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Decision-support Tools for Embedding Climate Change Thinking on Roads (DeTECToR)

Guidance on Economics and Climate Change

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DeTECToR
Decision-support Tools for Embedding Climate Change Thinking on Roads

Draft Guidance on Economics and Climate Change

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Table of contents

Glossary

Term/Acronym	Definition
Adaptive management	A long-established approach that uses monitoring, research, evaluation and iterative development to improve future management strategies.
Climate	Climate can be defined as the average weather, normally over 30 years. It is the statistical description of the mean and variability of relevant variables such as temperature and precipitation.
Climate change	A change in the state of the climate that can be identified by changes in the mean and/or variability of it properties and persists for an extended period *(e.g. decades or longer).
Climate change adaptation	The adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.
Climate change mitigation	A human intervention to reduce the sources or enhance the sinks of greenhouse gases (GHGs).
Climate projection	A projection of the response of the climate system to emissions or concentration scenarios of greenhouse gases and aerosols or radiative forcing scenarios, often based upon simulations of climate models. (IPCC)
Cost-benefit analysis (CBA)	An analytical methodology for the quantification of the positive and negative consequences of a project in monetary terms over a set appraisal period.
Cost-effectiveness analysis (CEA)	CEA compares the costs of an analysis to effectiveness where the measure does not have to be monetised.
Discount rate	A technique used to compare costs and benefits that occur in different time periods.
Multi-criteria analysis (MCA)	Assessment of options against a number of criteria, followed by their ranking and prioritisation.
Pavement asset Management System (PMS)	PMS is a systematic and objective tool to manage pavement networks based on rational, engineering and economic principles.
Risk	ISO 31000 describes risk as the effect of uncertainty on objectives. In engineering terms risk is often described as a combination of the likelihood of an event occurring and the magnitude of the consequences if it does occur. When considering climate change, likelihood is related to exposure to environmental conditions and the vulnerability of the asset.
Real options analysis (ROA)	Incorporates flexibility by enabling a staged approach with the measurement of risk and uncertainty into the appraisal of options.
Uncertainty	A state of limited knowledge with difficulty in describing the current state of future outcome.
National Road Administration (NRAs)	The organisations which manage the construction, maintenance and operation of a countries main roads.
Weather	The short-term variation in meteorological conditions, such as temperature, precipitation and wind.

Executive summary

Climate change presents a significant challenge for National Road Administrations (NRAs), both in dealing with its impacts on their network and in finding ways to reduce their greenhouse gas emissions. The DeTECToR (Decision-support Tools for Embedding Climate Change Thinking on Roads) project was commissioned through the Conference of European Directors of Roads (CEDR) Transnational Research Programme to help NRAs address these challenges. DeTECToR focuses on two key areas; developing the business case for climate change adaptation; and embedding consideration of climate change mitigation and adaptation into NRA operations and procurement. A decision-support tool and accompanying guidance was developed for both these areas. The risk assessment and cost-benefit analysis tool produced will enable NRAs to identify the level of risk to different routes/assets from relevant weather hazards and understand how this is likely to vary over time due to climate change. The procurement tool provides online guidance and case studies on embedding climate change using a wiki approach, enabling NRAs can add and update the tool after the end of the project.

This document is the economic guidance document accompanying the risk assessment and cost-benefit analysis tool. The guidance document is divided into two parts. Part A provides information, recommendations and examples of good practice on including climate change in economic appraisal. The types of topics included are selecting an appraisal methodology, discount rates and dealing with uncertainty. Part B is the manual for the risk assessment and cost-benefit analysis tool. It includes a description of the underlying methodology and assumptions behind the tool calculations and a guide on how to use the tool.

About DeTECToR

DeTECToR (Decision-support Tools for Embedding Climate change Thinking on Roads) is part of the CEDR transnational research programme and was commissioned under the 2015 call for proposals ‘Climate change: From desk to road’. The overall objective of DeTECToR is to help National Road Administrations (NRAs) put into practice the latest climate change research and good practice. The project produced decision-support tools and guidance documents that will enable NRAs to better integrate climate change considerations in economic and procurement decision making.

Specifically it produced:

- Summaries of relevant research projects, including recommendations and case studies describing how the findings and tools can be put into practice by NRAs;
- An economic decision-support tool that will enable cost-benefit analysis of different adaptation options for planning and asset management;
- A guidance document on embedding climate change research into economic decision making, which also provides guidelines and case studies on the use of the economic tool;
- An online procurement collaboration platform that will enable NRAs to share their approaches to including climate change in procurement and learn from each other’s experiences; and
- A guidance document for embedding climate change mitigation and adaptation into NRA operations and procurement procedures, with guidelines and case studies on using the procurement tool.

Further information can be found on the project website https://detector.trl.co.uk/

This document

This document is the economic guidance document which accompanies the risk assessment and cost-benefit analysis tool. It is based on the literature review, stakeholder survey and pilot studies carried out during the project.

The content is divided into two parts; Part A is guidance on embedding climate change in economic appraisal, and Part B is a manual on the DeTECToR risk assessment and cost-benefit tool. The document is divided into the following sections:

Part A: A guide to the inclusion of climate change in economic appraisal

Section 1 is an introduction to the guidance.

Section 2 provides information, recommendations and examples on different issues related to climate change and economic appraisal.

Part B: The DeTECToR CBA tool

Section 3 provides an overview of the tool, when to use it, the intended users and the different modules and functionality.

Section 4 describes the underlying calculations.

Section 5 is a step-by-step guide to using the tool.

Section 6 provides example results from one of the pilot studies.

PART A: A guide to the inclusion of climate change in economic appraisal

1 Guidance objectives and context

Section 1 provides an introduction to the guidance and why it was produced, sets it in the context of other CEDR projects and explains the structure of the document.

1.1 Why this guidance was produced

This guidance was produced to give readers an easily accessible reference on the subject of including climate change in economic appraisal. The document draws on the literature revised and the knowledge generated in the DeTECToR project and presents it as a series of recommendations and case studies to the reader. This guidance also demonstrates how to make use of the DeTECToR risk assessment and cost benefit analysis tool, including a step-by-step guide.

The tool and guidance build on previous CEDR projects in particular ROADAPT from the 2012 climate change call which produced guidelines on socioeconomic impact (Chevreuil, 2015). It also aligns with WATCH, DeTECToR 's sister project in the 2015 climate change call, which is carrying out CBA as part of its work on water management.

The DeTECToR risk assessment and cost benefit analysis tool focuses on the network level (as described in ROADAPT) and is based on classical CBA. However, this is only one aspect of socioeconomic appraisal. It should be combined with other types of appraisal such as multi-criteria analysis which considers a wider range of costs and benefits.

1.2 Guidance structure

The sections of the guidance are structured in a set way in order to make it easier for different readers to access the information they require.

Each section will start with some text which will serve to introduce the topic area and present questions and issues that a reader should consider when looking for guidance on the specific topic area.

There are then two separate highlight boxes that aim to draw out key information for the reader.

Following on from the general text the reader will be presented with a 'recommendations' box (see blue box below). The idea of these boxes is to present key recommendations to the reader for that specific topics area being discussed.

Recommendations:

- Example recommendation 1
    - Sub-point 1
- Example recommendation 2

Following on from the recommendations box, the reader will be presented with an 'examples' box (see orange box below). These boxes will highlight relevant projects or case studies that the reader can refer to for additional information. They will also give a short summary of why the project or case study is relevant within the specific topic area.

Example: Reference (Year). Text about the case study / reference.

Description of example.

The idea behind having the different boxes is that it allows a reader to quickly draw out key information from the separate sections, therefore helping to make the guidance document a key resource they can continue to refer back to because it is easy and quick to navigate around it.

2 Economic appraisal and climate change

2.1 Background

2.1.1 *The role of economic appraisal in NRAs*

Most NRAs carry out some form of economic appraisal when planning either a new construction scheme or the maintenance of an existing infrastructure asset. It is used to minimise the agency's risks and also to estimate costs of investment projects. In order to conduct all the required economic analyses, a wide range of economic decision support tools and national and local guidelines are used by NRAs. For example, WebTAG[1] is used in the UK to provide guidance on the role of transport modelling and appraisal, as well as providing various default data for input into economic analyses. The European Commission document Guide to Cost-benefit Analysis of Investment Projects (Economic appraisal tool for Cohesion Policy 2014-2020) (EC, 2014) is widely used by NRAs in Europe to conduct economic appraisal of road projects including maintenance and operation contracts.

The types of decisions influenced by economic appraisal include:

- Planning routine maintenance – when and where to carry out work, prioritisation of schemes and estimations of required budget
- Decisions on major projects – whether or not to proceed with a proposed scheme, which route or design option to take, setting out the business case for budget holders
- Asset strategies – intervention levels, policies on types of design or material

Often these address the direct costs of works only and may make no reference to either the wider costs to society or incorporating climate change impacts. The stakeholder survey that was conducted towards the end of October 2016 by the DeTECToR consortium revealed that 76 percent of responders do not include climate change impacts into the economic appraisal of their potential road construction projects or future maintenance plans.

There have been a number of research projects which have sought to address this, some of which have produced tools or methodologies for incorporating climate change into economic appraisal.

[1] The web-based Transport Appraisal Guidance (WebTAG) provides Government guidance and requirements on transport modelling and appraisal in the UK. https://www.gov.uk/guidance/transport-analysis-guidance-webtag

Examples: Tools/methodologies which take into account climate change in economic assessment

(1) Resilient Analytics developed Infrastructure Planning Support System (IPSSTM), a quantitative engineering-based analysis tool to better understand the impacts of climate change on current and future road building, and energy infrastructure (Resilient Analytics, n.d.). IPSSTM identifies vulnerabilities, plans adaptation investment options and manages risks using a CBA approach. Costs are assessed using the following two approaches - Reactive, no adaptation approach and Proactive, adaptation approach.

(2) The Highways Infrastructure Resilience Modelling tool (HIRAM), has been developed in South West England to aid highway authorities in managing weather and climate risk to their local road networks. It is a network-based strategic tool used to analyse the impacts and risks of climate change and their socio-economic impacts with a particular focus on improving resilience of the network (Ward, 2015). HIRAM is a map-based tool that includes data on drainage assets, flood events, bridges and geological layers to account for the risk of landslides.

(3) The Blue Spot Concept was developed by the Danish Road Directorate (DRD) for its road network with a focus on flooding for non-urban large and important roads. Blue spots refer to a stretch of a road where the likelihood of flooding is relatively high. The model is used within a Geographic Information System (GIS) and is divided into three levels to assess the vulnerability of specific cases through the initial screening of depressions in the landscape, rain sensitivity analyses and in-depth hydrodynamic analysis (Danish Road Institute, 2010).

2.1.2 *Benefits of considering climate change in economic appraisal*

Road infrastructure, vehicles and operations are constantly exposed to weather hazards, and their construction and operation is influenced by the climate in which they are located. Climate change brings a new element to this, as road operators seek to better understand the influence of different weather variables on different types of infrastructure and how changes in climate could these. The main climate variables are:

- **Temperature**: both extreme highs of temperature and extreme lows are a hazard to infrastructure. Climate projections show an increase of heat stress and also an increase in variability. This means that the temperature range to which the infrastructure is exposed increases.
- **Precipitation**: Climate projections point towards a climate shift in which summer precipitation decreases in large areas and winter precipitation increases. The picture is complex, though, due to the fact that numerous processes in the earth-atmosphere system contribute to precipitation or drought.
- **Wind**: Climate projections point at changes in the global wind systems, like displacement of storm tracks. The average wind velocity however is subject to relatively small deviation from current climate conditions.
- **Sea-level rise**: This is a hazard for coastal infrastructure particularly in areas of low lying land. Related to this is the impact of storm surge, where a higher sea level combined with a storm can cause severe inundation and damage to coastal roads.

Making decisions in the context of uncertainty about occurrence and magnitude of weather events is recognised as a key challenge in managing road infrastructure. Hence, approaches for managing risks resulting from weather events are of major importance for road administrations. Responses to the weather and climate change related events need to be planned carefully. One of the main areas where NRAs can incorporate procedures for planning and executing adaptation actions is in asset management strategies.

By undertaking asset management and economic appraisal activities that include the consideration of climate change with the assessment it allows strategies to be investigated that consider the wider impacts of climate change in an economic context.

Recommendations:

- Climate change impacts should be considered in economic decisions, particularly those with long term implications
- Economic appraisal should include consideration of the level of risk from adverse weather events, and the implication of the changing climate on lifespan
- CBA should not be used in isolation, but other wider impacts on communities should also be considered (e.g. using MCA)

2.2 Setting up your economic appraisal

2.2.1 *Selecting the appropriate method*

The main types of economic appraisal techniques used in analyses are:

- Cost-benefit analysis (CBA)
- Cost-effectiveness analysis (CEA)
- Multi-criteria analysis (MCA)

The methods have different strengths and weaknesses and can be useful in different situations. Therefore the choice of the most suitable method will be determined by a combination of the data being analysed, the costs involved and the type of outputs that are desired.

CBA is used extensively in transport and other sectors to inform investment decisions. It is used to quantify the positive and negative consequences of a project in monetary terms over a set appraisal period, producing a Benefit Cost Ratio (BCR) (Mediation Adaptation Platform, 2013a). The larger the BCR the stronger the business case for investment is. CBA is most effective when robust sources of data are available.

CEA compares the costs of an analysis to effectiveness; this measure does not have to be monetised. It is used to rank and prioritise options by finding the most cost efficient option for meeting targets. CEA is applicable for climate change mitigation studies because of its ability to compare and rank the incremental cost of greenhouse gas abatement options (Mediation Adaptation Platform, 2013c). However, its application to adaptation studies is more challenging due to it being the response of many different impacts. CEA faces some of the same difficulties as CBA, including problems of quantification.

MCA involves the assessment of options against a number of criteria, followed by their ranking and prioritisation, and it differs from CBA in that not all the benefits need to be monetised or quantified. MCA has high applicability for ranking options within an environmental context used to capture environmental and social aspects.

Table 1 – Strengths and weaknesses of the different methods

Method	Strengths	Weaknesses
CBA	Produces quantitative outputs with a direct analysis of economic benefits and costs	Difficulty of valuing all costs and benefits of a project such as externalities
	Ease of comparison between projects through BCR	Data and resource heavy
	Used as a standalone tool	Uncertainty analyses are limited to probabilistic risks
CEA	No requirement for benefits in monetary terms, which improves the application for externalities	No/little consideration of uncertainty and adaptive management
	Simple and transparent approach with low cost and time requirement	Less applicable to cross-sectoral or complex projects
	Combines qualitative and quantitative data	Not suitable as a standalone tool for many projects
MCA	Combination of quantitative and qualitative data	Highly subjective to stakeholder opinions
	High applicability to externalities	Difficulty in assigning weights to different criteria
	Encourages stakeholder engagement to discuss options	Analysis of uncertainty is only qualitative
	Used effectively as a supplementary tool to CBA	Not suitable as a standalone tool for many projects

Example: The Appraisal Summary Technique (AST) has been broadly used in the assessment of the economic, environmental and social impacts of a project. An example of an appraisal summary table is that of Department for Transport UK, published in its transport appraisal guidance document (Transport Analysis Guidance, UK Department for Transport 2014).

As in objective impact assessment, an appraisal summary table is created which include the description of objectives, sub-objectives, impacts and ratings or scores. Objectives are broadly classified into economic, social and environment. Sub-objectives are detailed breakdowns of objectives that assist in revealing an extensive range of impacts. The project proponent is required to enter the objectives and an assessment staff or team determines the impact through ratings or scores. Impacts are described qualitatively and quantitatively. For each impact a score is provided. The scoring could be a grade, a monetary value or general points on a scale.

Example:

The benefit-cost ratio (BCR) is given by Present Value Benefit (PVB) / Present Value Cost (PVC) and so indicates how much benefit is obtained for each unit of cost, with a BCR greater than 1 indicating that the benefits outweigh the costs. Whether an impact is included as a negative cost or a positive benefit (or vice versa) will impact on the BCR.

For example,

- Consider an appraisal comprising three elements: investment costs, time savings and greenhouse gas emissions; and comparing two options, both with investment costs of £10m.
- Option A generates time saving benefits of £50m and greenhouse gas benefits of £10m while Option B yields greater time savings of £100m but increases greenhouse emissions with a £10m dis-benefit.
- Both options cost the same and the total net benefit (NPV) of Option B is £80m compared with £50m for Option A, suggesting that Option B should be preferred.
- However, if the PVC is defined to include all negative impacts, Option A has a BCR of 6 ((50+10)/10) while Option B has a BCR of 5 (100/(10+10)).
- This definition of the PVC moves the greenhouse gas impact between the PVB and PVC for the two options and distorts the BCR, reducing its usefulness in comparing schemes or options.

Recommendations:

- CBA is a sensible starting point for the appraisal of climate change adaptation in transport projects. This can be supported by other economic appraisal techniques to provide a more robust assessment; for example, MCA can address externalities, while ROA is more effective at incorporating flexibility and uncertainty. The selection of a discount rate and a time period are both pertinent issues when considering climate change within economic appraisals.
- It has been recognised through the literature review and research that there is a need for robust datasets for economic appraisals so results can be comparable.
- As demonstrated by Environment Agency (2012) to conduct proper economic appraisal of projects impacted with climate change it is critical to be able to monetise as many costs as possible, including social and environmental impacts and incorporating uncertainty.

2.2.2 *Choosing a discount rate and appraisal period*

In terms of discount rates, the most common question a user of the tool will have is "what discount rate should I use"? The choice of a discount rate is important because it is the mechanism by which the tool will factor the costs incurred in the future back to a common base year.

When climate change and adaptation are included in analyses the issue over choosing a discount rate becomes more controversial, primarily due to the uncertainty over long-term impacts of climate change and how those impacts should be represented within analyses.

Example: RSSB (2016). The selection of the discount rate and analysis period are closely linked: for example a high discount rate combined with a long analysis period is not advisable because costs would be incurred towards the end of the analysis period and therefore, have little impact on the analysis.

RSSB recommend an analysis period of no fewer than 60 years due to the low frequency of extreme weather events.

Recommendations:

- Consult local standards for correct discount rates
    - HM Treasury (UK) recommends 3.5% for first 30 years
    - European Commission recommends 3.5% or 5.5%
    - The German National Transport Plan 2030 use the Social Time Preference Rate of 1.7% (without indexation)
- Longer-analysis periods should use a declining discount rate (after 30 years)

2.2.3 *Including wider costs*

Climate change can impact upon road infrastructure in different ways, from increasing maintenance costs, reducing the life of the asset or leading to significant clear-up costs after events. Whenever the road network is not serviceable it results in socio-economic costs, for example due to increased journey times or lack of access. This can further present itself as impacts on businesses and tourism, which can spread beyond just the initial area affected.

It is challenging to include wider costs and it is not always easy to monetise all the different impacts, resulting in many transport appraisals not taking into account the wider costs. In order to understand the costs of any adaptation measures as fully as possible it is recommended that as many wider costs as possible (data permitting) are included in an analysis.

Examples: ROADAPT (Roads of today, adapted for tomorrow) included methodologies for estimating the socio-economic impact of extreme weather events in Part D of the guidelines produced (Chevreuil and Jeannière, 2015). Travel time was considered to be the main indicator for impact and this was monetarised to give an estimate of the cost of the event. The guidance divided the impact into three different levels, the network level where only the user delay is estimated, the territorial level where the delay over the network is estimated and the economic system which included wider costs. It suggests using a traffic model in combination with a GIS model for estimating the consequence of a major event across the whole network.

Winter et al. (2012) also examined the indirect consequential economic impacts of landslide events in Scotland, including the direct costs of clean-up and repair, consequential impacts on road users due to closures/diversions and indirect consequential wider impacts.

Recommendations:

- Use frameworks from other studies to understand monetisation of wider costs
- Incorporate wider costs into analyses where data is available and there is confidence in the monetisation method

2.2.4 *Using climate projections*

Modelling climate, past, present and future is a major endeavour, since climate is a product of accumulation over time. Of most relevance to NRAs are regional climate projections. These use a global climate model of rather coarse resolution (e.g., 150 km) and apply a higher resolution regional climate model (with a resolution of, e.g., 10 km) to a focus area such as North America or Europe. Date produced by state-of-the-art cascades of global and regional climate models is made accessible, e.g., through the CORDEX activity. It aims at a standardisation across numerous climate models, including an agreed-upon resolution, set of modelled climate variables and data format.

For most climate indicators, projection data sets of daily resolution are required. Naturally, this leads to huge amounts of data from which certain areas of interest and certain time ranges can be extracted according to user needs. The raw data are in a highly condensed binary format which needs to be brought into analysis-compatible formats. Data providers offer distinct tools to achieve this, most of which are, nevertheless, more tailored to specialists.

The type of climate projection data required will depend on the purpose of the economic assessment. An overview of the trend and general magnitude of change for a particular geographic region enables identification and comparison of the types of future impacts that can be expected which may be sufficient for informing policy. Whereas higher resolution, more detailed data will be required for assessing more thoroughly the risk to a particular asset or site of proposed new road.

Example: In the Project CliPDaR (Design guideline for a transnational database of downscaled climate projection data for road impact models) there was extended work on devising road-specific climate indicators. It proved that, e.g., the indicator “zero temperature crossing” is not well suited for road management. Therefore CliPDaR proposed to devise a stronger version of it which marks days at which the minimum is below -2°C and the maximum is above +2°C. This improves robustness and helps determining days with a higher relevance to the frost-thaw challenge. Another indicator devised by CliPDaR combined the definitions of “hot day” and “tropical night” to form a “rutting day” indicator which identifies periods with particularly stressful conditions for road infrastructure. Moreover, CliPDaR made use of an ensemble of models to gain further insight into the bandwidth of modelled climate and potentially hazardous impacts.

