy civil engineering structures. For example, in certain circumstances structural flood defence systems can be replaced or partially replaced by a natural-based storm water system and thus use less emissions intensive materials.

The following characteristics of NBSs increase the benefits associated with climate adaptation and support climate mitigation of road networks:

- Materials with lower transport-related carbon emissions (e.g., locally manufactured, and sourced materials)
- Chosen design or solutions use less emission intensive materials
- Solution is easy to reconfigure during its life and an actual demolition stage can be avoided.

In addition, the quantity of embodied carbon in a material or structure is typically positively correlated with the number of natural resources used during its production. Therefore, the aim to quantify and achieve low-carbon outcomes is expected to also result in a reduction of resource consumption.

To quantify embodied carbon and thus the benefit of opting for low-emission measures, can be done by carbon management and accounting methods and tools. There are several international and local standards associated with carbon accounting, some of them explicitly cover the methodology whilst others have a broader focus which encompass other aspects of sustainability as well as carbon[7]. The four stages depicted in Figure 5-4 are frequently used in the most used standards.

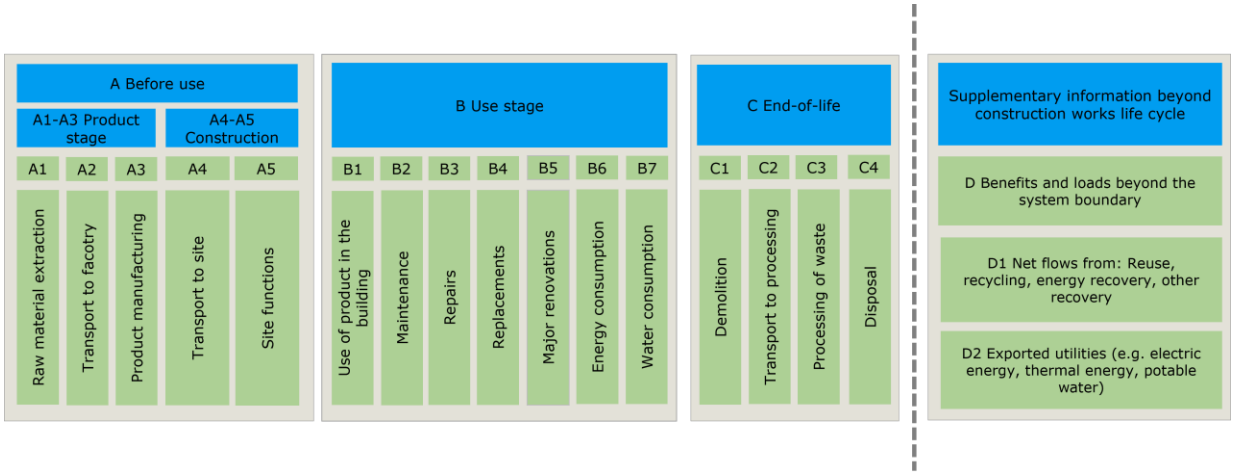

Figure 5-4. Different stages of infrastructure life cycle phases, according to EN 17472:2022.

Using carbon accounting as a guiding method in the road design process helps to understand and recognize the benefits of NBAs in relation to climate mitigation. It is however important to note that there is still uncertainty associated with standardized and recognized calculation methods, and that this limitation arises from a lack of comprehensive understanding of their sequestration potential.

The Social Cost of Carbon – SCC

The concept of social cost of carbon is becoming more widely accepted and is increasingly considered as one of the most important concepts for informing the public policy response to climate change. The idea of the concept is to represent the value of the marginal damage inquired from a unit of CO2e (Atkinson et al. 2018).

The use of SCC and how it should be estimated has been debated and therefor figures might differ between nations and institutions. If SCC is used it is recommended to giver consideration to the applied estimates and to use figures produced by generally accepted and recognized institutions.

For example, the National Academy of Sciences has provided a framework for the estimation of the social cost of carbon which relies on the use of integrated models of both climate and economy. In its most basic form, these models base their estimation on four essential measures

- Emissions: What is the projected path of CO2 emissions
- Impact: That are the impacts of the emissions on the physical world
- Damages: What are the economic damages associated with the projected path of physical changes
- Discounting: What is the discounted stream of economic damages to obtain a PV.

It is debated whether global or domestic SSCs should be applied in political decision-making context. The argument being that CO2 is a global pollutant and thus that the global externality should be

[7] Globally known standards describing technical methodology are ISO 14001 and related standards for environmental management, and CEN/TC 350 standards such as EN 17472:2022 and 15643:2021.

internalized with a global SCC domestically. However, domestically applied SCCs have been widely used.