Recommendations:

- Use more than one climate projection (Ensemble strategy), at least five to seven
- Be aware that some projected climate parameters will have less uncertainty than others, e.g. temperature projections have more certainty than those for precipitation or wind.
- Be aware that for some climate features it is difficult to establish how frequent they are under current conditions, let alone how their occurrence change according to projections.

2.2.5 *Dealing with uncertainty and risk*

Risk management is an essential element of asset management (AIRMIC *et al.*, 2010) and ISO 31000:2009 Risk Management provides guidance on developing a sound risk management process. **Risk** is defined as the "effect of uncertainty on objectives" and the **Risk Management** as *“coordinated activities to direct and control an organisation with regard to risk”*.

Risk Management needs to include climate change and its impact on the road authority, and the asset itself. Climate change and especially extreme weather events represent risks to the infrastructure which should be monitored and assessed. Therefore, there is a need to establish processes which manage and mitigate climate change risks within the Risk Management Process.

The **Risk Management Process**, which is defined as a *"systematic application of management policies, procedures and practices to the activities of communicating, consulting, establishing the context, and identifying, analysing, evaluating, treating, monitoring and reviewing risk"* is shown in Figure 1.

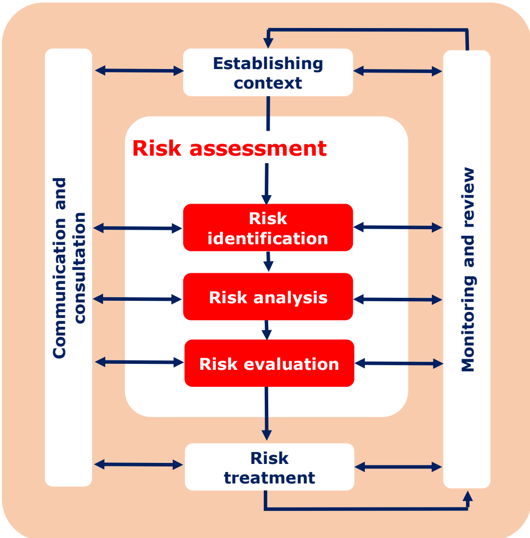


Figure 1. Risk Management process

All of the following elements should be considered as part of an economic evaluation:

- The **risk assessment** is a crucial part of all risk management activities. Individual risks are identified which are then used to generate a comprehensive list of threats and opportunities; based on events that might create, enhance, prevent, degrade, accelerate or delay the achievement of the strategic objectives.
- The **risk analysis** involves developing an understanding of the risk, to provide an input to risk evaluation and decisions on whether risks need to be addressed.
- The **risk evaluation** is most often carried out using a risk ranking matrix. A risk matrix combines the likelihood of the risk occurring and the risk consequence.

The four broad strategies for dealing with risks are:

- *Risk avoidance*: to eliminate sources of risk, or substantially reducing the likelihood of loss from the risk occurring.
- *Risk impact mitigation*: is action taken to minimise the consequences of an adverse event to an acceptable level.
- *Risk sharing*: is to shift responsibility for a risk from the agency to another party (i.e. insurance) who bears the consequences if the risk arises. Risk sharing will not lead to avoiding or reducing risk; it only changes the "risk owner".

- *Risk acceptance*: is when risks cannot be avoided or transferred, or the costs of doing so would not be worthwhile. Any costs associated with the risk will be accepted by the risk owner if the event occurs.

Overall objectives which need to be taken into account for the development of tools and guidance that meet the needs and framework conditions of NRAs include the following:

- Adequate level of detail and informative value of the assessment results to support decision making processes of NRAs
- Completeness of included risk aspects (conception of 'risk' as a function of cause and effect, sub-steps for deduction of indices for potential of hazard and potential of effect)
- Practicality of methods with reasonable resources and data needed for implementation of assessment
- Suitability for further development/update of method and integration of future findings

Recommendations:

- Road authorities are constantly confronted with various risks and the integration of risk management into all relevant Road Asset Management processes is thus indispensable.
- Include risks associated with climate change at all levels of analysis, from organisation, through network level, down to project level.

PART B: DeTECToR cost-benefit tool manual

3 Tool description

3.1 Overview

The DeTECToR risk assessment and CBA tool consists of two modules; the risk assessment module which provides information on the level of risk for different time periods and emission scenarios; and the CBA module which compares the costs of different climate change adaptation options and a “no adaptation” option (Figure 2).

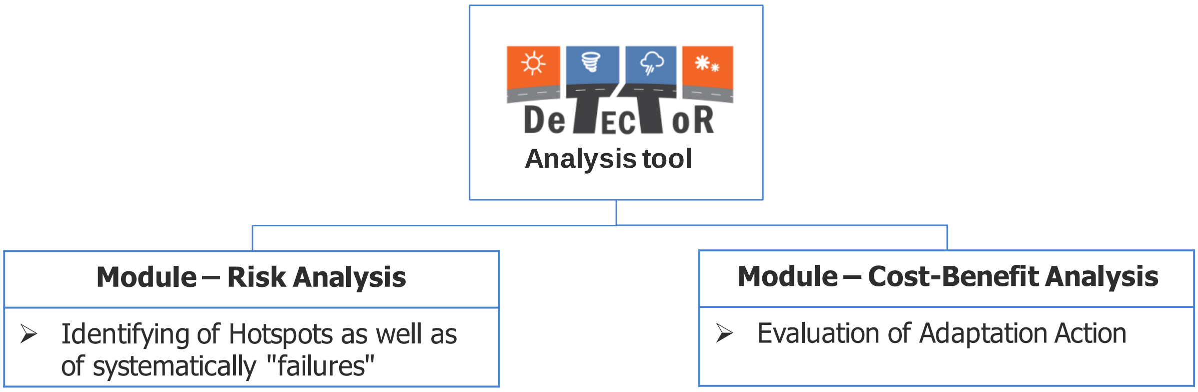


Figure 2. DeTECToR risk assessment and cost benefit analysis tool

The risk assessment module uses the theoretical concept of the RIVA-methodology. The RIVA-methodology is based on a hierarchical-structured indicator model using a series of indicators to ascertain climate risk. The risk potential is analysed as a function of cause (potential of hazards) and effect (potential of impacts). These are based on complex cause-effect chains (CEC), which were used in the RIVA-project for the systematic description of typically damage / restrictions caused by the climate. Furthermore, the CECs are the basis for the determination of so called damage(s)-patterns categories (DPC); the main unit of measurement of RIVA methodology (see Section **Error! Reference source not found.** for urther information).

Within the cost-benefit analysis module direct costs and indirect costs are calculated over an appraisal period. The benefits are expressed as a reduction in costs. The difference in costs between different climate change adaptation options/measurements can be compared using the tool. The optimal solution in terms of cost-benefit analysis is the one with the lowest sum of direct and indirect costs over the appraisal period. The frequency of a weather event occurrence is based on the risk potential of hazard calculated in the risk module, and the cost information and criteria are provided by the NRA.

The tool was tested using three pilot studies in Germany, Austria and Scotland. These pilot studies covered different geographical regions with differing climates, types of road network and formats of data. Selected damage pattern categories were tested within each pilot study. In practice the types of hazard and asset included in the analysis would be set by the individual NRAs depending on their priorities. The results from the pilot studies are used in Section 4 to illustrate the steps in using the tool.

3.2 Using the tool

Road infrastructure planning and asset management require different analyses, information and decisions at different process stages. The DeTECToR risk assessment and CBA tool is intended support these process and provide useful information for the planning, maintenance and operation of the road infrastructure in the context of climate change. For example, the results can be used for the amendment of design and material guidelines and regulations or, in relation to a specific section of the network, to provide additional information e.g. selecting suitable construction or materials.

3.2.1 *When to use the tool*

The tool is designed as a flexible framework which can be used for multiple types of assessment. It can be employed for both project specific and strategic assessment, and at different points of a project lifecycle. The tool processes information from the existing infrastructure, however data for planned new infrastructure such as the materials and design to be used, alignment etc. can also be uploaded and analysed to compare different options. Thus the tool can provide information at a very early planning stage (e.g. line determination) for new infrastructure as well as informing asset management of existing infrastructure.

3.2.2 *How to use the tool*

In the case of existing infrastructure, the tool offers a variety of uses; so for example in the course of maintenance planning or the planning of extensive repair measures this tool can be used to inform the appropriate design or material in the context of climate change. High risk sections can be identified via the risk assessment module. If the results suggest that most of the network or all those with certain characteristics are affected by a particular type of hazard modifications in standards may be required, whereas if only a few sections are affected, the tool supports the selection of suitable adaptation measures for these affected sections. The risk assessment module enables the road sections to be prioritised with regard to their risk potential. In a second step, the CBA module can be used to investigate various adaptation measures and compare the cost implications of implementing these.

In addition, the information provided with the tool, for example, the climate projection data can be used in isolation. Thus, for example, regions can be identified in which future winter precipitation is likely to be greatly increased and therefore early adaptation measures can be taken in relation to the operating service.

3.2.3 *Who should use the tool*

The tool is aimed primarily at the senior practitioner level, i.e. project managers, asset managers, engineers. However, the information that can be generated with the tool can also be used to inform strategic decisions at a higher level, for example proving business case evidence for adaptation action.

One or two people within the NRA will have the role of the Configuration Provider and adjust the configuration to tailor the tool for their network. All other users will utilise this configuration in their analysis. The configuration defines the data and assumptions which the calculations of all users within the NRA are based on. While the internal calculations can be adjusted to different needs, doing so requires understanding of the engineering and climate considerations and may produce quite different results which are not comparable between the individual users of the system. It was deliberately decided to limit the access of the road engineers to the parameterisation of their calculations rather than providing them with the ability to modify the underlying assumptions. This both provides consistency between users and prevents the user being overwhelmed with all the internal details.

3.3 Scope

The DeTECToR risk assessment and CBA tool as its name suggests only focuses on traditional CBA, it does not include an assessment of environmental or social impacts such as carbon or noise. It also does not cover the wider costs to the community of transport disruption as a result of climate change impacts, e.g. loss of business income or tourism. It focuses mainly on the direct costs to the NRA, although it does cover some indirect costs such as user delay and accidents. It should be noted that the tool will provide indicative costs for the specified options selected by the user. A significant number of assumptions and estimations are made in the calculations, so the results cannot be taken as an accurate costing. It does not in any way replace a full CBA for a specific scheme.

As suggested in the *ROADAPT Guidelines Part D – socioeconomic impact assessment* the different stages of the temporal sequence of socio-economic evaluation of a "network problem" should be considered. The Guidelines Part D divided the temporal sequence into the following 5 stages:

- Stage 1 - Initial situation before the event: network is operating normally before the event occurs.
- Stage 2 - Occurrence of the traffic event: network problem occurs, but no action has yet been implemented by the operating organisation. Vehicles continue to arrive on the scene of the incident:
- Stage 3 - Managing the problem. It is the situation after taking direct response measures. Emergency services and operators are involved for the return to a temporary situation with degraded conditions.
- Stage 4 - Operation in degraded conditions: take operational measures in order to return to initial stage, during which traffic conditions are deteriorated. The network is operating in a degraded mode for a certain period.
- Stage 5 - End of the incident: back to the initial situation. (Stages 1 and 5 are identical).

Since the CBA-module calculates *additional* direct and indirect cost stages 1 and 5 are not relevant within the calculation. Therefore, the CBA-module considers traffic interruptions during the weather event and after the event until the reason for the traffic interruption is removed; as well as delays arising from the work to repair the damage caused by the event.

3.4 Assumptions and limitations

The DeTECToR risk assessment and CBA tool is an analysis framework which needs to be adjusted and populated by the NRAs for their use. In the demonstration during the pilot studies example analysis was carried out for selected geographical regions and DPCs.

Therefore the risk assessment module currently gives the opportunity to analyse the following DPCs, the CBA-module is limited to heat and frost related damages on road surfaces (concrete and asphalt – 4 DPCs).

- DPC-01a Heat-related damages and restrictions at bridges
- DPC-01b Frost-related damages and restrictions at bridges
- DPC-01e Damages and restrictions caused by high wind velocity at bridges
- DPC-06a Heat-related damages and restrictions on the asphalt road surface
- DPC-06b Frost-related damages and restrictions on the asphalt road surface

- DPC-07a Heat-related damages and restrictions on the concrete road surface
- DPC-07b Frost-related damages and restrictions on the concrete road surface

Different assumptions and input data are necessary for both modules. This concerns both infrastructure asset data, as well as climate projection data and cost assumptions. Whereas infrastructure asset data and climate projection data should be provided in a digital format which allows GIS-analysis, cost related assumptions can be made by the users on the input screen of the CBA module.

The tool uses several estimation and assumptions. For the risk assessment module most of the assumptions are based on the RIVA-project. In particular, the indicators used, the indicator's weighting and the thresholds. Adjustment by the consortium was carried out for the different pilot studies where data sets for the indicators were not available or to tailor for a particular country. The modular structure of the RIVA-methodology and flexible design of the tool allows the user to make adjustments where necessary. The "*Manual - Country specific cost data provision*" in Appendix A provides guidance on how to define these assumptions and estimations.

Table 2 gives an overview of the assumption and estimations needed for the CBA-calculation and how these are integrated in the tool.

Table 2. The DeTECToR Risk assessment and cost-benefit analysis tool assumptions

Variable	Source of value	Integrated in the tool or user input
Power value of the reduction of lifespan function	Proposed by consortium	Integrated in the tool
Power value of the level of occurrence function	Proposed by consortium	Integrated in the tool
Average number of days for traffic interruption caused by a specific weather event	Proposed by consortium	Integrated in the tool
Average number of days for reconstruction	NRA	Integrated in the tool
Average speed of cars (HGV / passenger cars)	NRA	Integrated in the tool (data base)
Average speed of cars because of construction sites (HGV / passenger cars)	NRA	Integrated in the tool
Time saving costs for users (passenger cars / HGV)	NRA	Integrated in the tool
Accident cost rates for various severity of accidents on trunk roads	National appraisal guidance / NRA	Integrated in the tool
The average number of accidents per 1,000 cars for various severity of accidents with and without roadworks	National appraisal guidance / NRA	Integrated in the tool
Reduction of the accident rate	Proposed by consortium	User input
Cost categories and construction costs	NRA	Integrated in the tool
Lifespan of the asset	NRA	Integrated in the tool

Costs for repair as proportion of initial construction costs	Proposed by consortium	Integrated in the tool
Estimates of Prolongation of lifespan (adaptation measure)	Proposed by consortium	User input
Adaptation measure's implementation costs	NRA	User input
Operation / maintenance costs as percentage of initial construction costs	NRA	User input
Adaptation measure's impact on vulnerability indicators – depends on DPC and adaptation measure	Proposed by consortium	User input
Adaptation measure's impact on effect/impact indicators – depends on DPC and adaptation measure	Proposed by consortium	User input
Discount rate	Proposed by consortium	User input

3.5 Modules and functionality

The risk assessment module enables users to analyse the risks to road infrastructure as a result of different types of climate change impacts. There are four categories that can be configured: Asset Type, Damage Pattern Category, Projection Period and Greenhouse Gas Concentration. For the pilot studies, the tool has been set up so the user can choose between the asset types: bridge, asphalt road surface and concrete road surface and the impacts of heat-related, frost-related and storm damages and restrictions. The time period for which the climate data shall be analysed has to be selected by the user. There are four 30-year periods given. The first one comprises the period from 1971 to 2000 reproducing the state of the climate at the end of the 20th century using historic weather data to determine climate change signals. The other three time periods were chosen to be comparable with other studies and to enable near-future (2011-2040), mid-term (2041-2070) and long-term (2071-2100) climate projections based on models. Finally, the greenhouse gas concentration can be selected. Representative Concentration Pathways (RPCs) are used to model either a high or a low concentration of greenhouse gases.

The tool first calculates the Combination Value of Vulnerability (CVV), i.e. the condition of the asset objects, and the Combination Value of Climate (CVC). The CVV merges all information of the dimension vulnerability for the selected damage pattern category in the considered asset object. The CVC merges all the information of the dimension climate for the selected damage pattern category in the selected projection period and using selected emission scenario in the considered asset object. It is used for the derivation of the hazard potential. After that, the Risk Potential of Hazard (RPH) and the Risk Potential of Effect (RPE) are calculated. The RPH merges the CVV and the CVC for the selected damage pattern category in the considered asset object. The RPE is calculated by considering several relevant indicators and its weighting for selected damage pattern category in the considered asset object. This indicator is independent of the selected projection period and emission scenario. Finally, the Overall Risk Potential (oRP) is calculated. The displayed data can be exported either as a text file or as a shape file.

The Cost Benefit Analysis (CBA) module allows the user to add new configurations, to edit or delete existing configurations and to start calculations. After adding or editing a configuration, the user can order the corresponding calculation. The system will inform the user via E-Mail when the calculation is finished. The results of the calculation can be shown on the map of the Risk Assessment Module.

4 The calculations

This section provides the details of the calculations carried out in the tool. Whilst it is not strictly necessary to read this section in order to use the tool an understanding of the calculations behind the displayed outputs enables the user to better understand the limitations and assumptions, and to tailor the tool to a particular network. It is strongly recommended that Configuration Provider does read this section, and the authors believe it would be useful for other users too.

4.1 The risk assessment module

The risk assessment module is based on the principle of the RIVA risk assessment methodology. Following the theoretical concept of the RIVA-methodology all indicators are associated either to the sphere of causes or the sphere of impacts. Within these spheres, the indicators are broken down by dimensions of content (characteristics/attributes of the infrastructure and the climate). The dimensions "events of climate" and "vulnerability of elements" were dedicated to the sphere of cause / hazard. The dimensions "characteristics of effects" and "criticality" were classified into the sphere of effect / impact as depicted in Figure 3.

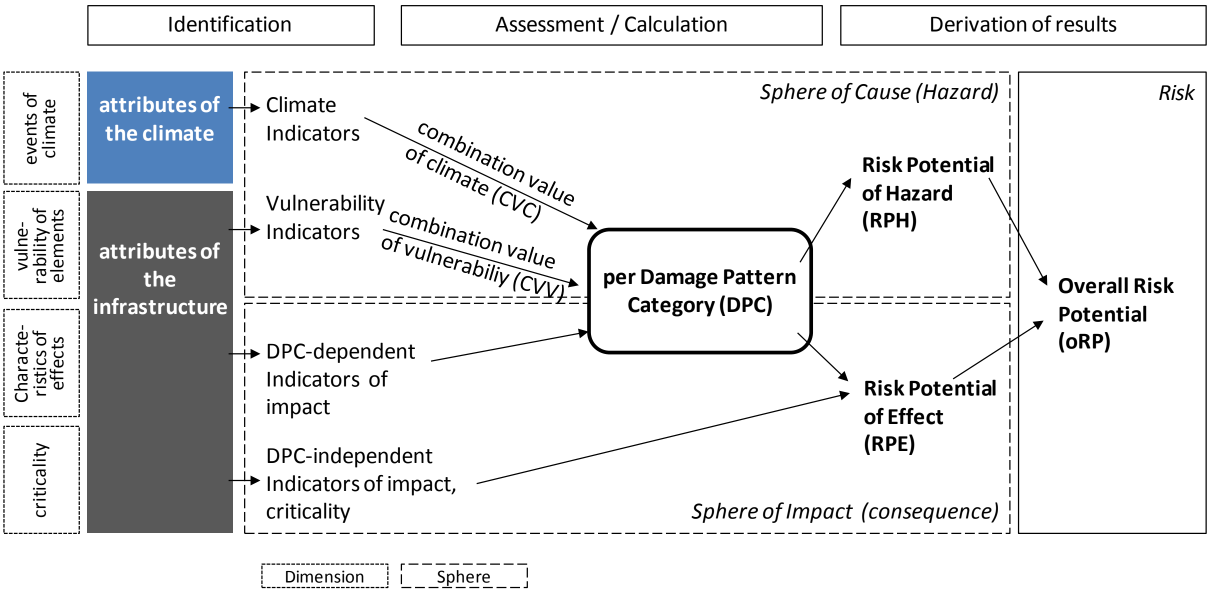


Figure 3. Calculation of risk

Potential risks may only be realised if an asset is vulnerable to a particular climate-related event. Therefore, the dimension "vulnerability" includes indicators for the vulnerability of the infrastructure, i.e. factors which affect the vulnerability of that specific asset type to the that particular hazard such as traffic-load, position and structural or construction attributes).

The dimension "characteristics of effects" includes all indicators of infrastructure attributes which determine the magnitude of the effects. These include costs of the refurbishment, maintenance and operation as well as the costs of accident and the extent of traffic interruptions.

The dimension “criticality” includes all the indicators of the importance of the road sections for the traffic which affects the economic scale of the traffic impacts.

On these premises, the calculation of the risks is based on a multi-step approach for each single damage pattern category and for each section or single elements. The damage pattern category (DPC) is the central unit of the RIVA risk assessment approach. A damage pattern category is defined for each asset element (e.g. bridge, tunnel, surface) by categories of damage caused by a defined type of weather related event.