5.3 Recommendations for gaining insight in the value of adaptation options

The link between climate hazards and benefits relates to the idea of capturing the value of climate resilience and adaptation measures, through the established KPIs. Enabling measurement of the established KPIs allows for measurement of performance, trends, and informed decisions on resource allocation. However, as also stated in section 4.3 the metrics used for KPIs, policies and other indicators are often not suitable for assessments, and thus needs to be converted to a more applicable metric. Section 5 has elaborated on how benefits can be operationalized within a decision-making context through valuation methods or, as a minimum through some form of quantification.

Section 5.2 has provided, first, an overall description of a generalized approach of applying valuation methods in relation to benefits, and secondly suggested generalized approaches of how to go about valuation for the list of benefits included in Table 5-1. In addition there are some recommendations to consider for valuation of benefits associated with adaptation options.

- As explained in 5 the application of valuation methods will always be associated with some uncertainty. The accuracy of applying a measure should be determined based on the level of detail needed to be sufficiently informative in the specific context and the number of available resources. This trade-off between needed level of detail and resources used should always be considered carefully.
- In continuation of the above, it is generally recommended to consider the magnitude/importance of the expected benefits. Whether a benefit is considered significant or not should go into the consideration given to the level of detail needed. Benefits that are expected to influence decision-making should in general require more scrutiny than benefits that are expected to influence decision making to a lesser extent. Section 5 has provided some overall information on possible indicators to consider for assessing the magnitude of the benefits included in the section.
- Carefully consider what the relevant baseline should be, before starting to assess the expected benefits. Choosing the right baseline scenario will be vital in terms of not only the results, but eventually also the context in which these are applied.

6 MAKING THE CASE FOR ADAPTATION

This chapter builds upon the previous chapters. When good insight is obtained in the way an NRA makes decisions (Section 3), how performance is measured and can be used in the decision making (Section 4), and know how to value the performance of climate adaptation options based on benefits and wider co-benefits (Section 5), the NRA can bring these together in the so-called case for climate adaptation. This chapter describes how NRAs can do this. In Section 6.1 three approaches for making the case for adaptation are recommended, Section 6.2 provides the methodological background to perform an evaluation of adaptation based on costs, benefits and co-benefits and 6.3 provides a description of other factors that should be considered in making the case.

6.1 Three approaches to make the case for climate adaptation

We found the following challenges (see Section 3.2) for making the case for climate adaptation, considering steering on outputs (via KPIs) and inputs (via guidelines):

1) The existence of a tactical gap:
    a. The metrics used for steering via input and output are different. It is not quantitatively understood how input steering leads to a certain performance (the output) of the road asset, connection or network.
    b. The quantitative and relative influence of climate and extreme weather events on KPIs is unknown. There are multiple factors influencing KPIs (like societal changes)
2) The quantitative effectiveness of adaptation options related to performance (via KPIs) is not known

In general, NRA's use both output steering via KPIs and input steering via guidelines. Many guidelines and policies are generally in place for organising the work. However, the budgets are likely to be determined via KPI performance. Hence, to be able to make the case for climate adaptation, we recommend the following approaches, that are further elaborated in the next sub sections:

1. facilitating decision-making by understanding the relationship between climate and KPIs (via output steering)
2. adapting guidelines (via input steering)
    a. with objective to maintain the current performance towards the future
    b. with objective to optimise the future performance based on an analysis of costs, benefits and performance
3. adapting on an individual project basis

The three approaches are depicted in the below figure in the blue boxes. The first approach is valid for the network level and if achievable also for the connection/corridor level. Strategic and tactical level of the NRA will be involved in the execution of the step.

The second and third approach are relevant for the asset and connection level, as this is the level at which the road network will be designed, maintained and operated. The tactical and operational level will be involved in the execution of the steps.