The RIVA-methodology is based on a hierarchical indicator model using a series of indicators to ascertain climate risk. The “Manual - Country specific adjustment of indicator´s thresholds” describes the indicators related to vulnerability and climate (see appendix A) and the “Manual – Country specifc cost data provision” the provision of cost data (see Appendix B). Each indicator is scored from 1 to 4, with 1 having a low impact on risk and 4 a high. Indicators can also be weighted to reflect the extent of the influence the characteristic being represented has on the level of risk, e.g. if traffic load has a larger influence on risk than pavement surface depth. For each of these indicators, thresholds for the value range 1 to 4 are defined. The scores are automatically assigned based on the data uploaded by the NRA and the thresholds set. The indicators, weightings and thresholds were set within the RIVA project for the use of the RIVA-pilot-tool for the Germany motorway network. Therefore, the thresholds have to be verified for the use in other countries and, if necessary, have to be adjusted to reflect differences in materials, design, collection of data etc. The objective of the manual is to guide this process. The assumptions behind the determination/definition of the thresholds are described in order to help the user decide on the adjustment.

4.1.1 *Risk assessment calculations*

In the following section the calculations relating to the single steps shown in Figure 3 are described.

4.1.1.1 CVC - Combination value of climate

The “combination value of climate” merges all the information of the dimension climate for a damage pattern category in the considered road section. It is used for the derivation of the hazard potential. The combination value of climate is determined through the aggregation of the individual assessments of climate indicators for the period under consideration and can assume a value between 1 and 4.

$$\sum_{i=1}^{n} CV_i * W_i = CVC$$

With:

CVC – combination value climate of the damage pattern category

CV_i – climate value for the indicator i to n of the damage pattern category the climate value is an integer value with a range of 1 to 4, depending on the value of climate signal (indicator) and the defined thresholds of the indicator for the damage pattern category for the climate region of stretch s

W_i – weighting [%] for the indicator i to n of the damage pattern category

By thumbing (from a climate table) the value of the relevant climate signal (the climate signal is used as indicator within the damage pattern category and depends on the period a [2011-

2040, 2041-2070, 2071-2100] and GHG emission scenario) and by the allocation of this value to one of the four threshold ranges, the climate value CV_i is determined. Therefore CV_i is calculated for each of the considered time periods. The tool provides look-up tables/default suggestions for the indicators as well as for the weightings and the thresholds, but these can be adjusted by the Configuration Provider.

4.1.1.2 CVV - Combination value of vulnerability

The "combination value of vulnerability" merges all the information of the dimension vulnerability for a damage pattern category in the considered road section / elements. The combination value of vulnerability is determined through the aggregation of the values of all the vulnerability indicators which have values between 1 and 4.

$$\sum_{i=1}^{n} VV_i * W_i = CVV$$

With:

CVV – combination value vulnerability of the damage pattern category

VV_i – vulnerability value for the indicator i to n of the damage pattern category the vulnerability value can have a value of 1 to 4, depending on status of the assets within the sector and the defined thresholds of the indicator for the damage pattern category

W_i – weighting [%] for the indicator i to n of the damage pattern category

By thumbing (from a table) the value of the relevant information of the status of the asset within the sector and by the allocation of this value to one of the four thresholds ranges, the vulnerability value VV_i is determined. VV_i is independent of the time period. The tool contains look-up tables/default suggestions for the indicators as well as for the weightings and the thresholds; however these can be adjusted by the user.

Depending on the structure of the asset information the determination of a spatially-weighted VV_i could be necessary as an intermediate step.

4.1.1.3 RPH - Risk potential of hazard

Both combination values (climate and vulnerability) are be used for the derivation of the risk potential of hazard.

$$\mathrm{RPH_{a,d,s}} = \sqrt{\mathrm{CVV_d} * \mathrm{CVC_{a,d}}}$$

With:

$CVC_{a,d}$ – combination value climate of the damage pattern category d within the time period a

CVV_d – combination value vulnerability of the damage pattern category d

$RPH_{a,d}$ – Risk Potential of Hazard of the damage pattern category d within the time period a for the considered stretch s of the network

It some instances it may be appropriate for the user to determine a Risk Potential of Hazard by merging several damage pattern categories ($d = 1\ to\ n$):

$$mRPH_a = \sqrt[n]{\prod_{d=1}^{n} \sqrt{CVV_d * CVC_{a,d}}}$$

With:

$CVC_{a,d}$– combination value climate of the damage pattern category d within the time period a

CVV_d– combination value vulnerability of the damage pattern category d of the stretch s

$mRPH_{a,d}$– merged Risk Potential of Hazard of the damage pattern category $d = 1\ to\ n$ within the time period a for the considered stretch of the network

4.1.1.4 RPE - Risk Potential of Effect

For the derivation of the "Risk Potential of Effect" the values of the five categories of impact for each damage pattern category of the considered road section are aggregated applying the specified weighting. Default weighting is provided, but this can be adjusted by the user.

The five categories of impact and the default weighting are:

- category of refurbishment costs (20%)
  - 80% - costs of refurbishment category
  - 20% - construction costs category of the section
- category of maintenance costs (30%)
  - 75% - costs of maintenance category
  - 25% - construction costs category of the section
- category of operating costs (5%)
  - 80% - costs of operational services category
  - 20% - construction costs category of the section
- category of accident costs (10%)
  - 50% - category of frequency of accidents
  - 50% - category of type of accidents
- category of traffic interruptions (35%)
  - 50% - category of interruption
  - 50% - category of criticality of the section

The Risk Potential of Effect $RPE_{d,s}$ is calculated by combining the several indicators and sub-indicators and their weighting for each damage pattern category d and each section s and is independent of the time period. It can have a value between 1 and 4.

4.1.1.5 oRP - Overall risk potential

The final result the "Overall Risk Potential" is calculated by merging the Risk Potential of Hazard and the Risk Potential of the Effect and can have a value between 1 and 4.

$$oRP_{a,d,s} = \sqrt{RPH_{a,d,s} * RPE_{d,s}}$$

With:

$oRP_{a,d,s}$– Overall Risk Potential of the damage pattern category d within the time period a of the section s

$RPH_{a,d,s}$– Risk Potential of Hazard of the damage pattern category d within the time period a for the considered section s of the network

$RPE_{d,s}$– Risk Potential of Effect of the damage pattern category d for the considered section s of the network

4.2 The cost benefit analysis module

4.2.1 *Overview of the CBA methodology*

The RIVA project did not include cost-benefit analysis; therefore the approach for the CBA module had to be developed by the DeTECToR consortium based on standard CBA approaches and good practice/research on including climate change in economic appraisal. A balance between the need for data for robust, relevant analysis and the resources required to source the data was sought.

Within the cost-benefit analysis direct costs and indirect costs are calculated over an appraisal period. The benefits are expressed as a reduction in costs (as adaptation actions reduce the costs associated with climate change in the long-term). The CBA tool enables the user to compare the costs associated with different adaptation actions or no adaptation action. The optimal solution in terms of cost-benefit analysis is the one with the lowest sum of direct and indirect costs over the appraisal period. In the calculations the potential of hazard calculated in the risk assessment module is used as an indicator of the occurrence of a weather related event, and the cost information, discount rate etc. are provided by the NRA.

It should be noted that the DeTECToR risk assessment and CBA tool provides indicative costs for the specified options selected by the user in order to compare general adaptation strategies. A significant number of assumptions and estimations are made in the calculations, so the results cannot be taken as an accurate costing for implementing a specific measure at that location.

The calculation is carried out per asset. An asset can be an individual bridge or in case of road surfaces, a whole section or small parts of the section e.g. 100m sections per lane. This depends on the resolution of the dataset provided by the user.

The calculation is carried out for a period of 30 years to align with the climate projection periods. The calculation considers costs for operation, maintenance and reconstruction over the appraisal period. The developed methodology includes the consideration of the asset lifecycle within the appraisal period (e.g. a pavement surfacing normally has a lifetime of 8-15 years). The projected lifecycle duration is influenced by climate change, therefore, an exponential function of the Risk Potential of Hazard is used for the approximately description of the relationship of the lifecycle and climate change.

The calculation within the risk assessment module for the Risk Potential of Hazard is conducted once per climate projection period of 30 years. Whereas, the CBA-module calculates values for each year of the 30 year appraisal period, and repeats this for each of the three climate projection periods. Therefore, the calculation includes a transformation of the Risk Potential of Hazard periodical value into an annual likelihood of occurrence and extrapolates this over a 30 year period.

4.3 Types of cost included

4.3.1 *Indirect costs*

The CBA-module calculates indirect costs caused by:

- increased journey time,
- congestion, and
- accidents.

Therefore, within the CBA-module the following indirect costs were calculated (see also Section 4.3):

- Costs of loss of journey time (calculated as differences in journey time with and without traffic interruptions). This includes:
  - The delay associated with a weather event as a result of part of the infrastructure being unavailable (e.g. a lane closed due to flooding or heat damage) or speed restriction
  - The delay during the regular reconstruction associated with the asset life span.
- Congestion costs - The delay as a result of repairs being carried out to repair damage caused by a weather event.
- Accident costs
  - The costs of an increased likelihood of accidents due to the event
  - The costs of an increased likelihood of accidents due to roadworks for repairing damage from events and for regular reconstruction.

The calculation of these indirect costs use different standard cost rates.

4.3.1.1 Direct costs

The CBA-module considers the following direct costs: costs of the operator (NRA) for regular reconstruction, repair (after an event), operation and maintenance. Costs of the users are considered as part of the indirect costs (see above).

It should be noted, that the end result of the CBA-module is a comparison of costs associated with different adaptation measurements for a period of 30 years. Hence, the methodology includes the cost of regular reconstructions as the sum of the depreciation of the 30 year period. This has the advantage of considering (indirectly) the residual value of an asset (which can differ from one adaptation measurement to another). The level of reduction in design life due to climate change is based on an exponential function of the Risk Potential of Hazard value calculated in the risk assessment module. The use of the depreciation instead of the individual costs of reconstruction in the year of the end of the life cycle provides a better comparison between adaptation measures. For example if for the first adaptation measurement the reconstruction is required in year 28 and for the second adaptation measurement it is needed in year 31, and the cost of the second adaptation measure would not be considered in the calculation. This would result in the costs of reconstruction of the first adaptation measure being twice as much, whereas the life span is only slightly longer. This will lead to an unreasonable disadvantage of the first adaptation measurement. Therefore, the calculation uses the depreciation of the regular reconstruction costs instead of the one-off expenses.

In the following the different parts of the direct costs used in the CBA-module are described more in detail.

Regular reconstruction costs

As the CBA calculation considers the lifecycle of the asset, direct costs for the reconstruction of the asset at the end of a lifecycle period has to be ascertained (the residual value). Within the CBA-module the reconstruction costs are calculated as linear depreciation based on a standard costs approach. This is necessary because the analysis period contains – depending on the duration of lifespan of the asset – several lifecycle periods, which do not end simultaneous with the end of analysis period.

The depreciation of reconstruction costs is determined through a standard cost approach as function of the dimensions (e.g. square metre) of the analysed asset. The standard costs are based on engineering experience and derived from average costs depending on the asset type. Since, the depreciation value depends not only on the reconstruction costs itself, but also on the duration of the lifecycle period influenced by climate event, a longer lifespan leads to lower depreciation values and therefore – in case of the same reconstruction costs – to lower total direct costs as part of the comparison of different adaptation measure scenarios. In other words, the shorter the lifecycle period the greater the annual depreciation value, and therefore the higher the costs of reconstruction as part of direct costs.

Repair costs (for damage caused by a weather event)

The CBA-calculation includes the repair costs after a weather event occurs. The value of the repair costs accumulated over the appraisal period depends on the number of events (referred to as the Level of Occurrence) and the cost of an average repair. The repair costs are calculated as a percentage of the initial construction costs (a value already used for the calculation of the reconstruction costs).

Additional direct costs for the implementation of adaptation measures

The implementation of an adaptation measure has associated direct costs, which depend on the type of adaptation measure. The CBA-calculation defines three different categories of adaptation measures:

Category 1 - modification of the infrastructure (e.g. design or material);

Category 2 - modification to operations/ maintenance; and

Category 3 - installation of additional infrastructure (e.g. traffic management).

The different adaptation categories are associated with different kinds of direct costs, which are included in the CBA-calculation as follows:

for category 1 - additional construction/implementation costs and operation/maintenance costs are added as percentage of initial costs of the asset

for category 2 - additional operation / maintenance costs are added as percentages of the asset

for category 3 - implementation costs and operation/maintenance costs of the additional infrastructure are added

For the purposes of the calculation it is assumed that the additional costs are those caused by implementing the adaptation measures rather than business as normal. For category 1 adaptation measures this means the additional construction / implementation costs are the difference between the entire construction / implementation costs and the initial construction costs of the current asset which are already considered in the calculation.

Aggregation of direct costs (discounted direct costs)

For the comparison of the different adaptation measures and these with the 'do nothing strategy' the annual direct costs (calculated as described above) are discounted and aggregated. The discount rate is determined by the user.

4.3.2 *The CBA calculations*

Several steps are necessary for the calculation within the CBA-module. These are based on user inputs e.g. for average costs of reconstruction or for average design life, but also the value of the Risk Potential of Hazard calculated in the risk assessment module.

The Risk Potential of Hazard (RPH) is calculated for the current situation of the analysed asset. However, some of the vulnerability indicators are dependent on the lifecycle (age) of the asset (for example the condition), whereas other indicators are be independent of lifecycle (for example the material). Therefore, the calculation within the CBA-module is based on an annual extrapolation of the RPH using an interpolation of life cycle related vulnerability indicators.

This extrapolated annually RPH is the basis for the two paths of the CBA-calculation. On the first path the reduction of the life span is calculated as function of the RPH. The higher the RPH the higher the reduction and consequently the shorter the life span of the analysed asset. This is the basis for the determination of the annually depreciation values (costs of regular reconstruction). The shorter the life span, the higher the depreciation values.

On the second path the RPH is the basis for the derivation of an average annual Level of Occurrence of a harmful climate (weather) event. This in turn is the basis for the calculation of the indirect costs and of the repair costs as part of the direct costs.

At the end of the calculation the net present value will be determined by the direct and indirect costs for the evaluation period of 30 years.

In the following the several steps of the calculation will be described more in detail.

4.3.2.1 Best and worst Risk Potential of Hazard

As described before, the CBA-module uses results calculated in the risk-assessment module (see DeTECToR Interim Report 2). It should be mentioned that the risk assessment is performed for the current situation/condition of the asset/element once per climate projection period (i.e. today’s infrastructure in the future climate). The results of the risk assessment module are presented therefore as periodic values for each of the climate projection periods. However, the calculation within the CBA-module is performed on an annual basis. This needs a transformation of periodical values into annual values.

The CBA-module compares different adaptation measures, which can affect the characteristics of the asset/element (i.e. its vulnerability) or the consequences if an event occurs (e.g. the level of disruption). The CBA-module calculations also reflect the lifecycle and the therefore the lifecycle costs of the asset/elements. Depending on the original lifespan of an asset/element several lifecycle periods (LCP) can occur during the analysis period (separately calculation for each climate projection period). Therefore, the calculation within the CBA-module is performed on an annual basis and assumes a development of lifecycle depending on the vulnerability indicators (used for the calculation of Risk Potential of Hazard (RPH) – for further information it is referred to DeTECToR Interim Report 2). In order to do so, it is assumed that at the beginning of a lifecycle the vulnerability-indicators relating to condition receive the best possible value (1), and at the end of the lifecycle the worst possible value (4). Hence, the calculation is based on the assumption that the RPH is the best (lowest) value at the beginning of a lifecycle and the worst (highest) value at the end of the lifecycle.

The best and worst value of the Risk Potential of Hazard (RPH) is calculated for without Action and the considered adaptation measure for each climate projection period.

4.3.2.2 Original lifecycle period (without climate event)

Some of the indicators used for the assessment of risk potential of hazard (RPH) are depended on the condition or the age of the element. Taking into account the fact that the calculation in the CBA-module is on an annual basis and the CBA-module calculation assumes a lifecycle approach repeated updating of the RPH value is necessary. Therefore, between the beginning and the end of a LCP a linear interpolation of the RPH-value is assumed. For the first year (1st calculated LCP) the current RPH-value of the climate projection periods (derived from the NRA asset date) is used as the starting value of the linear interpolation.

4.3.2.3 Transformation of periodical RPH into annual values

The calculation is based on the assumption that the RPH gets the best (lowest) value at the beginning of a lifecycle period (LCP) and the worst (highest) value at the end of a LCP (see 4.3.2.1 Best and worst Risk Potential of Hazard).

Between the beginning and the end of a LCP a linear interpolation of the RPH-value is assumed. For the first year (1st calculated LCP) the current RPH-value of the climate projection periods is used. For LCP=1 a linear interpolation is assumed between the current RPH (cRPH) and worst RPH of the first LCP. For LCP>1 the starting point of the interpolation is the best RPH-value and the ending point of the interpolation is the worst RPH-value. However, the best and/or worst values also depends also on the climate projection period.

4.3.2.4 Reduced lifecycle period (caused by climate event)

In principle, it is assumed that climate events have a negative effect on the lifespan of an asset/element and that the extent of lifespan reduction is a function of the RPH-value calculated annually (*see step 4.3.2.3*). The function has been assigned a power value of 3 (although this can be modified by the user). Furthermore, it is assumed that a RPH-value of 4 leads to a failure of the asset/element. *Figure 4* shows this function and indicates, a significantly increasing lifespan reduction for RPH-value above 2.5.

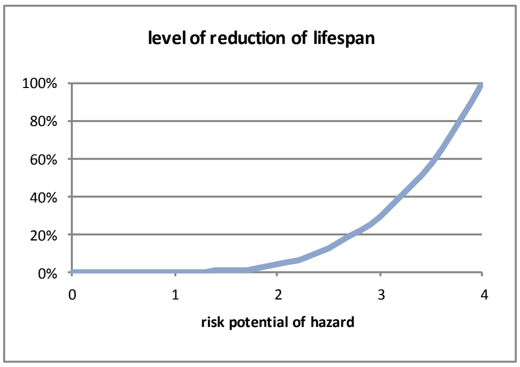


Figure 4: Reduction of lifespan as a result of climate change

This function is used for the calculation of reduced LCP (rLCP) based on the LCP calculated in step 4.3.2.2.

In principle, the calculation is similar to step 4.3.2.2 Original lifecycle period (without climate event); with the exception of the considered Level of Lifespan reduction (LoLsR).

During the pilot studies the assumptions of this function were discussed and verified. It is possible to use a different function for different DPC.

4.3.2.5 Adjustment of the annual RPH (step 4.3.2.3)

The calculation is similar to calculation described in 4.3.2.3 Transformation of periodical RPH into annual values. However, the Reduced lifecycle period (caused by climate event) is used instead of the Original lifecycle period (without climate event).

4.3.2.6 Level of Occurrence

For the calculation of the occurrence of a climate event per ten years an exponential function of the reduced RPH is used. The function is described by the following parameters. The following assumptions are made: It has a power value of 4; at a RPH-value of 4 the occurrence-value is 10. This results in a probability of occurrence of 100% within 10 years, if over the entire 10 years period the RPH-value is 4.

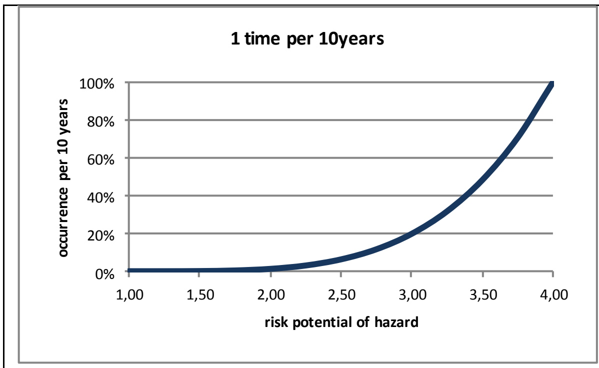


Figure 5: Level of occurrence

Figure 5 shows this function and indicates, a significantly increasing Level of Occurrence (LoC) for RPH-value above 2.5. This assumption of an exponential function is necessary to interpret the periodical RPH-values as a result of risk assessment module into a probability of occurrence that a climate event leads to damages or interruptions.

During the pilot study the assumptions of this function has to be discussed and verified.

4.3.2.7 Direct costs assessment

Regular reconstruction costs

As the CBA calculation considers the lifecycle of the asset/element, direct costs for the reconstruction of the asset/element at the end of a lifecycle period has to be ascertained (the residual value). Within the CBA-module the reconstruction costs are calculated as linear depreciation based on a standard costs approach. This is necessary because the analysis period contains – depending on the duration of lifespan of the asset – several lifecycle periods, which do not end simultaneous with the end of analysis period.

The depreciation of reconstruction costs is determined through a standard cost approach as function of the dimensions (e.g. square metre) of the analysed asset. The standard costs are based on engineering experiences and derived from average costs depending on the asset type. Since, the depreciation value depends not only on the reconstruction costs itself, but also on the duration of the lifecycle period influenced by climate event, a longer lifespan leads to lower depreciation values and therefore – in case of same reconstruction costs – to lower total direct costs as part of the comparison of different adaptation measure scenarios.

In other words, the shorter the lifecycle period (respectively the higher the reduction of the lifecycle) the higher the annual depreciation value, and therefore the higher the costs of reconstruction as part of direct costs.

Repair costs (caused by climate event)

The CBA-calculation considers repair costs after a climate event occurred. One basis for the repair cost calculation is the Level of Occurrence (*see 4.3.2.6 Level of Occurrence*). The other basis is the standard cost approach for repair costs as percentage of the initial construction costs (already used for the calculation of the reconstruction costs - see *0 Regular reconstruction costs*).

When a RPH value of 4 over the entire 10 year period (the sum of the Level of Occurrence ascertains to 100%) the asset will completely repaired once within 10 years, depending on the repair cost assumption.

Additional direct costs for the implementation of adaptation measures

The implementation of adaptation measures has associated direct costs. The kind of these direct costs depends on the type of adaptation measure. The CBA-calculation differs three different categories of adaptation measures: 1 – modification to the infrastructure (e.g. design or material); 2 – improvements to operations/ maintenance; and 3 – installation of additional infrastructure (e.g. traffic management).

The different adaptation categories are associated with different kinds of direct costs, which are included in the CBA-calculation as follows:

- for category 1 - additional construction/implementation costs and operation/maintenance costs are added as percentage of initial costs of the asset
- for category 2 - additional operation / maintenance costs are added as percentages of the asset
- for category 3 - implementation costs and operation/maintenance costs of the additional infrastructure are added

For the purposes of the calculation it is assumed that only the additional costs are those caused by implementing the adaptation measures will be considered. For category 1 adaptation measures this means the additional construction / implementation costs are the difference between the entire construction / implementation costs and the initial construction costs of the current asset which are already considered in the calculation (*see Regular reconstruction costs*).

The following additional direct costs caused by the adaptation measures are considered:

- additional (depreciated) (re-)construction costs,
    - for category 1: the adaptation measure will be implemented after the 1st LCP; therefore, no costs occur during the 1st LCP; the depreciation is calculated similar to those of the initial asset considering the assumed prolongation of the lifespan caused by the adaptation measure
    - for category 2: no additional construction is required, therefore, no costs occur over the entire period of analysis
    - for category 3: the implementation is carried out in the first year (a=1); therefore, the costs are calculated for the entire analysis period, considering the assumed lifespan of the additional infrastructure.

- additional operation/maintenance costs
  - for category 1: higher construction costs for implementation the adaptation measure leads to higher costs for maintenance. The annual maintenance costs are calculated as percentage of the construction/implementation costs of adaptation measure.
  - for category 2: implementation means additional costs for the operation/maintenance of the original asset. These are calculated as percentage of the initial construction costs of the asset, and therefore, when the initial maintenance costs were assumed with a value of 2%, an additional value of 1% considered within the CBA-calculation means an increase of 50% of the initial maintenance costs.
  - for category 3: additional infrastructure results in additional operation/maintenance costs.
- additional repair costs of the asset after climate event
  - for category 1: the higher construction costs leads to higher repair costs; the same assumption as described in *0 Repair costs (caused by climate event)* are used.
  - for category 2: no additional repair costs are incurred, because the initial repair costs are already considered.
  - for category 3: no additional repair costs of the asset are incurred, and also there are no repair costs for the additional infrastructure installed as the adaptation measure.

[Note: if the measure is selected for reasons other than adapting to climate change, will increase resilience to other types of hazard in addition to the analysed DPC, or even if the adaptation measure is part of an overarching strategy, the costs of the adaptation measure should be reduced accordingly.]

Aggregation of direct costs (discounted direct costs)

For the comparison of the different adaptation measures and these with the 'do nothing strategy' the annual direct costs (calculated as described above) are discounted and aggregated.

4.3.2.8 Indirect costs assessment

Loss of journey time after climate event

Traffic disruption leads to longer journey durations, and therefore to time losses for the road users. The delay time is calculated separately for passenger cars and for heavy good vehicles (HGVs). In the first step the average days of disruption per annum as function of the Level of Occurrence (*see 4.3.2.6 Level of Occurrence*) are determined, in order to calculate the time losses in hours per year for HGVs and passenger cars. In order to calculate the journey time losses further assumptions are need e.g. regarding the average of days of an interruption caused by a climate event (could be also DPC-specific), or regarding the original average speed and assumption regarding the average of speed reduction.

The time losses are calculated as differences of journey time with and without traffic interruptions.

The approach includes delay costs as a result of speed reduction and/or partly lane closure and not the closure of the section. The approach to the calculation of time losses caused by section closure is not fully completed.

Loss of journey time during regular reconstruction

Traffic interruption also occurs during the reconstruction. The time losses are calculated separately for passenger cars and for HGVs. Firstly, the days of interruptions per annum are determined, in order to calculate the time losses in hours per year for HGV and passenger cars. The interruption caused by reconstruction occurs only in the last year of a life cycle period (rLCP). An assumption of the average days need for reconstruction is required for the calculation.

The time losses will be calculated as differences in journey time with and without traffic interruptions. For the calculation it is assumed that traffic interruptions mean only speed reduction and/or partly lane closure and not the closure of the section.

Costs of loss of journey time

After ascertaining the time losses caused by climate and / or reconstruction the indirect costs of these time losses are be calculated. The time losses per year are summarised; and this sum multiplied with the time cost rates (standard costs approach). Different time cost rates are considered for HGV and for passenger cars.

Congestion costs

Congestion costs (as part of indirect costs) will be calculated as a function of the days with traffic interruption both caused by reconstruction works (*see formula (1) Loss of journey time during regular reconstruction*) or after a climate event (*see formula (1) Loss of journey time after climate event*). The days of interruption per year are summarised; and this sum multiplied with the congestion cost rates (standard costs approach). One congestion cost rate is considered for HGV and for passenger cars.

Accident costs

Traffic interruptions leads to a higher possibility of accidents. This type of accidents costs (as part of indirect costs) are be calculated as a function of the days with traffic interruption caused by both reconstruction works (*see Loss of journey time during regular reconstruction*) or after climate event (*see Loss of journey time after climate event*). The days of interruption per year are summarised; and this sum multiplied with the accidents cost rates (standard costs approach). One accident cost rate is considered for HGV and for passenger cars.

In addition to this, accident costs caused during the climate events are be considered. The annual average level of occurrence is used for the calculation. The accident cost rate depends on the DPC-specific kind of accidents.

Aggregation of indirect costs

For the comparison of the different adaptation measures and these with the 'do nothing strategy' the annual indirect costs (calculated as described above) are discounted and aggregated.

5 Step-by-step guide to use

5.1 Set-up and data preparation

NRAs will need to appoint a configuration provider to carry out the initial data upload and configuration of the tool. They will also need to select which DPCs to include in the analysis, as this will determine the type of data required.

5.1.1 *Data collection and preparation*

Before starting the analysis, the required data needs to be imported into the project database and the algorithms for the calculations adjusted for the specific network to be analysed. The project geospatial database is located on the server, on which the DeTECToR tool is running.

The required data can be divided into following groups:

- **Road network data.** This group contains information about road network such as the road ID, road sections and their lengths, if the section is a part of the European TEN-T network, the number of lanes etc. As the tool is spatial, the road location is necessary and the data provided need to be linked to a specific location.

Figure 6: Example of road network data (part of the Austrian road network)

- **Asset data**. All the analysis will be performed for single asset object, and the information about the assets imported into the database. There are two types of asset objects supported by the current application: pavement assets and bridge assets. The pavement asset is a defined part of the pavement, typically the pavement is divided into 100 metre long sections per lane. The bridge asset represents a single bridge. For each single asset object a number of technical parameters need to be provided (see Figure 7). The required parameters depend on the DPCs which are being analysed. For the DPCs selected for pilot studies, the list of parameters consists of following items:
    - AADT vehicles
    - AADT heavy vehicles
    - Material type (bridge)
    - Static system of the bridge
    - Overall bridge condition index
    - Year of bridge construction
    - Position (exposure)
    - Longitudinal slope
    - Cracks (note, Index)
    - Surface layer type for asphalt pavement
    - Age of surface layer
    - Patches (percentage value)
    - Thickness of asphalt or concrete layers
    - Rut depth (value)
    - Surface Condition Index for concrete pavement
    - Patched spots (partial replacements with asphalt) for concrete pavement

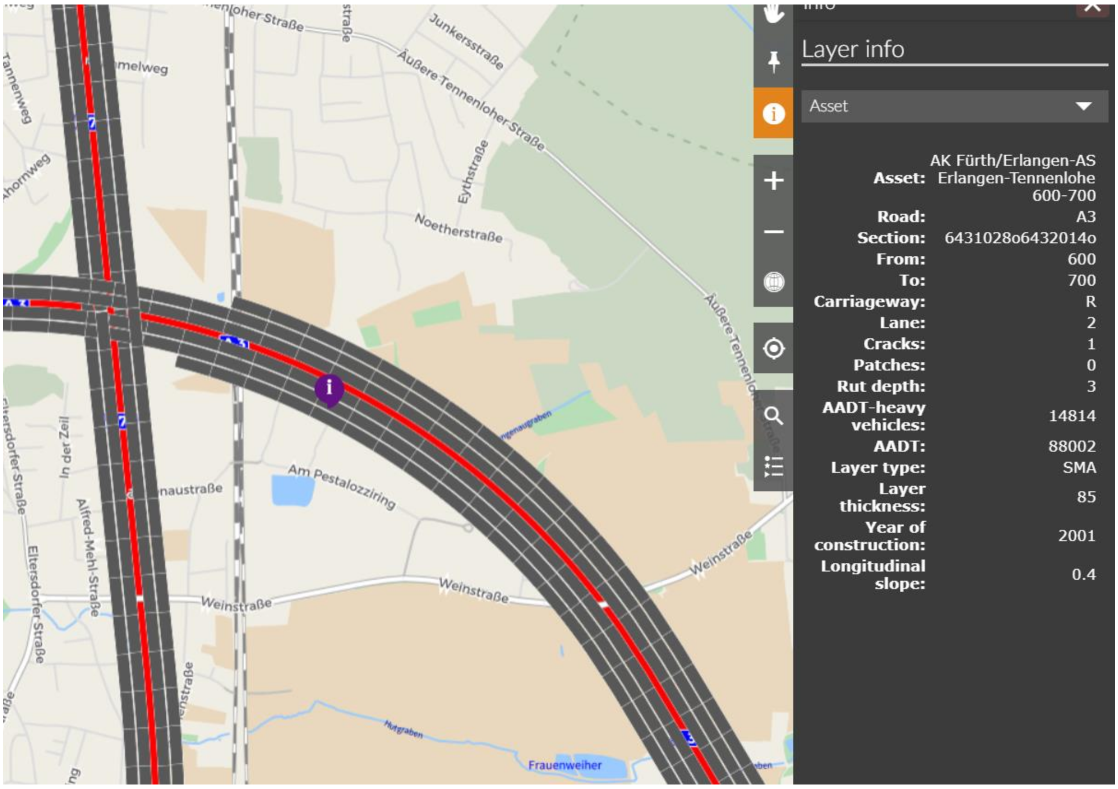


Figure 7: Example of the data required for a pavement asset object

- **Additional parameters** are required for the cost benefit calculation. The calculation of direct and indirect costs takes into account additional parameters. The list of parameters depends also on the DPCs being analysed and indicators defined. For the pilot studies the following parameters were taken into account:
    - Type of soil
    - Urbanity
    - Topography
- While some parameters can be taken directly from asset databases maintained by road administration, other values need to be calculated. For example the topography indicator can be calculated from a digital terrain model. In Figure 8 the topography indicator for Bavaria is shown.

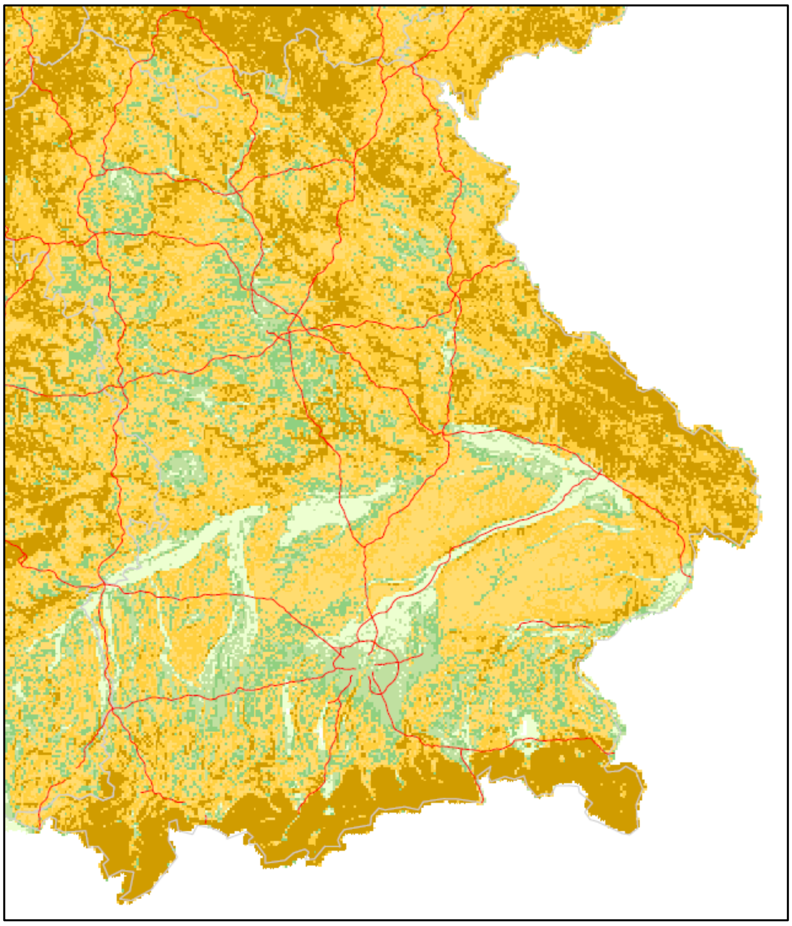


Figure 8: Topography indicator for Bavaria (Example)

- **Climate projection data**. The climate data was obtained from the European project CORDEX. CORDEX is an unprecedented initiative to cover continent-wide areas concerning climate model data. This encompasses re-simulations of the current climate and climate projections with regional climate models. CORDEX relies on a unified grid that covers Europe and the contributing models are forced to produce their output on that grid. The resolution of the CORDEX grid is 10km (see Figure 9). The following climate indicators were calculated:

- number of hot days per year
- number of summer days [d] per year
- number of [n] heat waves per year
- number of tropical nights per year
- maximum temperature within the period [Tmax in °C]
- maximum spread [K] TX and TN per year
- number of hot days with PR>20 mm (temperature drop)
- number of days with freeze thaw cycle [d] per year
- lowest temperature within period [Tmin in °C]
- number of frost days [d] per year
- change (%) number of frost days per year against 1971-2000
- number of Ice days [d] per year
- number of days [d] of the longest continuous frost period (TM < -5°C) per year
- number of days [d] mit PR > 20 mm precipitation per year
- change [%] number of days with PR > 20 mm NS per year against 1971-2000
- sum precipitation [mm] within 5 days . Maximum within period.
- number of days [d] with PR > 10 mm precipitation per year
- sum [mm] PR precipitations hN per year
- change [%] Sum PR precipitations hN per year against 1971-2000
- number of potential snow days [d] (days with precipitation and daily mean temperature ≤ 2°C) per year
- number of [n] events per year where strong rainfalls occurs after long dry period [n]
- Average of mid value of wind speed within the period
- Average number of days with wind speed >15m/s within the period
- Average of max value of wind speed within the period
- Relative sea level rise

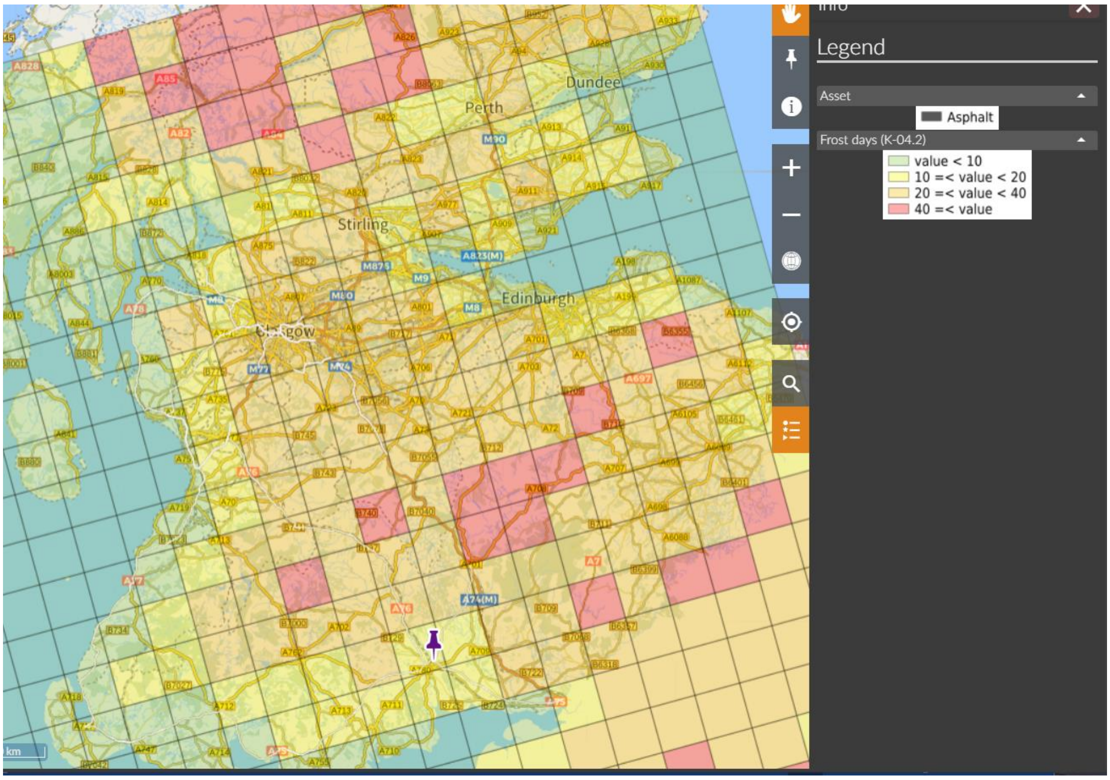


Figure 9: Climate projection parameter: Frost days for Scotland (example)

5.1.2 *Configuration*

Both functional modules (the Risk Assessment and Cost-Benefit modules) are fully configurable. The calculation algorithms are stored in configuration files. This enables the designated NRA Configuration Provider to undertake adjustments in the calculations to tailor the tool to their network if desired. Configuration is stored in a form of structured plain text document (please refer to Figure 10).

The project provides the basic configuration which was created for the pilot studies. The risk assessment approach was based mainly on the RIVA project; however during the pilot studies the configurations were developed based on NRA feedback, and tailored to the type of network and focus of the individual pilot studies. The NRA needs to adjust and verify the configuration before run the pre-calculation.

```
Node "Asphalt road surface" (asphalt_road_surface) {
    property: [
        1 "Cracks (IT-ZEB ZWRISS)" (cracks, .Any)
        1 "Tendency (IT-ZEB)" (tendency, .Any)
        1 "Rut depth (IT-ZEB MSPT)" (rut_depth, .Any)
        1 "Type of the layer (construction data)" (type_of_the_layer, .Any)
            1 "Layer thickness (construction data)" (layer_thickness, .Any)
        1 "AADT-heavy vehicles (road traffic count)" (aadt_heavy_vehicles, .Integer)
            1 "Number of lanes (per lane)" (number_of_lanes, .Integer)
            1 "Age (construction data)" (age, .Any)
            1 "Condition (from SIB)" (condition, .Any)
            1 "Mends (IT-ZEB FLI)" (mends, .Any)
            1  "Surface  layer  thickness  (construction  data)"  (surface_layer_thickness,
.Any)
            1 "Position (derived from flood risk maps)" (position, .String)
            1 "Type of Drainage (currently no data)" (type_of_drainage, .String)
            1 "Embankment (currently no data)" (embankment, .String)
```

~~~~
            1 "Number of twisting area (currently no data)" (number_of_twisting_area,
.Any)
    ]
}

Node "06a - Asphalt road surface - heat-related damages and restrictions on the asphalt
road surface" (dpc_06a) {
    property: [
        1 "Value" (Value, .Double)
    ]
}
Rules For dpc_06_aadt_heavy_vehicles Through firstCalculatedGate("Value") [

    ```lua

            value = ${asphalt_road_surface}.aadt_heavy_vehicles

            if value < 4000 then
                   return 1
            elseif 4000 <= value and value < 9000 then
                   return 2
            elseif 9000 <= value and value < 12000 then
                   return 3
            elseif 12000 <= value then
                   return 4
            else
                   error ("Invalid key value")
            end

    ```
]
Rules For dpc_06_type_of_the_layer Through firstCalculatedGate("Value") [
    ```lua
            value = ${asphalt_road_surface}.type_of_the_layer

            if (value == "PA" or value == "MA" or value == "GA" or value == "OPA") then
                   return 2
            elseif (value == "SMA" or value == "AC" or value == "AB") then
                   return 3
            else
                   error ("Invalid key value")
            end

    ```
]
~~~~

Figure 10: Example of configuration script

5.1.3 *Pre-Calculation*

After the data is imported into the database and the configuration scripts are adjusted the pre-calculation is run. Due to the large amount of data (the tool works on a network wide level) and number of parameters it is necessary to run a pre-calculation. In this step the risk assessment indicators are calculated for all DPCs being analysed for the whole network. This operation takes some time, but is only performed once for the whole database. The calculated values are then valid until the next import of data.

5.2 *Using the risk assessment module*

The DeTECToR tool is implemented as a web application and runs in a typical web browser. In order to run the application the user needs to enter the URL into web browser. During the project, the tool was deployed on the server of one of the members of the project consortium. Following the completion of the project, CEDR will host the tool and provide access to CEDR members. The pilot projects develop for the DeTECToR project are available as examples. To run the application following URL needs to be entered in web browser: https://beta.heller-ig.de/detector.

To enter the application, the user needs to enter their user name and password (see Figure 11). The credentials can be obtained from the administrators who are responsible for the deployment of the application.