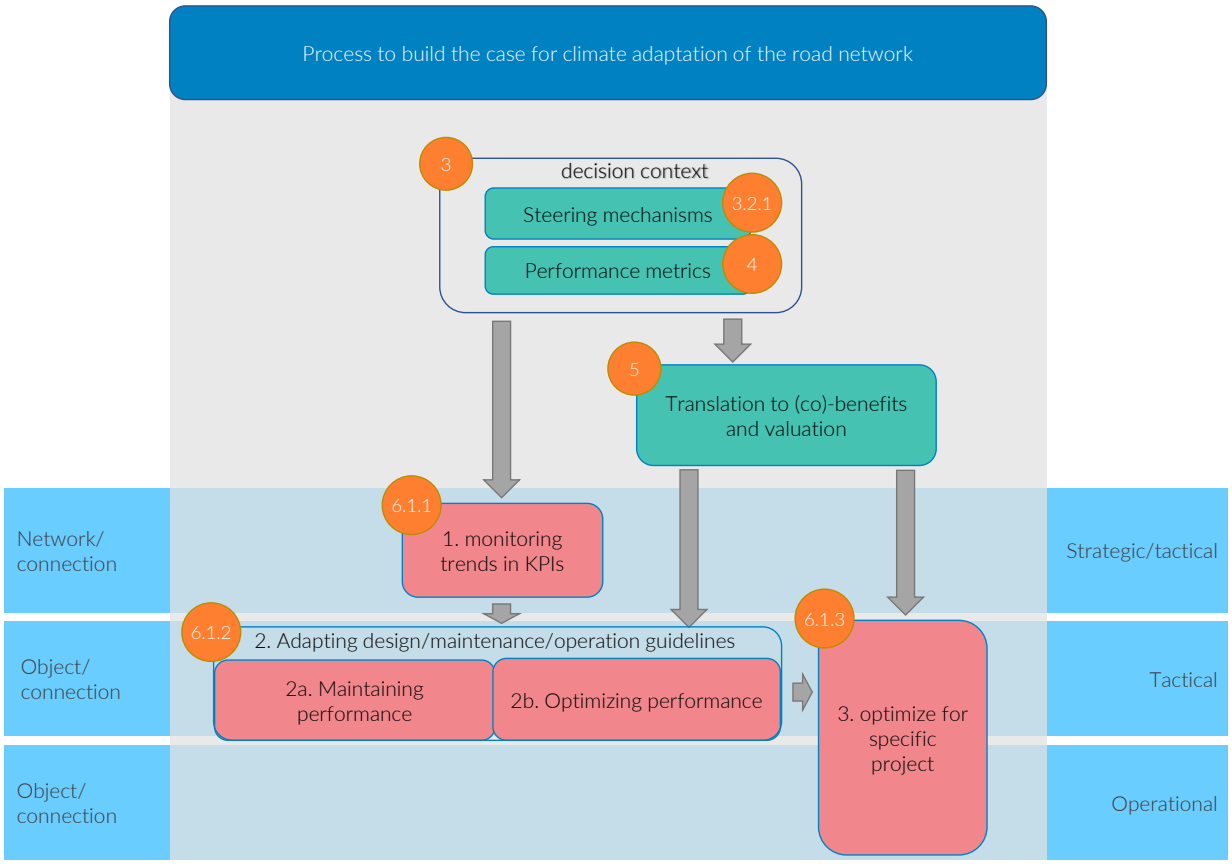

Figure 6-1 Process to build the case for climate adaptation with 3 approaches. The orange circles refer to the different section in this guideline,

The three approaches can be used independently of each other; there is no explicit need to conduct the three approaches after each other. However, the decision-making case can be made more effectively when all three approaches are adopted since they are likely to strengthen each other. The first approach will provide the arguments (if found), to further conduct research for updating the guidelines in the second approach. Updated guidelines will always facilitate the decision case for adaptation of an individual project since it will provide a solid and minimum basis of adaptation for every project.

Table 6-1 The advantages and disadvantages of the three approaches

Approach	Advantages	Disadvantages
1. making the case for adaptation by understanding performance in relation to climate threats	+ It provides an understanding of the need for adaptation, using the 'language' of the strategic management level (KPI metrics) + It leads to a quantitative understanding of the relationship between climate and performance of roads (dose effect relationship) + Leads to an understanding of effectiveness of adaptation options + May also lead to insight of other factors determining the performance of roads	– This approach does not lead to adaptation directly as it only provides general arguments for the case for adaptation – Only possible for climate threats that occur relatively frequently – Necessity to have good monitoring data of performance and climate threats in the past years
2a. climate proofing of guidelines while maintaining performance	+ Straightforward approach + No change in performance and thus possibly less discussions with strategic level + Adaptation of guidelines 'automatically' will lead to adaptation in practice	– Probably no optimized performance achieved, meaning that costs can be too high and/or performance can be too low – No insights obtained in (wider) benefits. This may complicate the need to have additional budgets for fulfilling the updated guidelines – Knowledge base not expanded
2b. climate proofing of guidelines while optimising performance	+ An optimization on a universal basis via guidelines will lead to an efficient use of public money + Adaptation of guidelines 'automatically' will lead to adaptation in practice + Expansion of the knowledge base	– Case based research needed with associated budgets and capacity – Elaborate approach since it requires an evaluation of costs and (wider) benefits of several locations along the road network for several climate threats – Data availability to conduct this approach may be limited or will require substantiative efforts
3. optimisation of climate adaptation of specific project	+ An optimization on a project basis will lead to the most efficient use of public money + Especially worth considering for bigger/complex/critical projects + When sufficient projects have been assessed, guidelines can be updated according to approach 2b	– Elaborative approach; not efficient to be done for every project – Knowledge and capacity not likely to be sufficiently available at the operational level to conduct this approach for every project

6.1.1 Approach 1: Making the case for adaptation via KPIs

Given the tactical gap, it is complicated to make a case for climate adaptation based on KPIs, even when the KPIs are applied to connection or asset level. It is therefore not possible to make a case for specific adaptation options by demonstrating the effects on the KPIs. What is possible though, is to gain insight into the effects of extreme weather and climate hazards on the performance of the roads, for those threats that occur on a relatively frequent basis. When this information is obtained this will aid in making a case for adaptation by showing that when no adaptation is considered, the performance is expected to decrease. The following steps are recommended:

- Conduct a trends-analysis with research to understand the correlation between the performance of the KPIs and climate threats, based on monitoring/performance measurements over past years
- By evaluating the obtained correlation, gain an understanding in the relative contribution of (not reaching) the KPIs due to climate threats. After this analysis, it will be known what the effect is of climate hazards on performance in terms of KPIs.
- This makes it possible to consider climate change projections, to identify and estimate how the performance will change towards the future due to climate change.