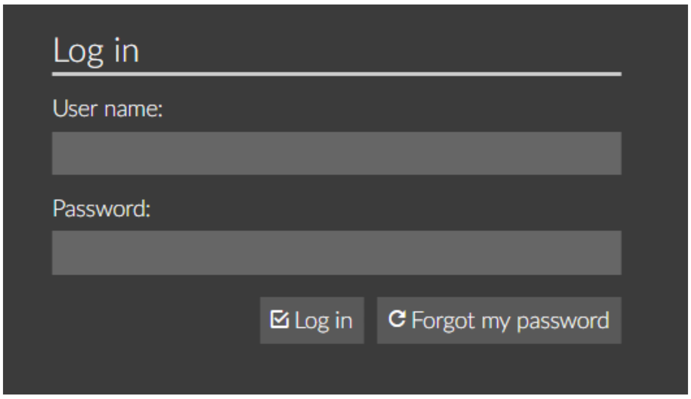


Figure 11: Login dialogue

Typically, when the account was being created, an email with user name and password will be sent automatically to the user.

After login, a dialogue with available working spaces ('project') will be shown (see Figure 12). The availability of the project can be controlled in the user management module. The user can be granted with right to access one or more working spaces (projects) available on the server.

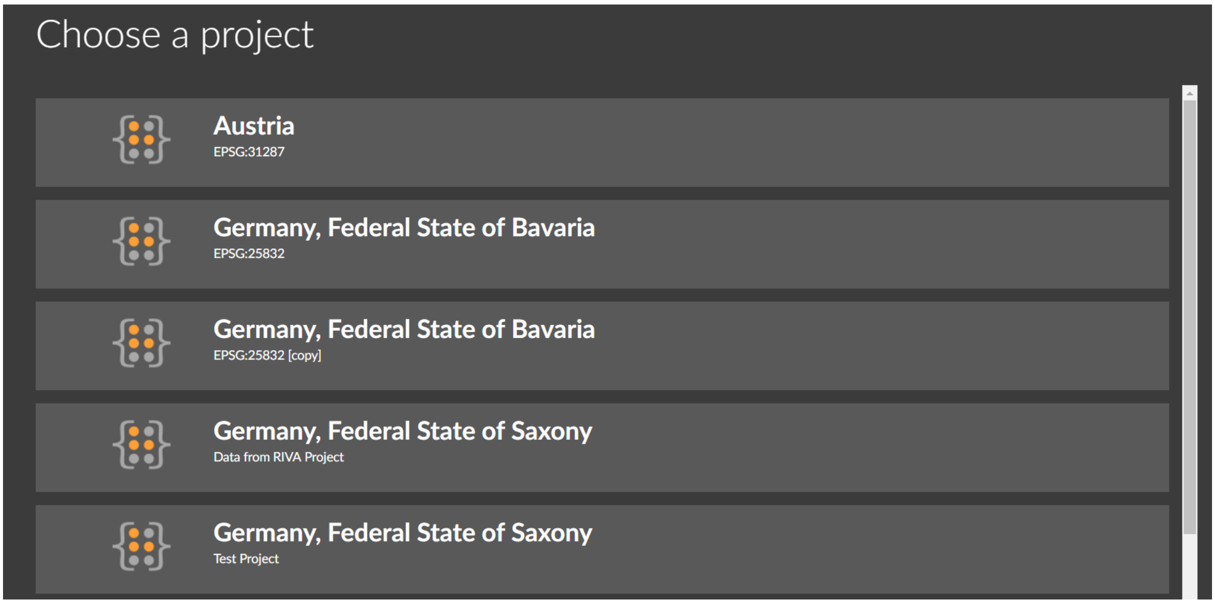


Figure 12: Dialogue for selection of the working space (project)

After selection of the project the application switches into the risk assessment analysis view. The second view, configuration of cost benefit analysis needs to be activated separately. The functionality of both views will be described in next sections. The active view can be switched by clicking of the button in the application tool bar (see Figure 13).

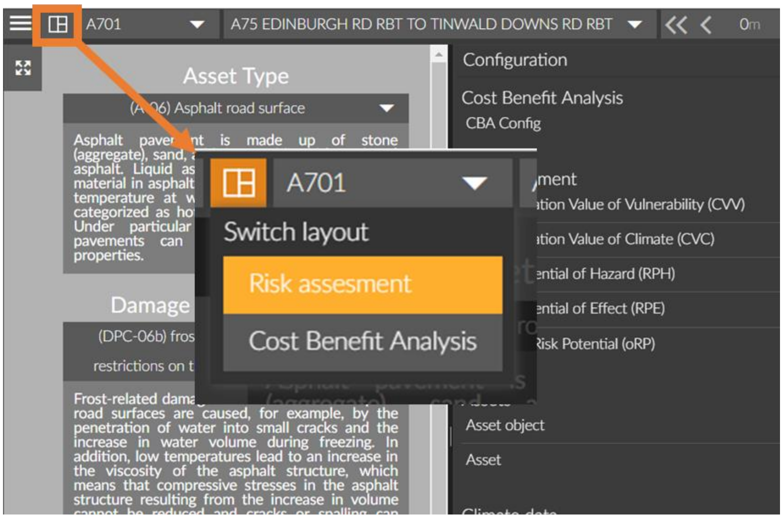


Figure 13: Switching between views

5.2.1.1 Main window

The main window in the risk assessment module consists of three parts which are marked in blue, orange and green in Figure 14.

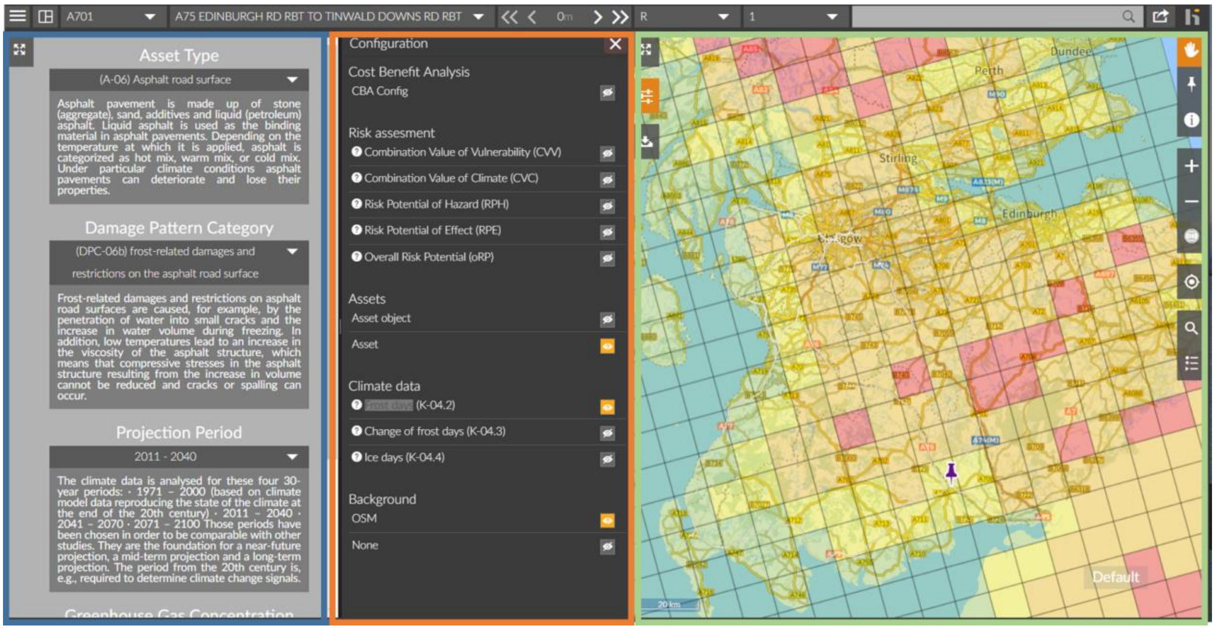


Figure 14: Main window of DeTECToR-Tool in Risk assessment mode

The blue rectangle outlines the configuration panel of the risk assessment module. The orange rectangle marks configuration panel dedicated for the map. With green colour the map is marked.

The main window in the cost benefit configuration module consists of two parts (Figure 15).

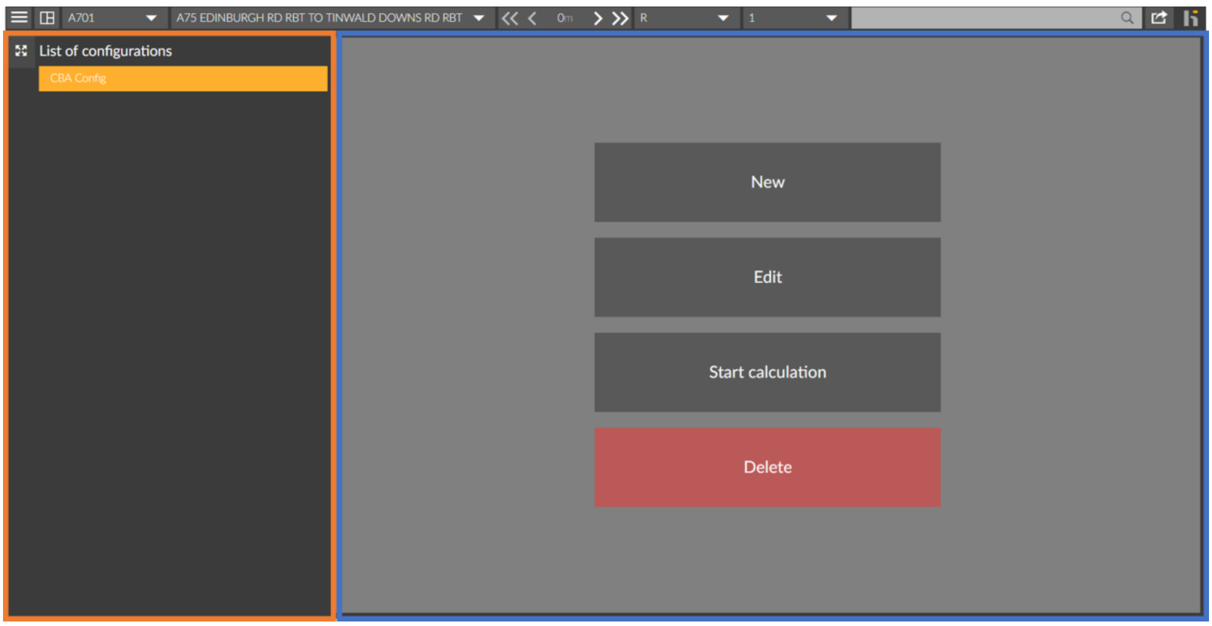


Figure 15: Main window of the cost benefit module

Within the orange rectangle the list of available configuration is shown. The blue rectangle marks the area with tools for management of the selected configuration.

The functionality of each marked areas are described in the following sections.

5.2.1.2 Configuration of risk assessment module

This panel allows the user to configure the risk assessment analysis. The settings selected in this panel determine the content of the map. The following settings can be chosen (see Figure 16):

- **Asset type**: the user has to select the asset type they wish to investigate. The available asset types depend on the selected project. For the pilot project following asset types have been implemented: asphalt pavements, concrete pavements and bridges. The RIVA Methodology, which is the basis the module, contains other asset types. The Configuration Provider can provide the configuration and data for another asset types.
- **Damage Pattern Category (DPC)**: the available Damage Pattern Categories depend on the selected asset type. The user can select one for further analysis. For the pilot studies a small number of possible Damage Pattern Categories (developed by RIVA) have been implemented. Also a few new Damage Pattern Categories have been elaborated and implemented to illustrate the potential of the tool.
- **Projection Period**: the user can select a projection period for the climate data. For the pilot studies the following periods were implemented: 1971 – 2000, 2011 – 2040, 2041 – 2070, 2071 – 2100. The first projection period, 1971 – 2000 represents historical measured data as a comparison with the climate model data. The climate projection data for the pilot studies has been taken from CORDEX, however data from, national climate projections can be used. The Configuration Provider will need to prepare and import the climate data into the database. The Configuration Provider can define other projection periods or provide the data on different raster.
- **Greenhouse Gas Concentration:** this represents the trajectories used for modelling of the greenhouse gas concentration. The Intergovernmental Panel on Climate Change (IPCC) has determined four RCPs, e.g., four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come. Out of these four the lowest and the highest were selected for DeTECToR in order to mark an “event corridor” for different future developments · Low Concentration is represented by RCP 2.6 and High Concentration by RCP 8.5.

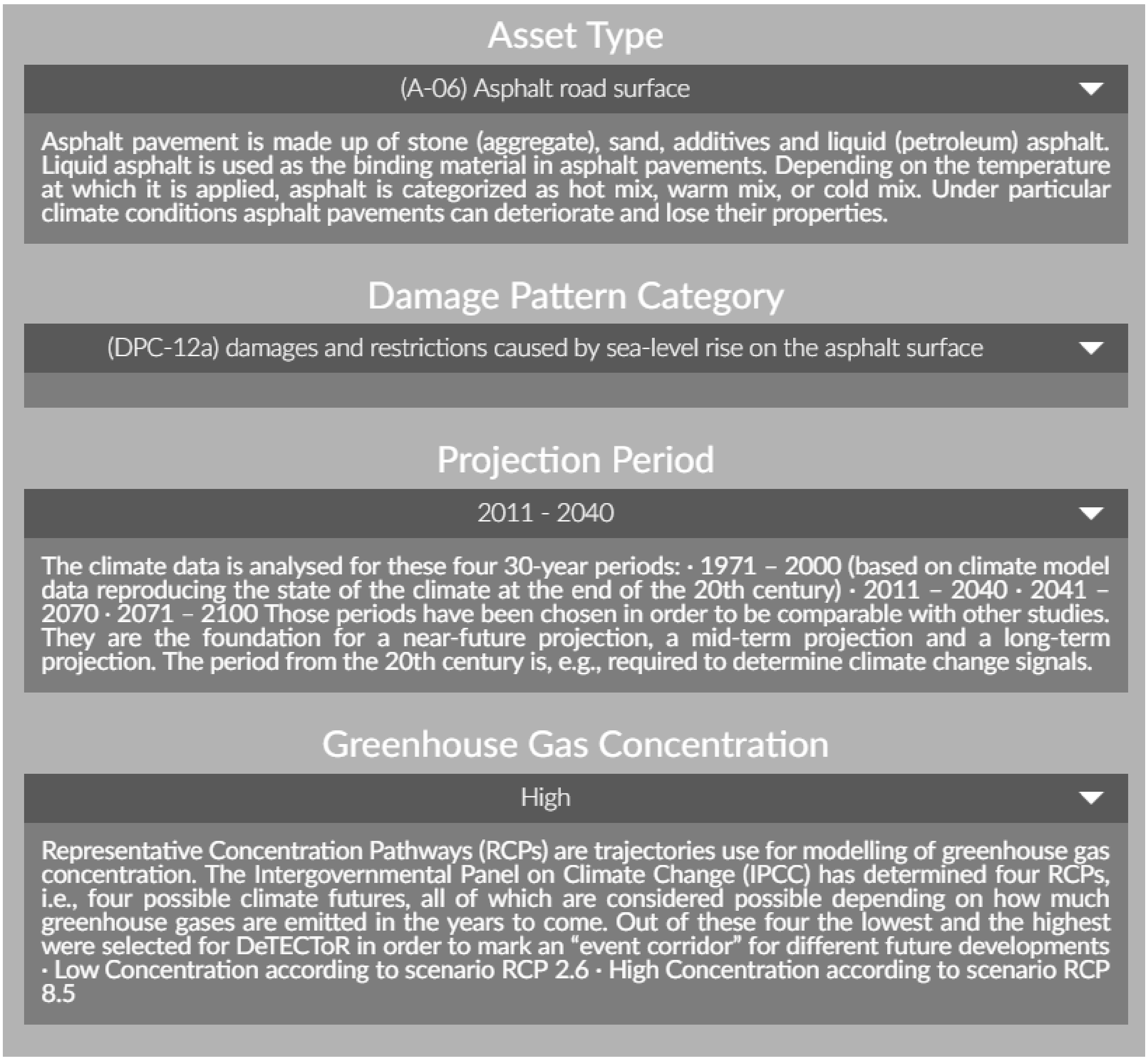


Figure 16: Configuration panel for risk assessment analysis

5.2.1.3 Map and its configuration panel

The map shows the relevant information, according to configuration of risk assessment module. The map layers can be adapted via the configuration panel.

In the configuration panel (Figure 17) the visible layers can be switched on or off by . The available layers are combined together into several groups.

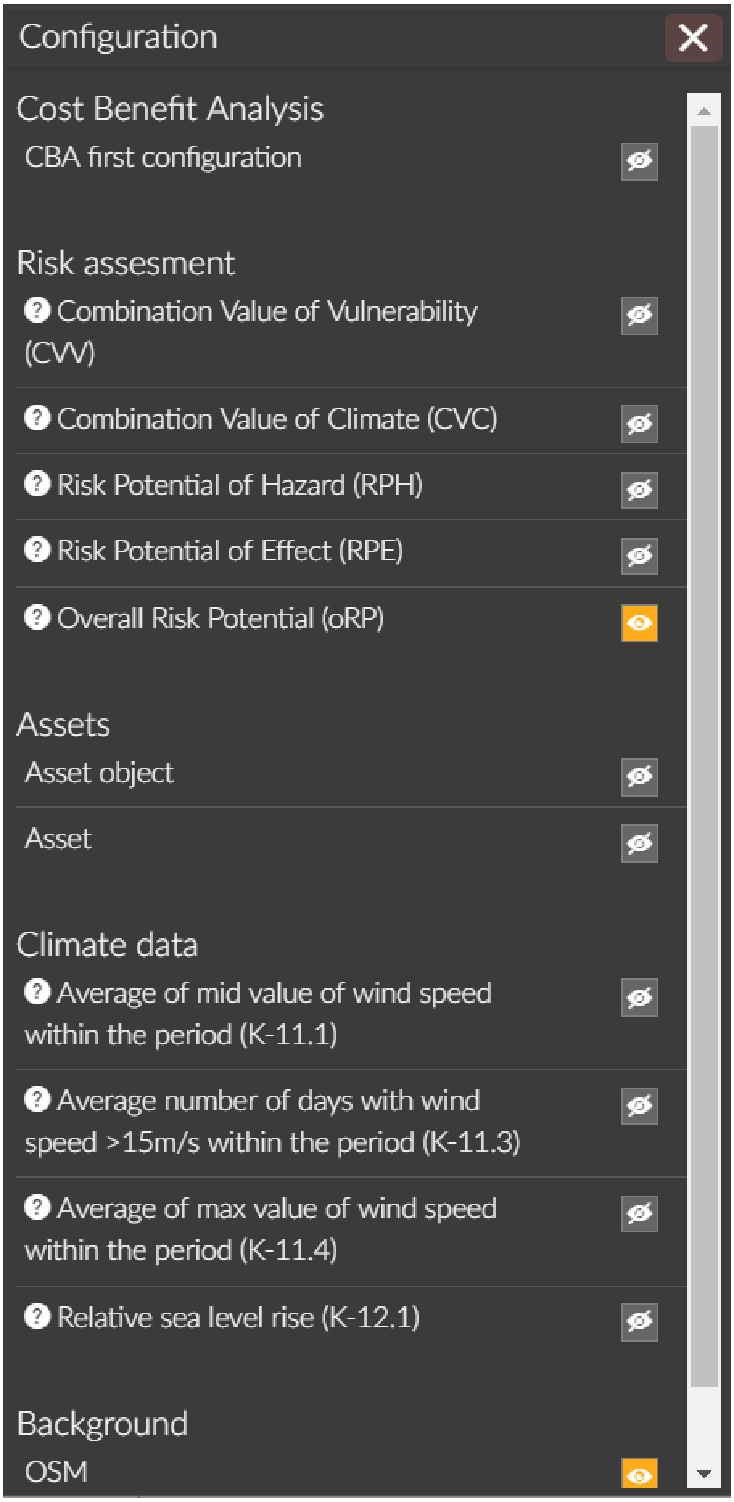


Figure 17: Map configuration panel

The following groups are available:

- **Cost Benefit Analysis**: this group contains all calculated cost benefits analysis. The content of this group depends on selected asset type.
- **Risk Assessment**: this group contains the five risk analysis indicator options:

- Combination Value of Vulnerability (CVV)
- Combination Value of Climate (CVC)
- Risk Potential of Hazard (RPH)
- Risk Potential of Effect (RPE)
- Overall Risk Potential (oRP)

- The meaning and calculation algorithm for these indicators is described in section 4.1.1 of this document.
- **Climate Data**. This section displays a layer with relevant for selected DPC climate parameters.
- **Background**. In this section the background layer can be selected. For the pilot studies two background layers were provided: a map based on OpenStreetMap-data and blank background. The Configuration Provider can configure an alternative background layer if they wish. Each background layer has to be accessible by the WMS interface in order to display the content in the tool.

The user can use the "Define position" function to select any position in the road network. If a position is selected next to the respective road network, the pin automatically jumps to the nearest position on the road network. All other windows are automatically synchronised.

With the function "Show information about object" , the information connected with the object can be queried and displayed (see Figure 18).

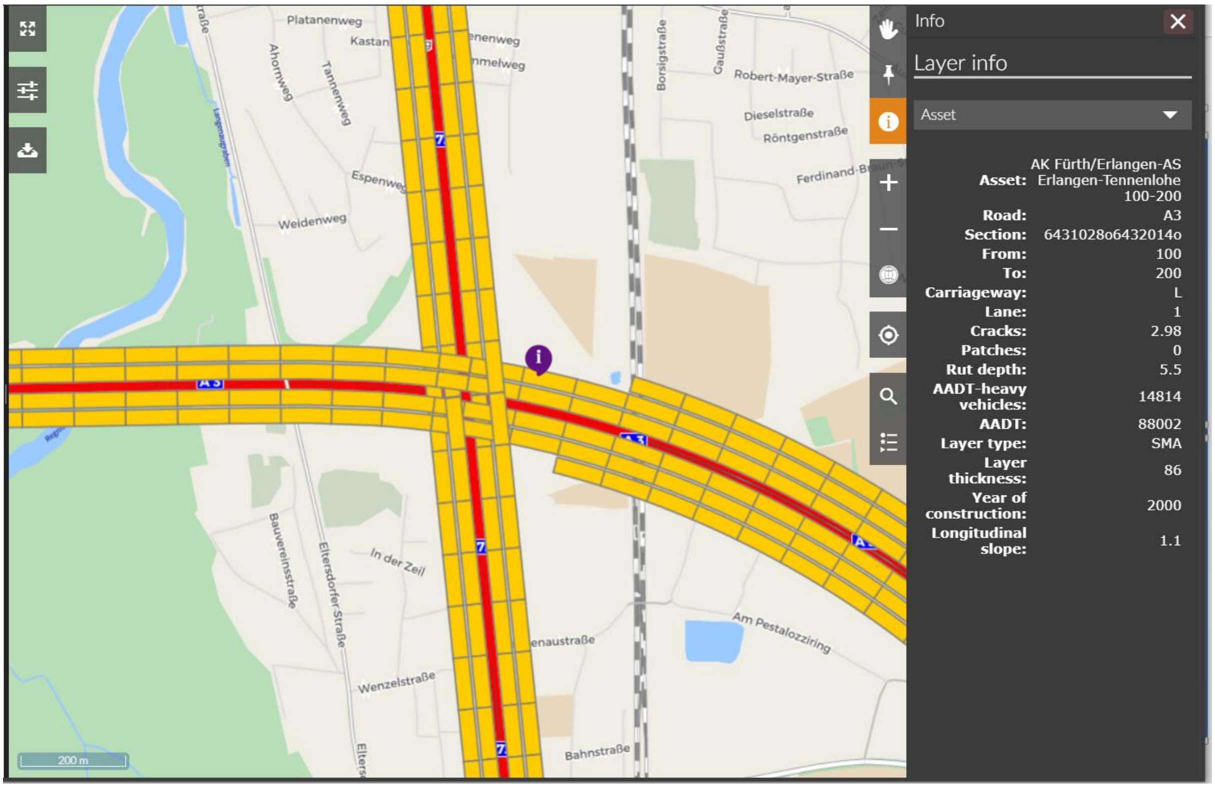


Figure 18: Showing information about object

The legend can be displayed with the "Legend"  button (see Figure 19).

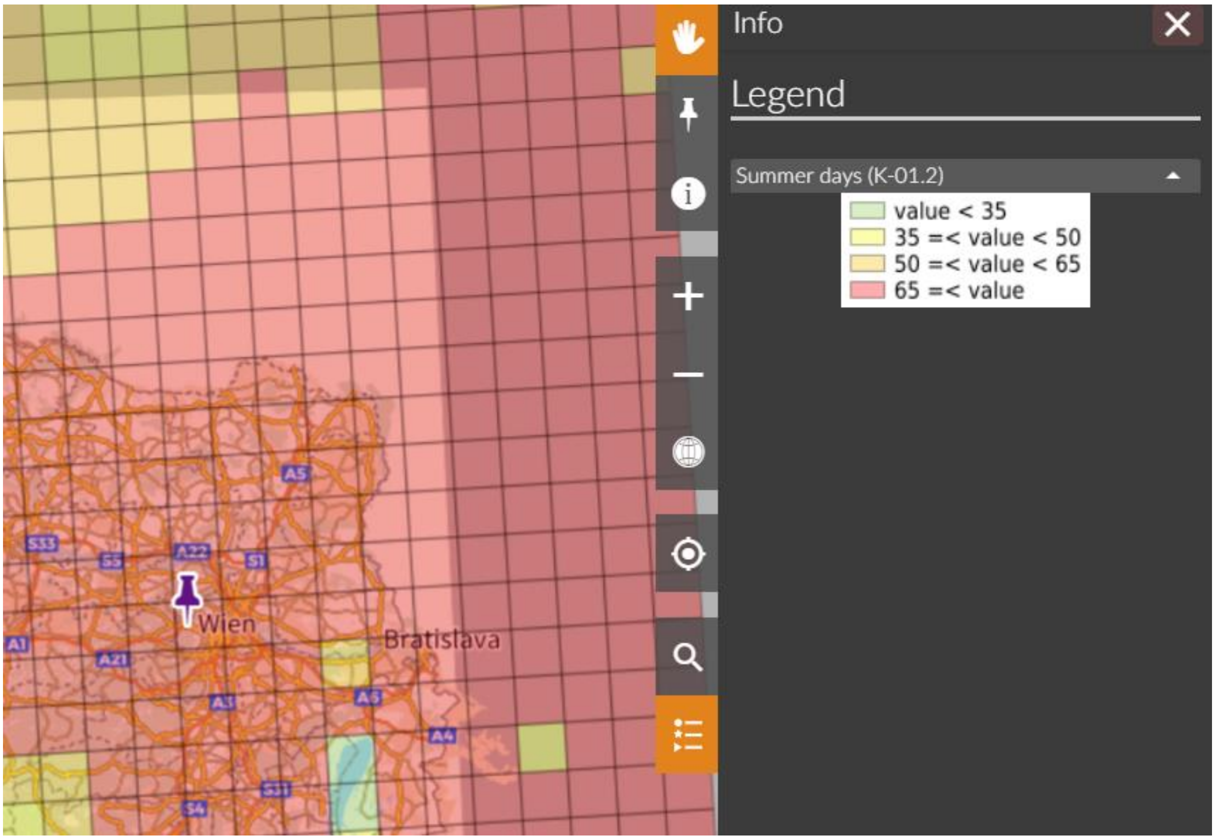
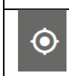
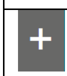
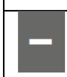
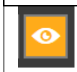


Figure 19: Legend (example)

Overview of all functions in map panel

Function	Description
	**Pan** Move the map content
	**Set position** Select position on the map
	**Information about object** Show additional information for selected object
	**Center** Center the map to selected position (Pin)
	**Zoom out** Zoom out the map content
	**Zoom in** Zoom in the map content

	**Show all** Show whole map content
	**Location search** Search for a location in the OSM data
	**Legend** Show the legend
	**Sichtbarkeit** Ein- bzw. Ausblenden der Kartenschicht
	**Export data** Export visible data to csv or shape file

5.3 Using the cost benefit analysis module

This module enables the user to manage configurations for cost benefit calculation. This includes creation of a new configuration, modification of existing one and deleting of an existing configuration (Figure 20). For one database many configuration can be created and calculated. In Figure 21 an example content of a configuration for cost benefit analysis is presented.

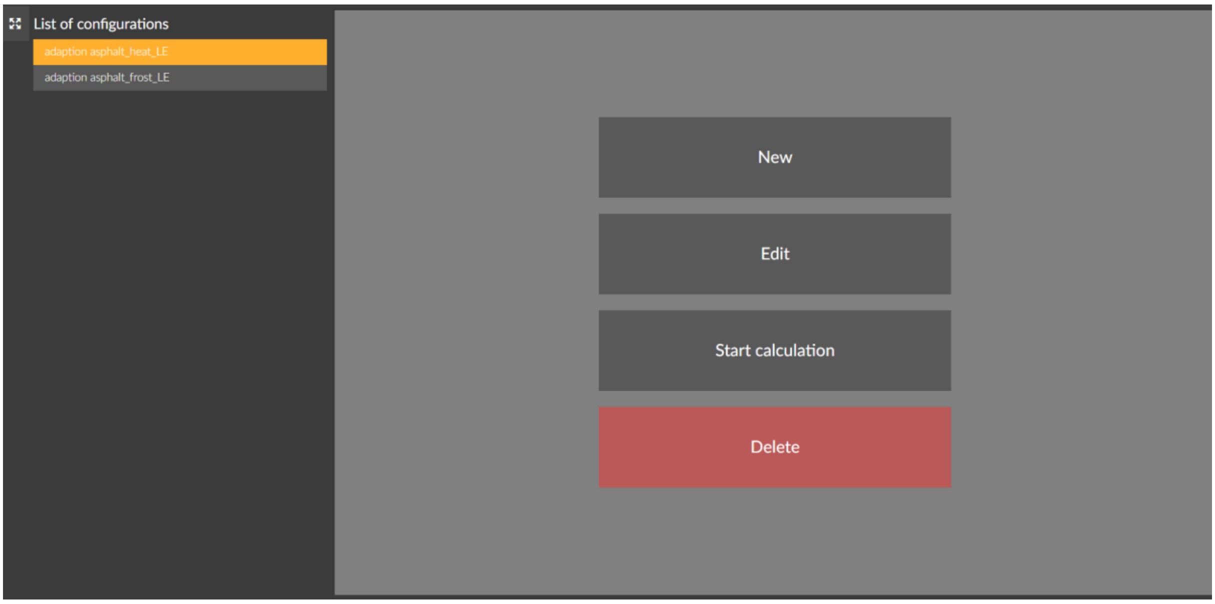


Figure 20: Cost benefit configuration module

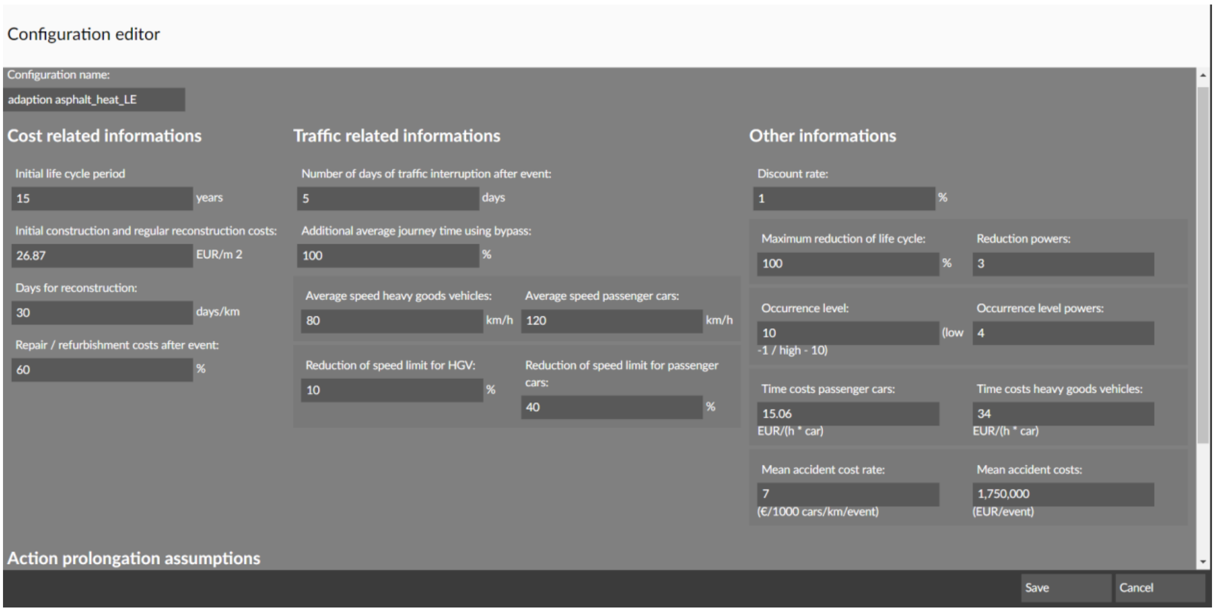


Figure 21: Configuration panel with parameters of cost benefit calculation

From the configuration panel the results of an existing configuration can be calculated. To do this, the function “Start calculation” needs to be selected. A new dialogue will be shown (see Figure 22), on which the user has to select asset type and Damage Pattern Category of interests. Since, the calculation can take a while; an email address has to be provided. After the calculation is finished, user will receive an email with confirmation status or error log, if errors occurred during calculation.

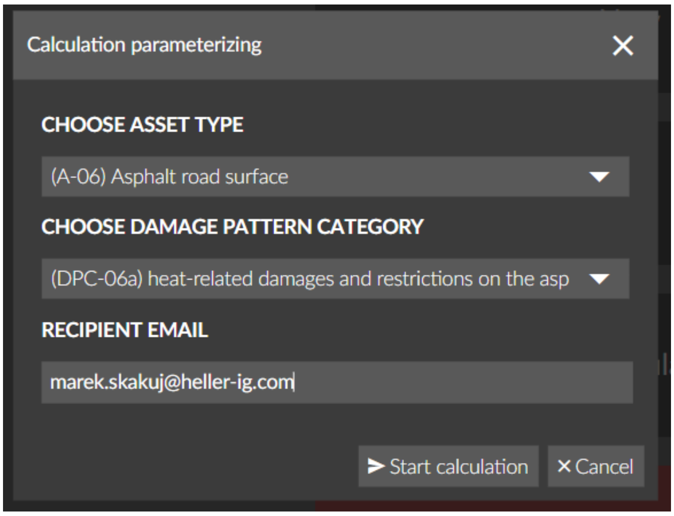


Figure 22: Dialog to run the cost benefit calculation

The results of the cost benefit calculation are shown on the map as a thematic layer. The name of the layer will be the same as the name of the configuration (see Figure 23).

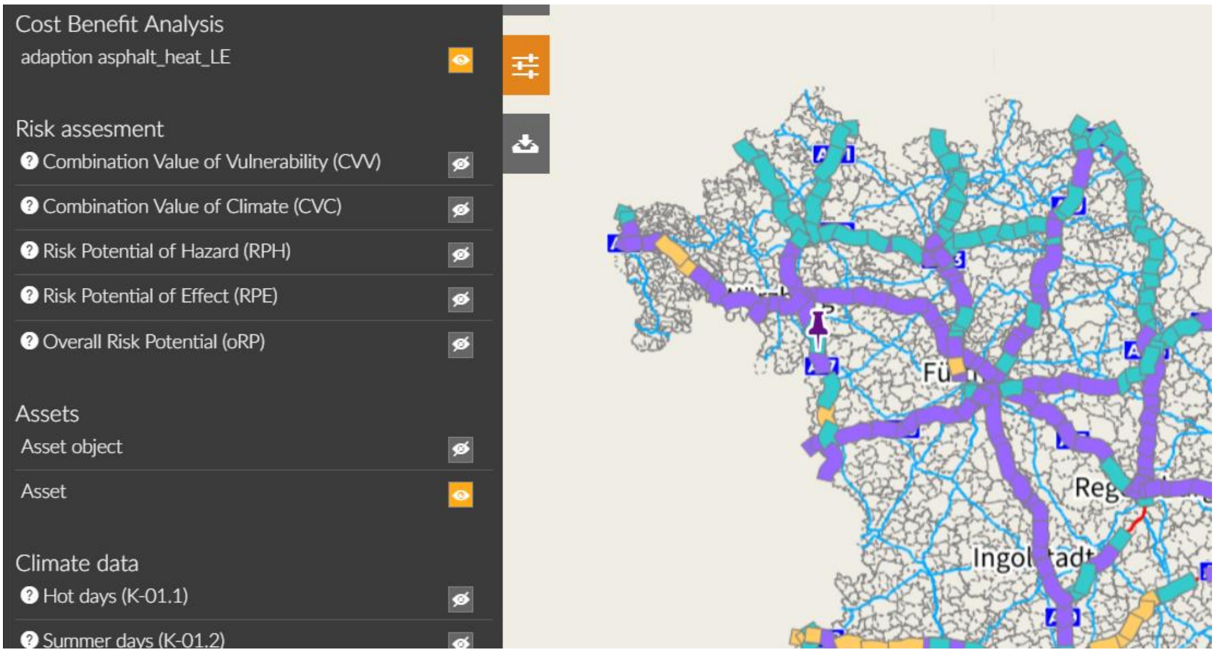


Figure 23: Results of cost benefit calculation

5.4 *Viewing results*

The results from the risk assessment and cost benefit analysis are presented on the map as interactive thematic layers.

5.4.1 *Viewing results of risk assessment for pavement assets*

In order to run the risk assessment calculation the pavement asset (both asphalt and concrete) is divided into parts with length of 100 meter and width of a lane. For each single slab, the five risk assessment indicators are calculated and displayed in different colour (see Figure 24).

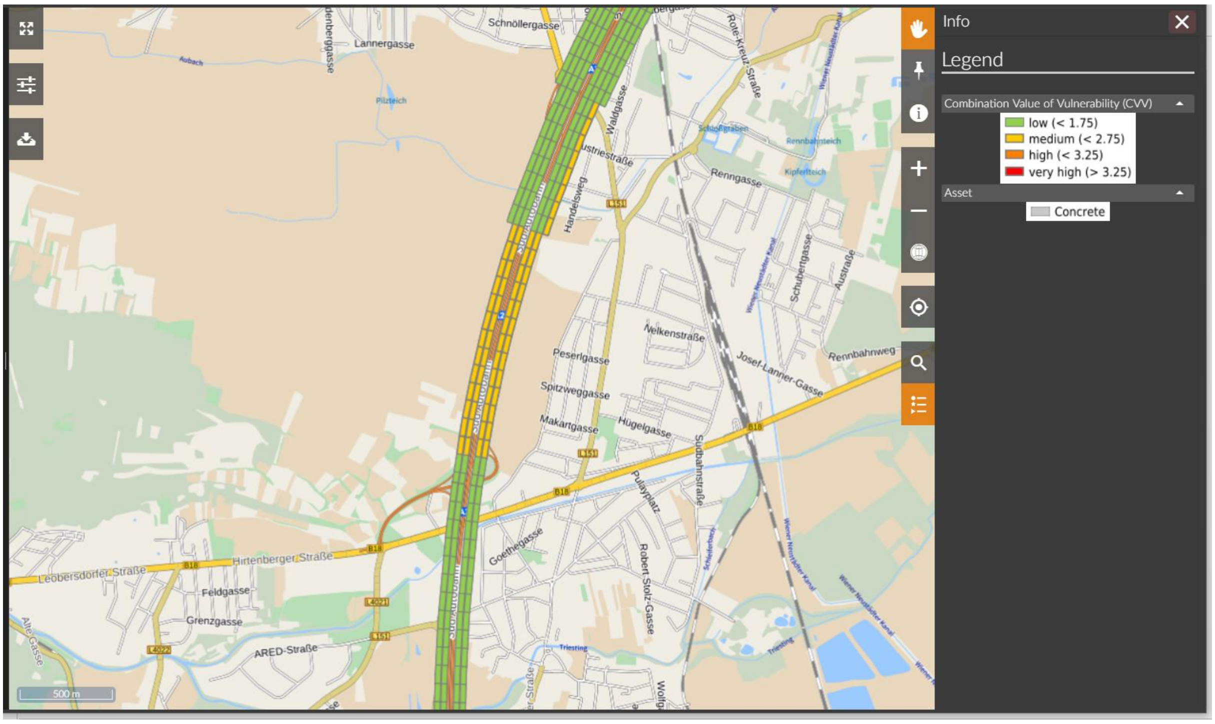


Figure 24: Graphical representation of Combination Value of Vulnerability for concrete road surfaces

The colour represents the level of risk and is explained in the legend. For each risk indicators the same scale and colours are used in order to make the maps comparable.

This level of detail is useful for object-based investigation but is not suitable for an overview of the whole road network to identify hotspots. To facilitate this, the calculated values of risk indicators are aggregated (as a length weighted average) into a longer section (Figure 25). Typically such longer section represents a road section between two motorway exits or crossings. It is important to note, that the aggregation is based on the calculated indicators.

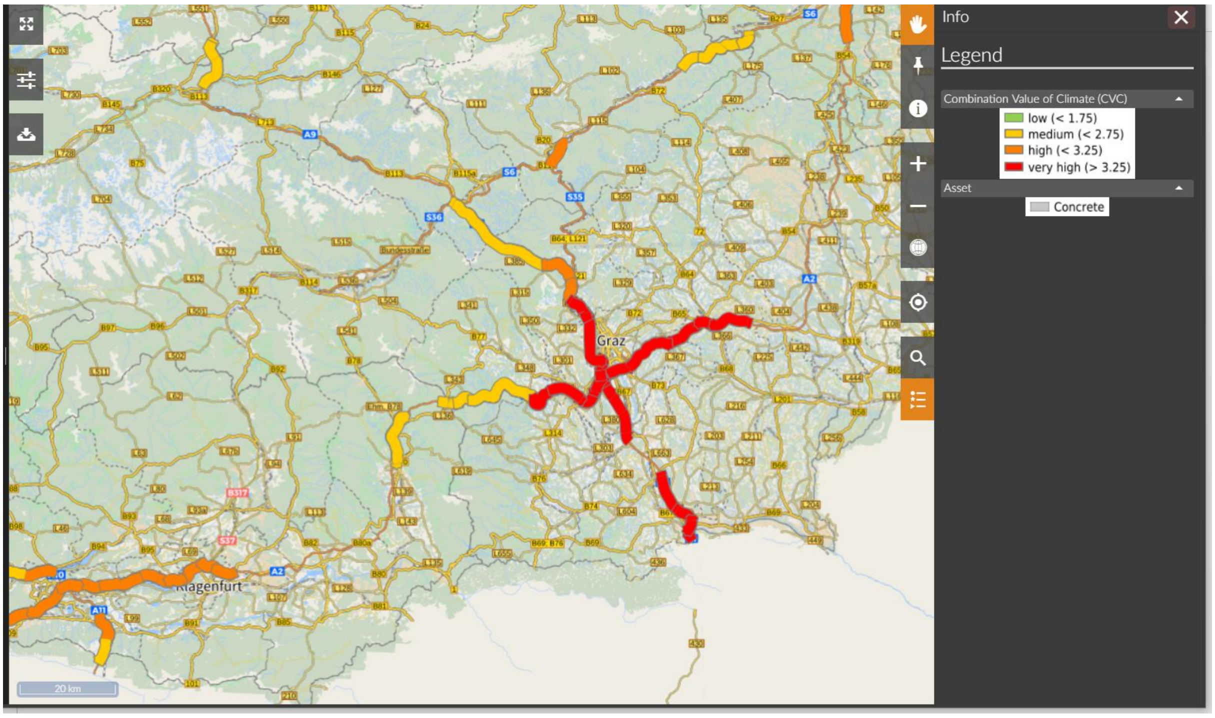


Figure 25: An overview on Combination Value of Climate for concrete surfaces

The same colour scheme is used to distinguish the risk levels.