When these steps are taken, insight is gained into the effects of climate change on the performance of the road network in the future. This makes it possible to conclude whether, based on the thresholds for the KPIs, there is a case for adaptation or not. If it is concluded that action needs to be taken, approaches 2 and 3 can be followed (see Figure 6-1 and elaboration the following sub sections). Another conclusion may also be to lower the thresholds for the KPIs or in other words to require less performance of the road network. A substantiation for such a decision can be made via approaches 2 and 3 as well.

Figure 6-2 flow chart of approach 1: how to make the case for climate adaptation through monitoring of trends in KPIs

6.1.2 Approach 2: Making the case for adaptation via changes of guidelines and standards

By changing the guidelines and standards for design, maintenance and operation, that are being used for asset management by the operational level, it is ensured that climate change adaptation will 'automatically' find its way to implementation in practice. The process of changing such documents however can be very substantive as it will require approval by strategic decision makers, as well as support by the operational level. In this section we provide recommendations to aid in that process.

Approach 2a: Maintaining current performance

As explained in section 3.2.2, it is not quantitatively known how a certain maintenance or design guideline leads to a specific performance of the network. Still, it may be concluded that for the current climate / circumstances the performance is deemed sufficient. However, understanding that the climate is changing, one can conclude that the performance of today should also be achieved in the future. This could be substantiated when approach 1 has been followed (previous section). For the case of maintaining the current performance, the following recommendations are made:

- Identify all design, maintenance and operation guidelines/regimes/standards which influence the performance of roads under climate hazards.
- Identify how the climate is expected to change. Consider different climate change scenarios, climatic zones and time horizons. It makes sense to consider the lifetime expectancy of the asset under consideration to identify what time horizon should be chosen.
- Analyse how the inputs in the guidelines need to be changed, to have the same performance in the future as the current performance and change the requirements accordingly. Note that, since the effectiveness of certain measures/procedures is not always well understood, it may

be necessary to conduct additional research or to make assumptions. The impact chains that are being developed in D1.2 will also be of help to aid in the analyses.

It is likely that the changes to the design and maintenance regimes will require additional budgets for design and maintenance. This approach 2a does not make the case for adaptation, hence, the approach does not include estimation and comparison of benefits and costs. This may lead to questioning of the feasibility of changing the guidelines. If that is the case, the case for adaptation can be made by considering the optimisation of performance in approach 2b, or, an analysis of the KPIs (as explained in the previous section) may be of help to aid in making the case.

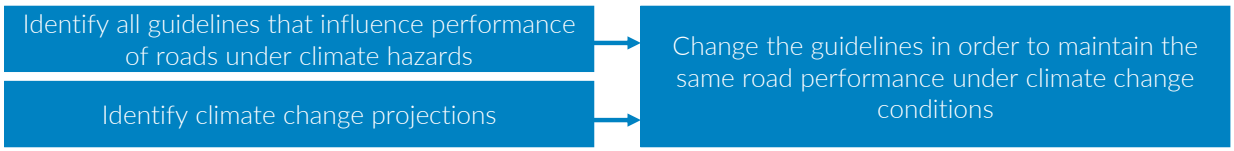

Figure 6-3 Process to make the case for climate adaptation through adapting maintenance guidelines to maintain the same performance

Approach 2b: Optimising the performance

When enhancing adaptation by changing the design, maintenance and operation guidelines/regimes/standards, it makes sense to conduct an analysis in which costs and (wider) benefits are evaluated. As explained, the advantages of adaptation options cannot be expressed in terms of changes in the performance of the road via the KPIs (Section 3.2.2). However, what can be done is to express the advantages in terms of benefits and co-benefits that can be linked to the KPIs (Section 4.2).