5.4.2 *Viewing results of risk assessment for bridges*

In case of bridges, the calculation of risk indicators is performed for each bridge separately. On the map, the bridges are represents by points labelled by the name of the bridge. The colour represents the risk level. The same colour scheme as for pavement surfaces is used.

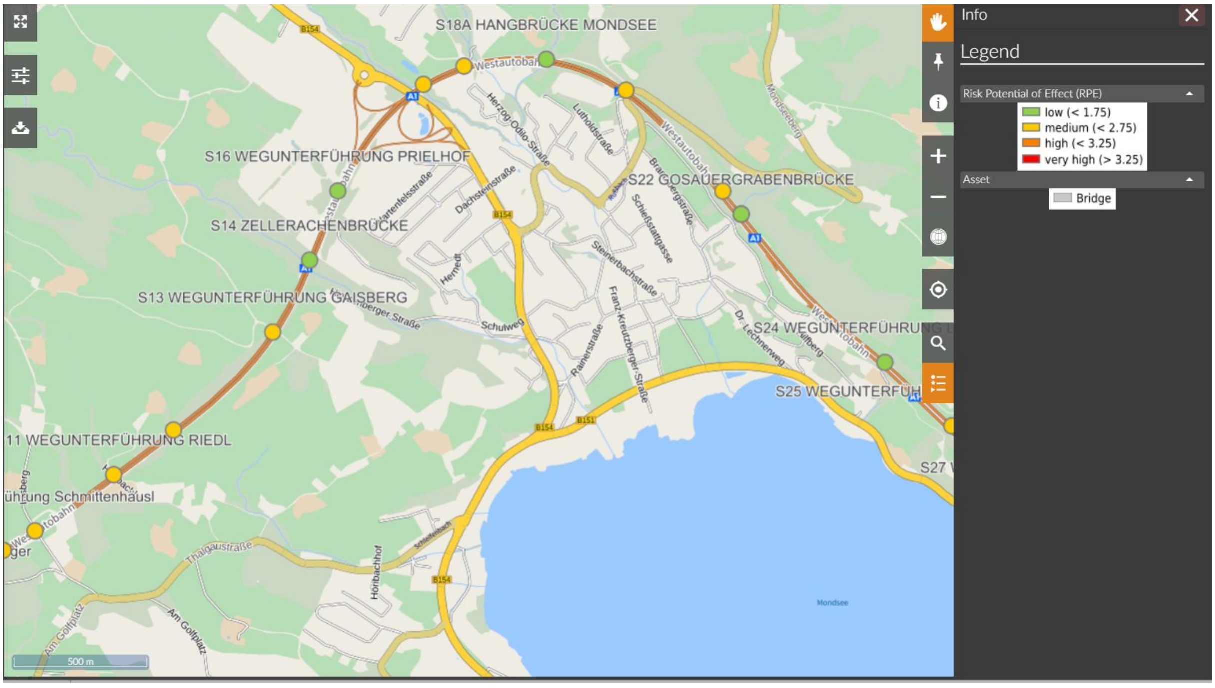


Figure 26: Graphical representation of Risk Potential of Effects for bridges.

Also in the case of bridges, calculated values of risk indicators can be arrogated into longer section. In this case the normal average value of risk indicator is calculated. The average value can be displayed on the map (Figure 27).

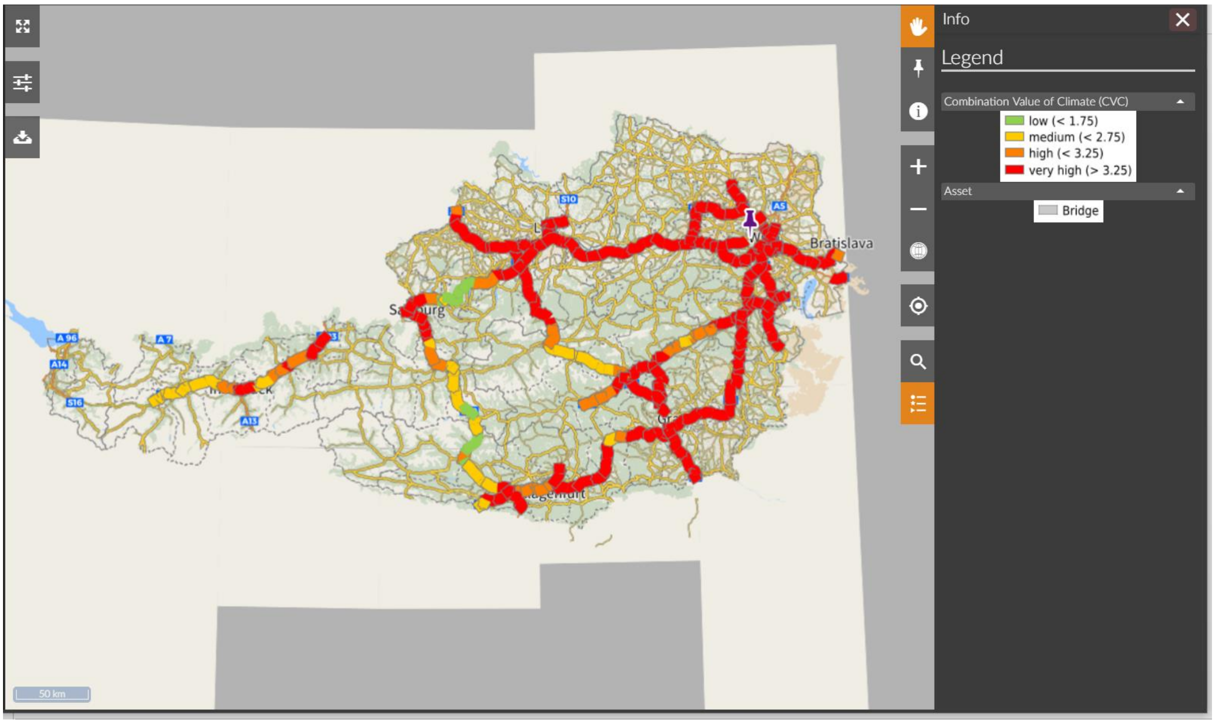


Figure 27: An overview of Combination Value of Climate for bridges (aggregation into sections between two motorway exits).

5.4.3 *Viewing results of cost benefit calculation*

The cost benefit calculation is performed for three different adaptation actions. The parametrisation of each action can be taken by user. For each adaptation action the total costs as a sum of direct and indirect cost is calculated. The results of the cost benefit calculation are displayed also in form of the thematic layer (Figure 28).

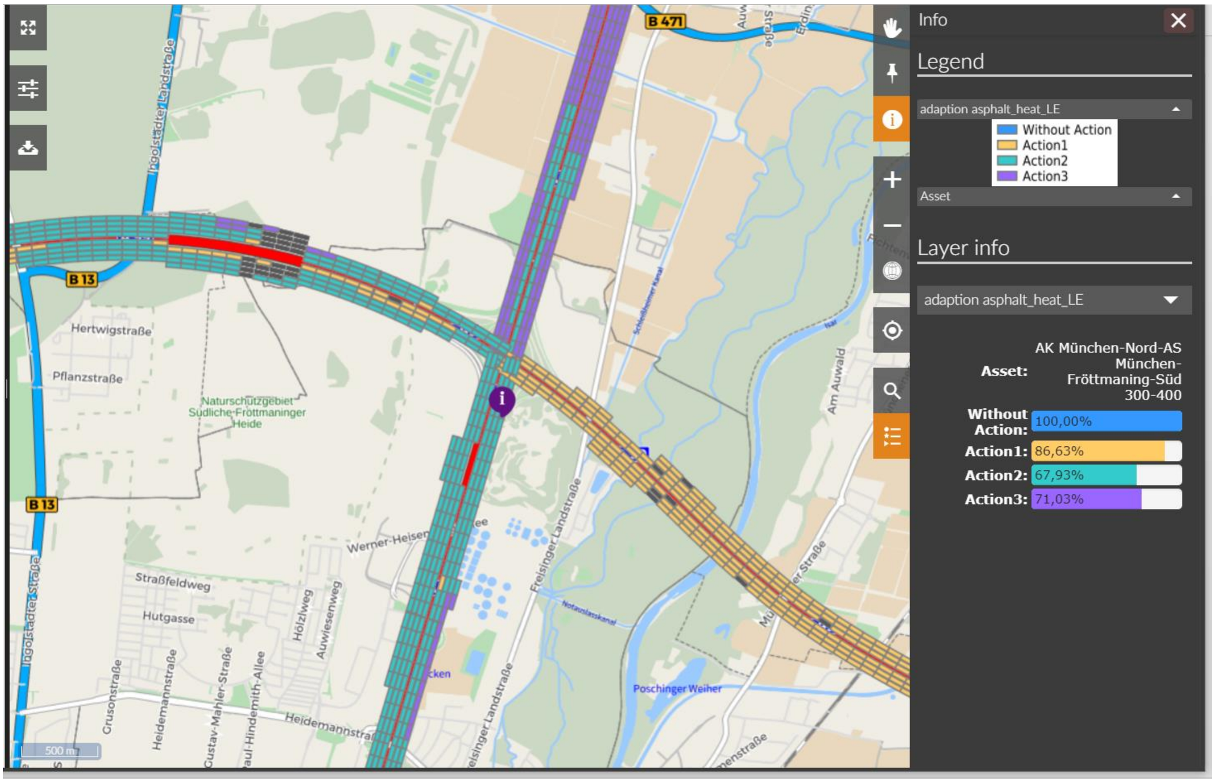


Figure 28: Graphical representation of cost benefit calculation

The colour of the asset object represents the lowest cost action for this object. The decision on which adaptation action is selected is made on the basis of the calculated costs for the whole appraisal period.

Additionally a diagram with the percentage of adaptation action cost in comparison with action “do nothing” can be displayed (Figure 29).

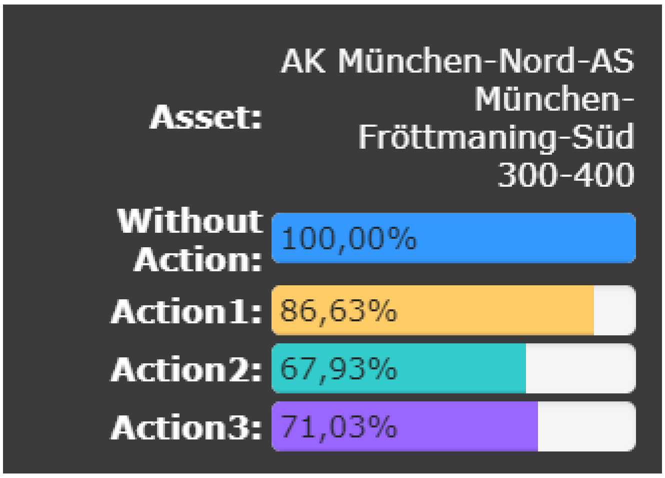


Figure 29: Cost comparison between adaptation actions

6 Example results

Results from the German pilot study are provided as an example.

6.1 *Overview of the network*

The German motorway network comprises a total length of approximately 12,500 km. For the German pilot study, the area of the Federal State of Bavaria was selected for in-depth analysis of the effects of climate change on the road infrastructure (see **Figure 30**). The motorway Bavarian primary road network consists of almost 2,500 km of road with more than 3,500 bridges. Nearly 85% of the road surface consists of asphalt and 15% concrete pavement.

Figure 30: Overview Bavarian pilot region

6.2 *DPCs*

For the German pilot study the following Damage Pattern Categories (DPC) were selected for the analysis.

<table>
<tr><th>Caption</th><th>Description</th><th>Asset type</th><th>Asset indicators</th></tr>
<tr><td>DPC-01a</td><td>Heat-related damages and restrictions at bridges</td><td>Bridge</td><td rowspan="2">• AADT-heavy vehicles
• Position (exposure)
• Material class
• Statical system
• Condition
• Year of construction</td></tr>
<tr><td>DPC-01b</td><td>Frost-related damages and restrictions at bridges</td><td>Bridge</td></tr>
<tr><td>DPC-06a</td><td>Heat-related damages and restrictions on the asphalt road surface</td><td>Asphalt road surface</td><td>• AADT-heavy vehicles
• Position (exposure)
• Tendency
• Cracks</td></tr>
</table>

			• Layer type • Rut depth • Layer thickness
DPC-06b	Frost-related damages and restrictions on the asphalt road surface	Asphalt road surface	• AADT-heavy vehicles • Position (exposure) • Cracks • Layer type • Age • Mends • Layer thickness
DPC-07a	Heat-related damages and restrictions on the concrete road surface	Concrete road surface	• AADT-heavy vehicles • Tendency • Position (Exposure) • Condition • Mends • Spalling • Layer thickness
DPC-07b	Frost-related damages and restrictions on the concrete road surface	Concrete road surface	

Table 3: Bavarian Pilot Study – selected DPCs

6.3 Data sourcing and formatting

Asset data

Except for the indicator "Position (exposure") all the relevant data was provided by the NRA and uploaded into the tool. Before starting the calculations for the risk assessment all available data describing the indicators was transformed into an appropriate data format, and in some cases adjusted, before being uploaded into the tool.

The asset data for the road surfaces of the Bavarian trunk road network are available for each lane, for each direction and for each 100m-stretch (see **Figure 31**).

Figure 31: detail, asset data road surface, Bavarian trunk road network

Climate data

In addition to the asset data, the relevant climate projection data were also uploaded to the tool. The following picture shows and example of the Bavarian trunk road network (in red) and the CORDEX-climate projection data for hot days left-hand site for the period 2011-2040 (low emission) and right-hand site for the period 2071-2100 (high emission scenario).

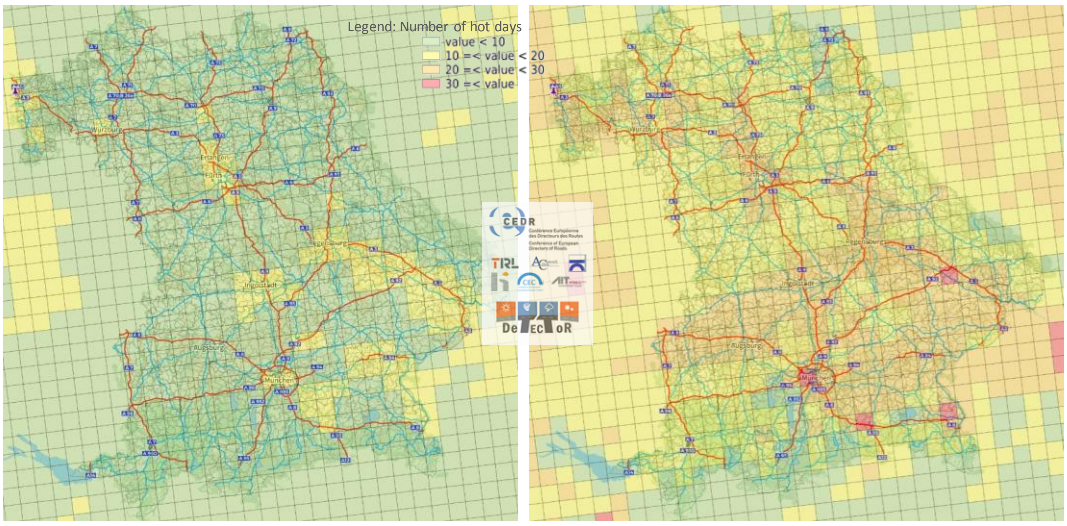


Figure 32: Bavarian Pilot Region – Trunk road network and CORDEX-projection data (number of hot days for 2011-2040 low emissions (left) and 2071-2100 high emissions (right)).

6.4 *Risk assessment*

Hereinafter, the results of the DPC 06a heat related damages and restrictions on asphalt surfaces will be presented in detail as an example.

6.4.1 *CVC*

Following the methodology of the calculation of the risk assessment, which is described in detail in chapter 4.1.1., the calculation starts with the determination of the Combination Value of Climate (CVC), followed by the calculation of the Combination Value of Vulnerability (CVV).

The CVC value is calculated for each CORDEX-grid cell (see **Figure 32**). This is repeated for each projection period and emission scenario. **Figure 33** show the calculation of a selected CORDEX-grid cell for the projection period 2011-2040.

Indicator	projection value	weighting	low [1]	middle [2]	high [3]	very high [4]	value	weighted value
Hot days (K-01.1)	11.5667	25%	x<10	10≤x<20	20≤x<30	30≤x	2	0.5
Summer days (K-01.2)	50.9333	20%	x<35	35≤x<50	50≤x<65	65≤x	3	0.6
Heat waves (K-01.3)	0.4	30%	x<1	1≤x<2	2≤x<3	3≤x	1	0.3
Tropical nights (K-01.4)	0.9667	5%	x<1	1≤x<3	3≤x<5	5≤x	1	0.05
Max temperature (K-01.5)	38.506	20%	x<33°C	33°C≤x<37°C	37°C≤x<41°C	41°C≤x	3	0.6
							CVC	**2.05**

Figure 33: Example CVC-calculation (taken from the German pilot study, heat related damages and restrictions on asphalt surfaces, 2011 -2040, high emissions)

The assets located within a grid cell are assigned the appropriate CVC value which can be displayed on the network map. The results of the individual indicator calculations can be also be displayed on the map view as different coloured grids. Figure 34 shows the indicator "number of hot days" for different projection periods and emission scenarios for the Bavarian pilot study. As it can be seen in Figure 34 the number of hot days is projected to increase in the future, as is the values of the other indicators listed above, consequently the calculated CVC value is also increased. This represents the increased exposure of the infrastructure to the type of weather conditions that could cause heat related damage and restrictions.

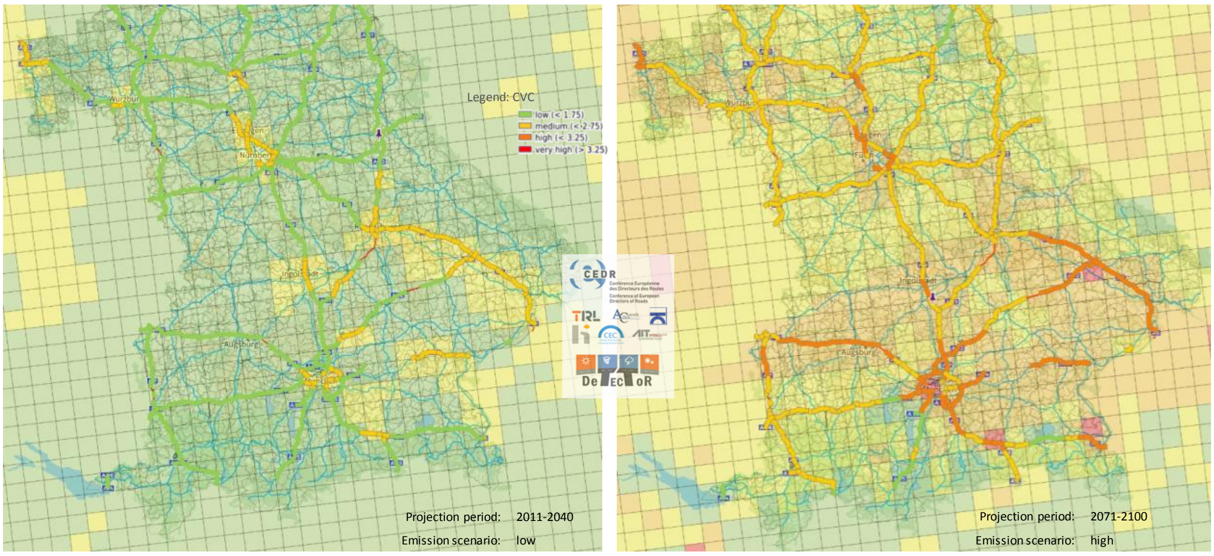


Figure 34: CVC-calculation result, map view of heat related damages and restrictions on asphalt road surfaces, the number of hot days is shown as the underlying map

6.4.2 *CVV*

The calculation of the Combination Value of Vulnerability (CVV) is performed for each asset (when assessing road surfaces this is for each 100m section, per lane, per direction (see **Figure 36**) and when assessing bridges for each bridge). Unlike the CVC, the CVV does not vary with climate projection period or emission scenario. While traffic levels and asset characteristics are unlikely to be the same in the 2080s as today, for the purposes of the assessment they are kept constant, so that the impact of climate change can be assessed. The tool provides an assessment of today's infrastructure in different plausible future climates in order for users to understand the impact of different factors on risk. It does not try to model all possible future changes to a road network.

Dealing with missing data

The user may not have the data required to calculate every indicator for a particular DPC. For example in the Bavarian pilot study, data relating to the "position (exposure)" indicator was not available. When data is missing the indicator can be excluded from the calculation and the remaining indicator weightings adjusted as shown in **Figure 35**.