The following steps are recommended:

- Identify all design, maintenance and operation guidelines/regimes/standards which influence the performance of roads under climate hazards.
- Identify different options how the guidelines/regimes/standards can be updated. Vary the options so they vary from strongly increased performance to similar or even decreased performance.
- Identify the benefits and co-benefits that result from changing the guidelines/regimes/standards. The benefits link to the KPIs that the road authority is using. The co-benefits link to wider benefits that are also strived for by the road authority or society in general (see section 4.2). Section 5 aids in the process of selecting and valuing the (wider) benefits.
- Select relevant cases along the road network for which an evaluation of changes of the guidelines makes sense. The selection can be made based on:
    - Different criticality (eg. high/low traffic intensity, high/low redundancy, high/low critical)
    - Both new/to be designed and existing roads
    - Different climatic zones
- Evaluate the different options by comparing costs and benefits that are linked with the changes made in the guidelines/regimes/standards, according to the method that is described in Section 6.2. Make an overview of the different options in terms of required (additional) budgets and acquired performance in terms of the (wider) benefits.
- Evaluate the cases together with the strategic level and choose the option for which costs and (wider) benefits are deemed optimized.
- Update the guidelines/regimes/standards accordingly.

This approach will eventually lead to the optimized use of public money. It may also lead to the conclusion that thresholds for KPIs are not well chosen (and may lead to revision of KPI thresholds). For this, reference is made to the analysis for approach 1 that is described before. It is also noted that this approach 2 needs to be evaluated on a regular basis when new information if obtained regarding the changes towards the future (e.g. climate change and socio economic developments). It is to be foreseen that the guidelines/regimes/standards need periodic updating to reflect these new insights.

Figure 6-4 Process to make the case for climate adaptation through adapting maintenance guidelines to optimize performance

6.1.3 Approach 3: Making the case for adaptation on an individual project basis

Sometimes it might be necessary to make a case for adaptation on a project-by-project basis for specific construction, maintenance or renovation works. Reasons to do this can be political concerns, past climate events, high criticality of the road, budget constraints, stakeholder involvement or image.
The approach for making the case for adaptation on a project basis is further described in Section 6.2 and includes evaluation of benefits and costs. When considering the benefits of the project, they must be linked to the KPIs used by the road authority. Additionally, the co-benefits should link to wider benefits that are important to the road authority or society at large. Section 5 can help with selecting these broader benefits. It might be worth considering applying approach 3 first and using the evaluated projects as cases for optimizing the corresponding guidelines as explained in approach 2b.

6.2 Roadmap for evaluation of climate adaptation

In the previous section three approaches to make the case for climate adaptation options were presented: Either via KPIs, changes in guidelines and standards or on an individual project basis. The following section outlines an overall roadmap for evaluation of climate adaptation. Thus, this roadmap is relevant, if it's concluded that there is a case for adaptation and action is needed. To effectively evaluate climate adaptation, NRAs need to decide what is relevant to consider and how to evaluate the potential costs, benefits and co-benefits. This regards decision-making at both the strategic, tactical and/or operational level and also relates back the ability to evaluate and compare different options within the three approaches for making the case for adaptation presented in section 6.1. Thus, the following roadmap relates to the evaluation of the specific climate adaptation options, and presents approaches for evaluating and comparing benefits and costs, which is particularly relevant for approach 2b and 3.

In Section 3.1 it was explained how adaptation options can be viewed from both the strategic, tactical, and operational level, and Deliverable D2.3 presents a catalogue of the various adaption options. Hence, it is apparent that there are many different potential adaptation options and in practice it will never be possible to evaluate all of them in details. However, it will often be possible to limit the number of relevant options with a crude initial screening where all the impossible / irrelevant options can be discarded. This will leave a shortlist of potentially feasible options that need to be evaluated.

The subsequent sections will be looking at:

- The linkage between benefits, co-benefits and adaptation options
- How to determine what is key (benefits) and what is desirable (co-benefit)
- When to use CBA or other analysis methods

6.2.1 Analysis of adaptation options

The ICARUS catalogue of adaptation options (See Deliverable D2.3) contains various options that could be relevant to consider when looking for a solution to an adaptation problem. But not all options will be equally relevant to look at in each case, and by applying a simple elimination strategy it will be possible to limit the number of relevant options considerably. First, all the options that are not suitable for addressing the identified hazard in questions can be eliminated. Secondly, options that are not suitable for the geographical zone can also be eliminated. Thirdly, options that are not aligned with the governing benefits and co-benefits for the NRA can normally also be eliminated, though with the caveat that these might provide the wrong incentives for the NRA to do the right thing, in which case the benefits and co-benefits might need to be changed.

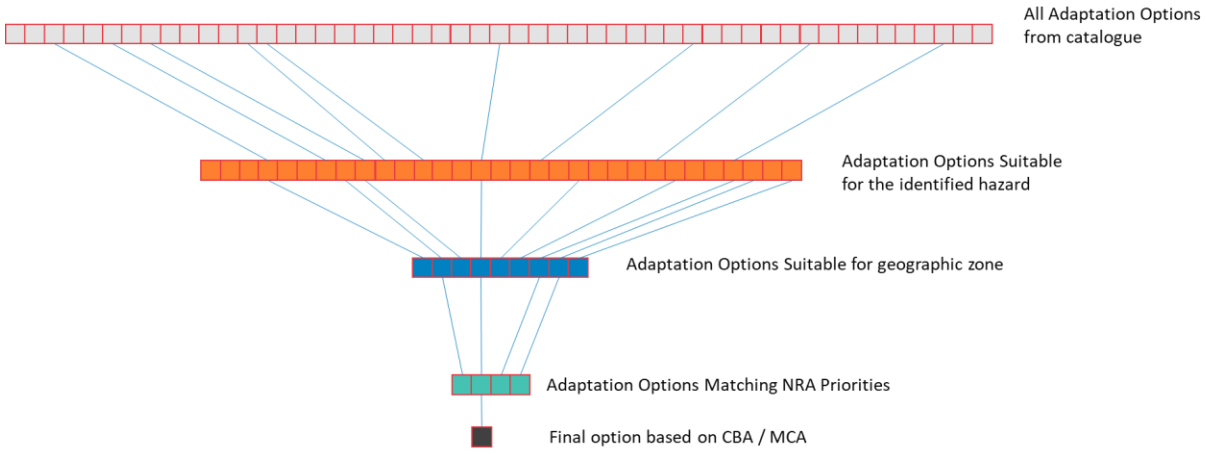

Figure 6-5 Evaluation and selection of adaptation options

This process is likely to reduce the number of relevant adaptation options significantly, and hence also the amount of work that needs to go into the further analysis of these options. Section 6.2.2 below discusses further when it will be possible to do a cost-benefit analysis (CBA), or if there might be non-quantifiable costs or benefits that might prohibit a CBA to be performed.

6.2.2 Choice of Analysis methods

Once it has been established which adaptation options that might be relevant it needs to be established if they are also feasible from a cost benefit point of view. Even if it turns out that there might only be a single possible adaption option it could still be useful to look at the cost and benefits, as it might turn out that to "do nothing" could be a better option from a socio-economic perspective.

From a theoretical point of view the Cost-Benefit Analysis (CBA) is an excellent analysis method due to its simplicity and clarity. The options with the highest ratio of benefits to costs (benefit-cost ratio) is simply the preferred option. In practice there are several issues that the analyst needs to consider to avoid some of the pitfalls related to an uncritical application of the CBA methodology.

It is not the intention to include a full description of the CBA methodology, or the pitfalls, here as that can be found various textbooks. Rather the points below should be seen as a short summary of some of the most common problems that will be encountered when working with CBA in practice.

Based on cash flow

The CBA methodology is a financial methodology used to evaluate investments, and as such it is analysing the cash flow related to an investment. The CBA is normally not concerned with how the investment is financed, and in principle the result will be the same whether the investor decides to use equity or loans to finance the investment. Hence the possible disbursement and repayment of a loan, and interest payments, related to the investment will normally not be included in CBA. But in most cases the subsequent calculation of an internal rate of return (IRR) can be performed to see that the IRR is actually higher than the interest rate charged on the financing.

The role of time

If the project extends beyond one period (normally a year - but could in theory also be a day for short projects) the CBA requires that the monetary value can be compared across the different periods. Technically this is done by discounting the future values back to the first period. The discount rate used for this reflects the interest rate, and in most countries the Ministry of Finance (or similar institutions) will provide guidance on how to decide on the appropriate discount rate. In general a higher discount rate will reduce the weight of amounts in the distant future, and even with a rate of perhaps 4%-5% the weight of amounts beyond 10 to 15 years might become so small that they might not have much impact on the calculation. But as many infrastructure projects have a much longer expected lifespan the calculation will often need to include a "scrap value" in the final year to be able to compare different options in a meaningful manner.

Whole life cycle cost

When deciding how many periods (years) should be included in the CBA it is important to ensure that the whole life cycle of the adaptation option(s) in question is included. This will especially be important when comparing options with different expected lifespans. If one option has a lifespan of 5 years and the other of 10 years, then it will only be possible to compare the CBA's for these two options if the first option includes a re-investment in the sixth year. Alternatively, a scrap value for the second option could be included in the fifth year.

The different adaptation options might also have different profiles in terms of initial CAPEX investment and subsequent OPEX costs, and for this reason it is also important to ensure that the options are compared over the same number of periods.

Non-monetary, or non-quantifiable benefits (or costs)

Section 5 described many of the benefits and co-benefits that might relate to the various adaptation options. Many of these benefits can be hard to quantify, or monetize, so they might not easily fit into a CBA.

In those cases where it is not possible to include all relevant benefits and costs into the CBA there will be a need to resort to other tools to decide on the optimal adaptation option.

Least-cost analysis

Often it is easier to quantify the costs, while the benefits are much harder to deal with. But if we are in a situation where the benefits related to two (or more) adaptation options are likely to be of the

same magnitude, then it might be much simpler to compare the options based on which involves the least cost. For example, it might be difficult to estimate the value of a road being available 95% of the time, but if two adaption options have the same availability, the option with the lowest cost (defined as Net Present Value) will be the preferable option.

Multi Criteria Analysis

In many cases it might not be possible to quantify all benefits and costs to the level of details required for a CBA, or the time and resources needed to do so might be prohibitive. In such cases it might be useful to allow for more qualitative assessment criteria in the analysis; the so-called Multi Criteria Analysis (MCA). An example of an evaluation matrix for an MCA is shown in Figure 6-6.

Evaluation Criteria	Weight	Option 1	Option 2	Option 3
Challenges	X %	Score	Score	Score
Opportunities	X %	Score	Score	Score
Criteria	X %	Score	Score	Score
Criteria	X %	Score	Score	Score
Conclusion		**Ranking**	**Ranking**	**Ranking**

Figure 6-6 Example of evaluation matrix for MCA

The MCA is often used in areas such as studies related to social equity and inclusion, where it is more common to apply qualitative measures which can be applied in e.g., the multi-criteria analyses, and thereby be included in the decision-making case. The combination of monetary valuations and non-monetary criteria can be applied in decision-making by applying a weighing procedure of the specified qualitative criteria (Henke et al. 2022).

Van Marle et al. (2022)[8] describes a process for including equity considerations in resilience network planning, which can also be applied to other areas:

1. Identify socially vulnerable groups. Literature suggests that some of the most important indicators of socio-economic status are wealth, household composition, age and ethnicity.
2. Create an *origin-destination* matrix to provide information on volume and intensities between origin-destination points.
3. Identify and rank network criticality based on assumptions regarding e.g., flood depth. For example, that a road is assumed to be disrupted when the flood depth is larger than a specified height[9].

[8] Including equity considerations in resilient transport network planning and analysis: A flood impact perspective Margreet van Marlea* , Bramka Arga Jafinoa,b , Lotte Lourensa,b, Lieke Hüsken

[9] For example by application of a depth-diruption functin: Pregnolato, M., Ford, A., Wilkinson, S. M., & Dawson, R. J. (2017). The impact of flooding on road transport: A depth-disruption function. Transportation research part D: transport and environment, 55, 67-81.

4. Define consequences for the different socially vulnerable groups and determine how the weighing of the consequences across the identified socially vulnerable groups should be. Weights could be assigned by different objectives:
    a. Maximizing the benefits regardless of the vulnerability levels of the groups
    b. Equal distribution of accessibility across the vulnerability groups
    c. Priority given to the most vulnerable groups.

6.3 Other influencing factors

It is easy to view through a narrow lens when considering adaptation of a scheme to climate change and extreme weather, However, as touched on in the previous sub-section the highways network is the means to an end (e.g. transport of goods, commuting and social cohesion), rather than the end in itself. In addition to the direct benefits that might be achieved by adaptation of a scheme and any co-benefits that may improve the business case, there can be other factors that influence the decision to pursue a scheme or not, depending on local factors. These could include, for example:

Political

Whilst National Road Administrations are responsible for the strategic road networks, generally they are part of, or answer to, a Governmental Department for Transport. This Department, in turn is responsible to the Government of the day and the transport policies they have. Governments change, and often their manifesto will have points on transport that they say they will deliver.

The construction of or opposition to, for example, a new road scheme can often be a considerable political issue. Whilst there should be an objective view of schemes or adaptation options, purely on merit (including co-benefits), marginal schemes might get pursued where the likely votes for political parties might be close, in the hope that the incumbent member of parliament retains his or her seat, whereas they might not if there was little prospect of a seat being won or lost.

The stability of a Government itself, or its point in the electoral cycle can also affect the policies being pursued. A Government with a large majority and likely success in future elections might pursue more radical policies than one with a small majority and a forthcoming election.

Image

The image portrayed, or wished to be portrayed is an important consideration by Governments and Government departments, as it is for businesses. Famous brands, such as Apple, Rolls-Royce and Nike convey an image beyond merely their logo or products, which in turn, causes people to buy, or to aspire to buy their products and services, and creates brand loyalty. Governments can also have 'brand' values that drive decision making in various ways.

For example, the Welsh Government places a high priority on environmental protection. It has consistently had far higher recycling rates than the other UK countries (third highest worldwide) and has passed acts such as the Wellbeing of Future Generations Act which requires public bodies in Wales to think about the long-term impact of their decisions in various areas and the Active Travel (Wales) Act, which places a requirement on local authorities to continuously improve facilities and routes for walkers and cyclists. This has expanded into areas of transport policy, initially scrapping a proposed motorway scheme in part on incompatibility with having declared a climate emergency, and subsequently essentially halting all new road schemes, with the aim of maintaining what exists and

promoting public and active transport. Decision making will therefore be driven, at least in part, on compatibility with the public image of the organization.

Economic Conditions

The prevailing economic conditions faced by a country have an impact on scheme affordability. What might be affordable in one country might not be in another. Or what might be affordable at one time, might not be in another.

Sometimes the budget for a scheme might be simply unaffordable, despite having a positive CBA. Other schemes, with lower CBA ratios may go ahead because they are more affordable, or potentially if there are future plans for other development, that a scheme would protect.

Social

Social conditions can have an impact on schemes depending on the demographics, socio-economic situation or projected population growth / decline / change. For example, a small, remote community predominantly occupied by elderly residents may be afforded greater protection than would be offered purely based on economics, if it meant that the road being blocked would prevent healthcare professionals delivering medicines or visiting patients.

NRA Maturity and Priorities

The technical maturity of an NRA will have an impact on the potential schemes that are considered. For example, a client with prescriptive specifications around construction and maintenance may choose solely hard measures, such as increased size drainage culverts to mitigate against increased rainfall. Alternative nature based solutions, such as the restoration / improvement of an off-site peat bog to serve as a sponge for rainfall, may not be considered, yet may be more effective, more affordable and with a range of biodiversity co-benefits.

The different priorities of NRAs might also influence scheme selection when co-benefits are considered. One NRA might have a priority of, for example, net gain biodiversity, whereas another might have a priority of local employment. The weighting applied to this might influence one solution over another, or one scheme over another.

6.4 Recommendations for making the case for adaptation

When making the case for climate adaptation in the context of National Road Authorities (NRAs), there are a number of factors to consider; NRA decision-making processes, performance measurement, and valuation of climate adaptation options. In general, NRA's use both output steering via KPIs and input steering via guidelines, creating a tactical gap. To address this, 3 recommended approaches were considered.

Approach 1 involves gaining insight into the effects of climate hazards on road performance by analysing trends in KPIs and their correlation with climate threats. This understanding helps determine the need for adaptation and future performance changes.

Approaches 2a and 2b focus on changing guidelines and standards to incorporate climate adaptation. The former aims to maintain current performance, while the latter involves optimising performance by evaluating costs, benefits, and co-benefits associated with guideline changes.

Approach 3 addresses the need for adaptation on a project-specific basis, considering factors such as political concerns, past climate events, and stakeholder involvement. Applying approach 3 can also serve as a basis for optimising guidelines through approach 2b.

These approaches are also linked to the different management levels at the NRAs and the roles and jurisdiction that come with these levels:

- Strategic level: At the strategic level, KPIs may be determined and changed. By doing so, a strategy to become more resilient can be strived for. Approach 1 above directly links to this level. The actions taken in approach 2 can provide arguments for keeping or changing the KPIs.
- Tactical level: The tactical level provides ways to operationalize the strategic level decisions into practical operational procedures. Given this role, the tactical level should be very keen on using the approach 2, to change the design, maintenance and operational guidelines in such a way that the target service levels will be met and thus a high score on the KPIs will result.
- Operational level: On the operational level it is key to understand what benefits are and how these should be used to build a decision case. If benefits alone are not sufficient, it should also be understood how co-benefits can be included to make the decision case. This is essential background to be used, especially for building the decision case for a specific project.

Adaptation options and their evaluation can be undertaken at strategic, tactical, and operational levels. The ICARUS project will develop a catalogue of adaptation options, containing hard engineering measures, nature-based solutions and hybrid solutions. NRAs will be able to use the catalogue to identify options for consideration based on the identified hazards, the climatic zone and the KPIs they use. Benefits and co-benefits can be used to help make the case, with benefits generally being able to be categorised using CBA, whereas not all co-benefits can be monetised. There remain practical considerations and pitfalls associated with applying CBA, such as cash flow analysis, the role of time, whole life cycle cost, and non-monetary benefits or costs.

Alternatives to CBA that can be used (particularly for non-monetary costs and benefits), include the least-cost analysis, which compares options based on their costs when benefits are similar, and multi-criteria analysis (MCA), which incorporates qualitative assessments. able groups, creation of an origin-destination matrix, ranking network criticality based on assumptions, and determining consequences and weighing across socially vulnerable groups.
Other factors that might be relevant when making the decision around pursuing a scheme or adaptation were identified. These include, political considerations, such as the influence of government policies and the potential impact on electoral outcomes. The image and values associated with the government or organisation involved also play a role in decision-making. Economic conditions and affordability are important factors, as schemes need to be financially viable. Social factors, such as demographics and social conditions, can influence the prioritisation of schemes. The maturity and priorities of the National Road Administrations (NRAs) can also shape the selection of schemes, with different NRAs emphasising different aspects like technical specifications, biodiversity, or local employment. Overall, these factors highlight the complexity involved in decision-making for adaptation options and the need to consider a range of considerations beyond direct benefits and cost-benefit analysis.

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