Indicator	value	weighting	low [1]	middle [2]	high [3]	very high [4]	value	adjusted weighting	weighted value
AADT-heavy vehicles	9 200	25%	x<4 000	4 000≤x<9 000	9 000≤x<12 000	12 000≤x	3	27.8%	0.83
Position (exposure)		10%		not available					0.00
Tendency	2.4	20%	x<2%	2%≤x<5%	5%≤x<7%	7%≤x	2	22.2%	0.44
Cracks	0.9	5%	x<1	1≤x<3	3≤x<5	5≤x	1	5.6%	0.06
Layer type	SMA	15%		PA (OPA), MA (GA)	SMA, AC (AB)		3	16.7%	0.50
Rut depth	2	10%	x<2	2≤x<3	3≤x<4	4≤x	2	11.1%	0.22
Layer thickness	48	15%	x≥30	30>x≥25	25>x≥22	x<22	1	16.7%	0.17
							CVV	100.0%	**2.22**

Figure 35: Example of modifying the CVV-calculation to compensate for lack of data

Whilst this approach is suitable for one or two missing indicators, if too many indicators for one DPC are removed the robustness of the results may be threatened. As previously noted the indicators used can be modified, so alternative/additional indicators could also be added. However the series of indicators should reflect the most significant factors influencing the vulnerability of the asset to the type hazard and engineering judgement needs to be used.

Displaying the results

The CVV can be displayed on the network map in two ways; at a detailed level where the values/colours for individual assets can be seen (Figure 36) or at a network wide scale to gain an overview of the whole network or regions (Figure 37). In order to show the network wide results, the tool combines the individual CVV per asset to calculate a mean value per section (from junction to junction).

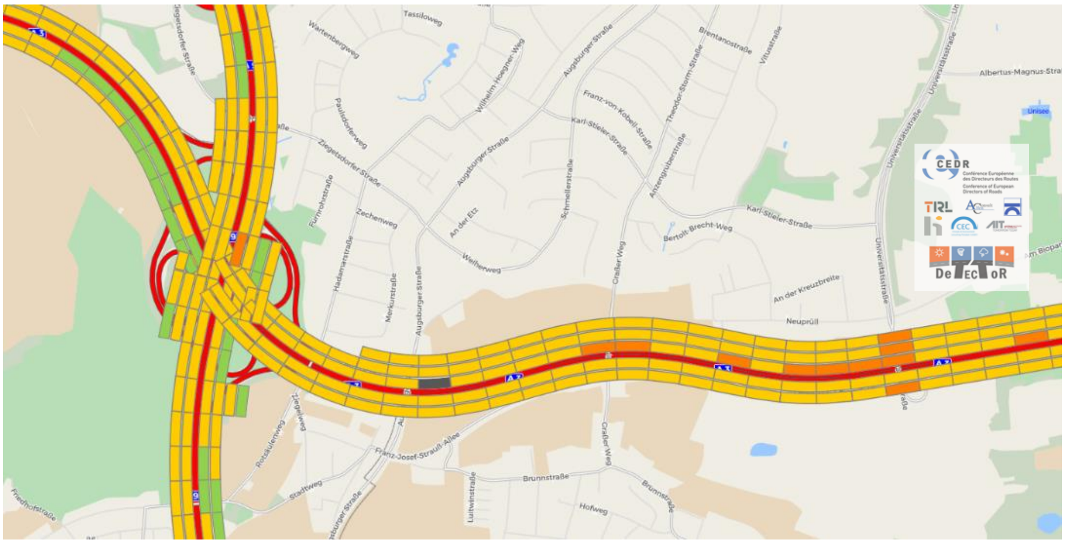


Figure 36: CVV-calculation result, detailed map view

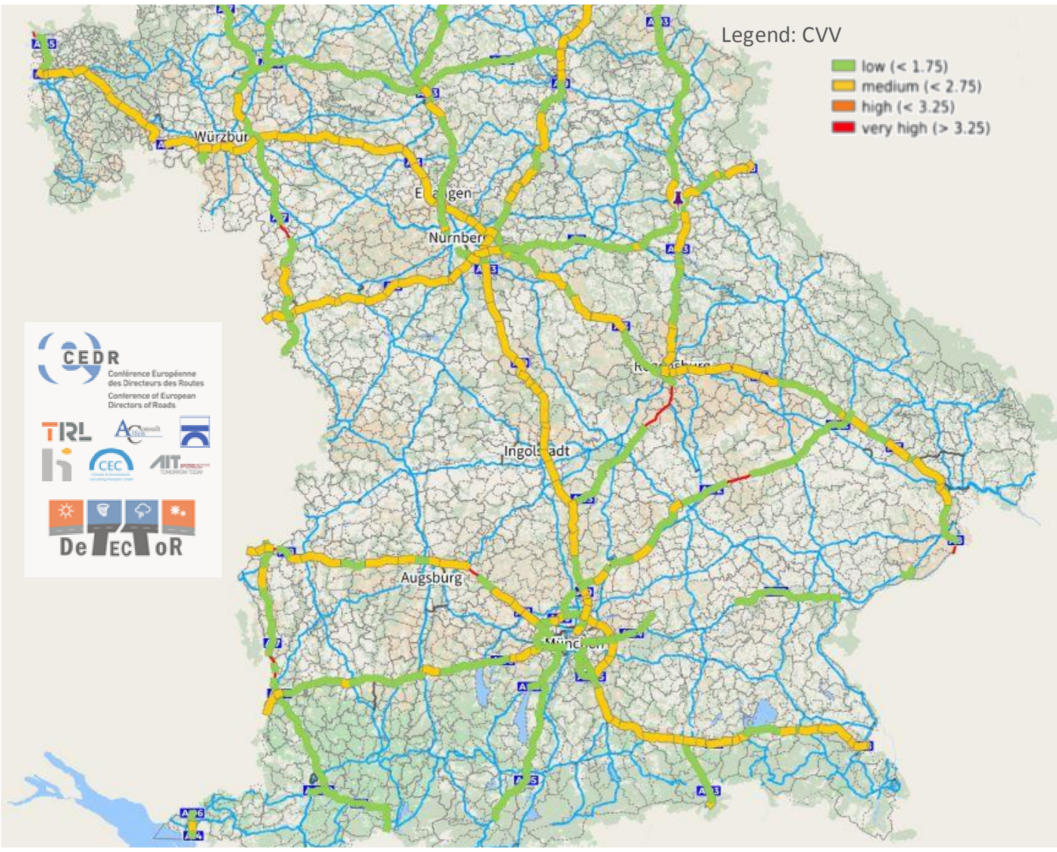


Figure 37: CVV-calculation result, map view networkwide (heat related damages and restrictions on asphalt road surfaces)

Figure 37 shows the mean RPH-values per analysed section. As can be seen in this figure, around 50% of the network have low CVV-values (<1.75) and 50% have medium values (<2.75, but >1.75).

6.4.3 *RPH*

In the second step of the calculation CVC and CVV were combined to produce the Risk Potential of Hazard (RPH) – see chapter 4.1.1.3. Figure 38 shows the change in RPH depending on the time period and emission scenario as it is influenced by the CVC (see also Figure 34). For the period 2011-2040 with low emissions the majority of the sections have a low RPH, whereas for the period 2071-2100 with high emissions the majority of sections have RPH-values. This represents an increase in likelihood of damage or restrictions occurring as a result of the increase in exposure to high temperatures.

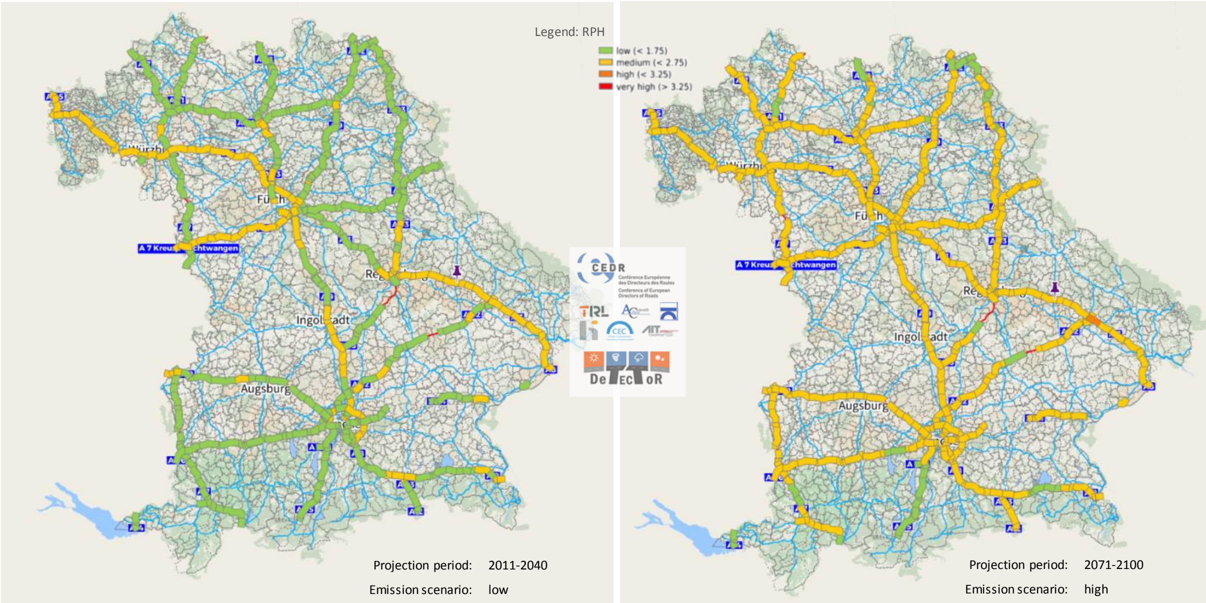


Figure 38: RPH-calculation result, map view network wide (heat related damages and restrictions on asphalt road surfaces)

6.4.4 *RPE*

The third step of the calculation is the determination of the Risk Potential of Effect (see also chapter 4.1.1.4). The calculation uses DPC-specific indicators (in order to compare/weighting the impact of different DPCs in relation to the costs e.g. of maintenance and services or the kind of accidents) as well as section specific indicators (e.g. traffic volume, criticality). This enables a comparison of the consequences of different parts of the network being affected by a type of hazard, and the effects of different DPCs.

As a result of discussions with the Bavarian NRA a further use of the tool was explored in the German pilot study. A calculation of the RPE using only the indicators specific to the section (not those which vary by DPC) was performed in order to identify the sections of the network likely to experience the largest impact for any DPC. Figure 39 shows the differences between the two approaches. The left picture shows the results of the complete RPE calculation and the right picture only the section specific indicators. In the right picture the differences between different sections of the network are more visible. In the left picture the differences in values are smaller and not visible in the picture due to the banding of the values.

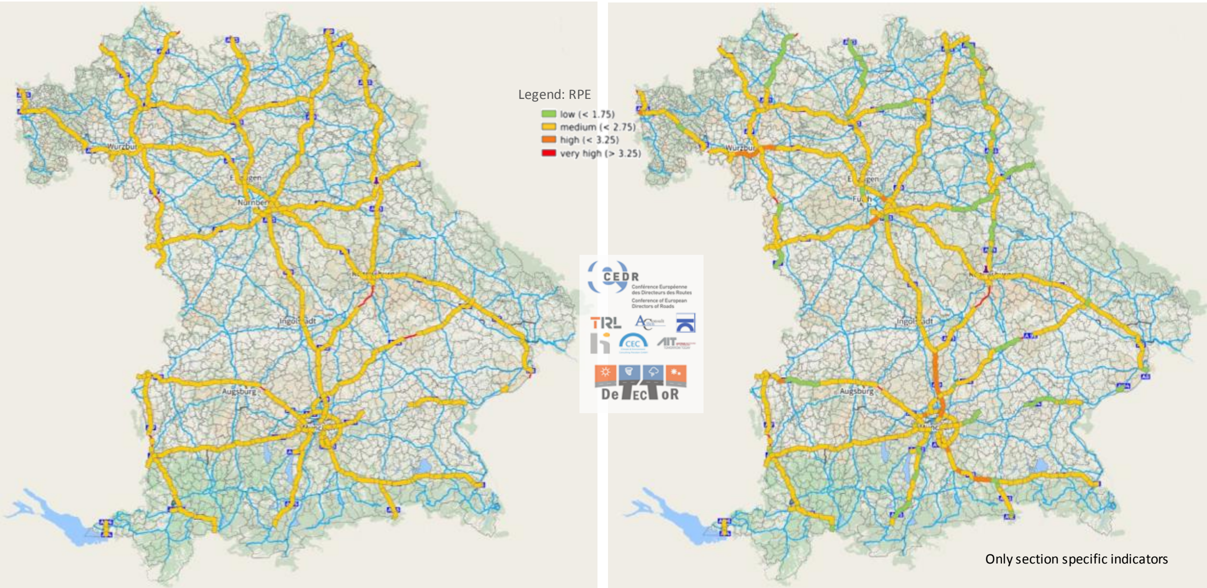


Figure 39: RPE-calculation result, map view networkwide (heat related damages and restrictions on asphalt road surfaces)

6.4.5 *oRP*

The final step of the risk assessment is the determination of the overall Risk Potential (oRP) – see chapter 4.1.1.5. The oRP-value is calculated by merging the Risk Potential of Hazard and the Risk Potential of Effects.

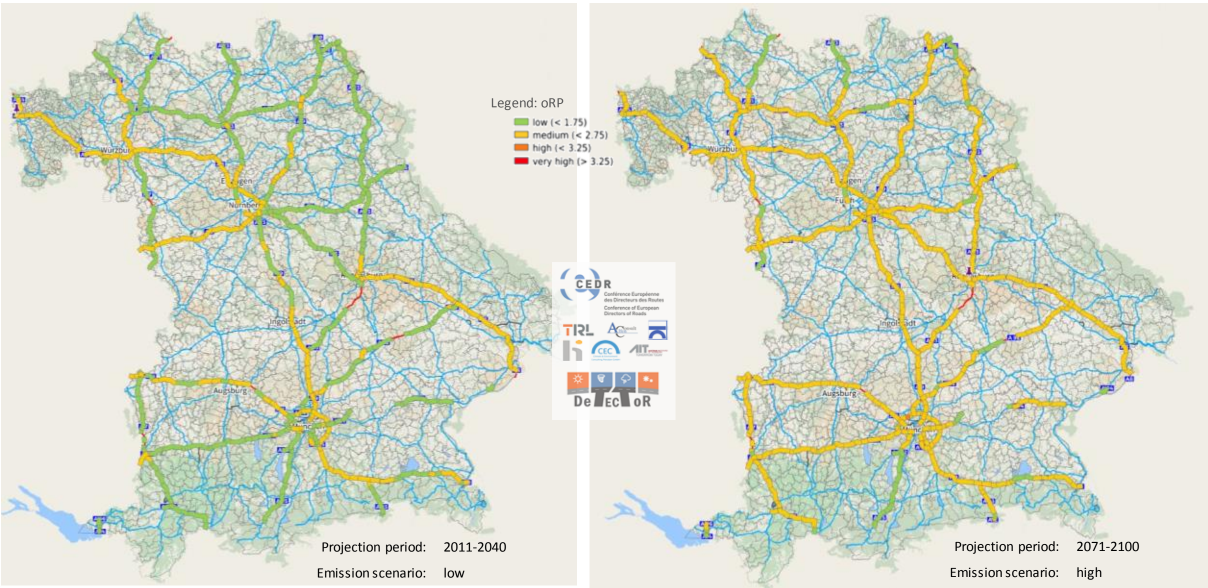


Figure 40: oRP-calculation result, map view network wide (heat related damages and restrictions on asphalt road surfaces)

Figure 40 shows the difference in the overall risk potential from the projection period 2011-2040 low emissions to the projection period 2071-2100 high emissions. The calculation includes only the section specific RPE indicators. The oRP for the period 2071-2100 is increased compared to the period 2011-2040 as a result of the higher CVC (see Figure 34) i.e. the change in climate.

The map showing the oRP enables the tool users to identify the assets at most from a particular type of hazard, and therefore where additional investigation is warranted. It also enables the user to see how climate change is likely to impact on the risk level and if any sections which are currently low risk, become medium risk. This helps the user to assess the sensitivity of the risk level to the projected climate change and to compare the magnitude of the change for different DPCs.

6.5 Results of the cost-benefit analysis

The results of the risk assessment are used in the CBA-calculation (see also chapter 4.2), so the CBA module can only be used after running the risk assessment module for the DPC of interest.

Before starting the calculation the user needs to enter values for a number of variables, using the CBA editor. These relate to indicative costs for different activities, national CBA requirements e.g. discount rates, typical traffic management procedures and details of the propose adaptation measures.

After the user has entered these values, the analysis is run. The calculations are performed for all sections and all climate projection periods. As explained in chapter 4.2 the option with the lowest costs (indirect and direct) for the relevant section is displayed on the network map (even there is only a very small advantage; this should be keep in mind when interpreting the results of the CBA-module).

The calculations are conducted for a 30 year appraisal period and include both direct and indirect costs. The direct costs considered are the costs of the operator (NRA) for regular reconstruction, repair (after a weather event damages the infrastructure), operation and maintenance. The indirect costs included are the delay costs, and costs associated with congestion and accidents.

Figure 41 shows an example of the results of the CBA-calculation. In the example Action 2 and Action 3 are the most cost-effective options for the next 30 years for a climate of the projection period 2011-2040. For the climate of the projection period 2071-2100 over 30 years Action 3 will be the most cost-effective option for the majority of the analysed sections.

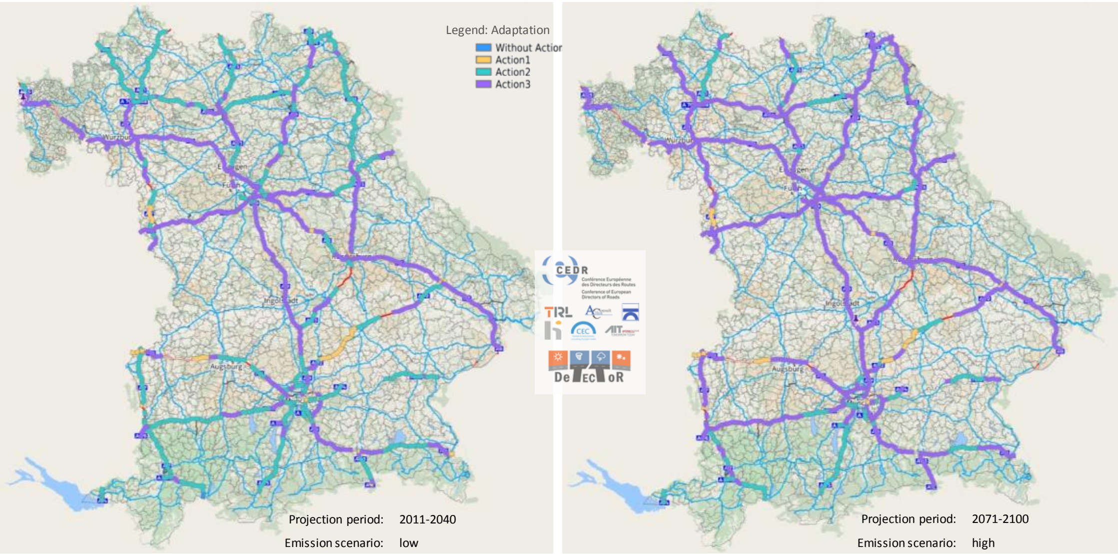


Figure 41: CBA-calculation result, map view network wide (heat related damages and restrictions on asphalt road surfaces)

The tool enables the user to both view the results of the network-wide analysis and to drill into the details of specific sections. This means that as a first step the user can identify the high-risk road sections and as a second step carry out CBA calculations for these identified sections.

7 Acknowledgements

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Appendix A: Manual for country specific adjustment of indicator thresholds

CEDR Transnational Road Research Programme
Call 2015: Climate Change: From desk to Road

funded by Germany, Netherlands, Ireland, Norway, Sweden and Austria

Decision-support Tools for Embedding Climate Change Thinking on Roads (DeTECToR)

Manual
Country specific adjustment of indicator thresholds

February, 2018

Prepared by TRL, AC, HI, IBDiM, CEC and AIT

With contributions from UBIMET and DWD

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CEDR Call 2015: Climate Change
DeTECToR
Decision-support Tools for Embedding Climate Change Thinking on Roads

Manual
Country specific adjustment of indicator´s thresholds

Start date of project: 01/09/2016 End date of project: 30/04/2019

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Version: 1, 15.02.2018

CEDR Conférence Européenne des Directeurs des Routes
Conference of European Directors of Roads

Table of contents

1 Introduction

The RIVA-methodology is based on a hierarchical indicator model using several indicators to ascertain climate risk. This document describes the indicators related to vulnerability and climate. These are combined with indicators relating to the consequences of a climate related damage/restrictions occurring to give the overall risk.
For each of these indicators thresholds for the value range 1 to 4 were be defined within the RIVA project for the use of the RIVA-pilot-tool for the Germany motorway network. Therefore, the thresholds have to be verified for the use in other countries and, if necessary, have to be adjusted to reflect differences in materials, design, collection of data etc..
The objective of this manual is to guide this process. Doing so, the assumptions of the determination/definition of the thresholds will be described as the basis for the adjustment.
In the following the vulnerability indicators and the climate indicators will be described for the selected damage pattern categories used in the DeTECToR pilot studies.

2 Adjustment of vulnerability indicators

2.1 DPC-01a Heat-related damages and restrictions at bridges (Germany, Austria)

DPC Description
Damages and restrictions at bridges caused by heat / high temperatures can be, for example:

- Exceeding of permissible longitudinal expansion
- Damage to bearing structures and superstructure

High temperatures can have different effects on bridge structures or substructures and superstructures, causing damage and ultimately reducing their life span. Heat-related damages can also be caused by rapid drops in temperature.

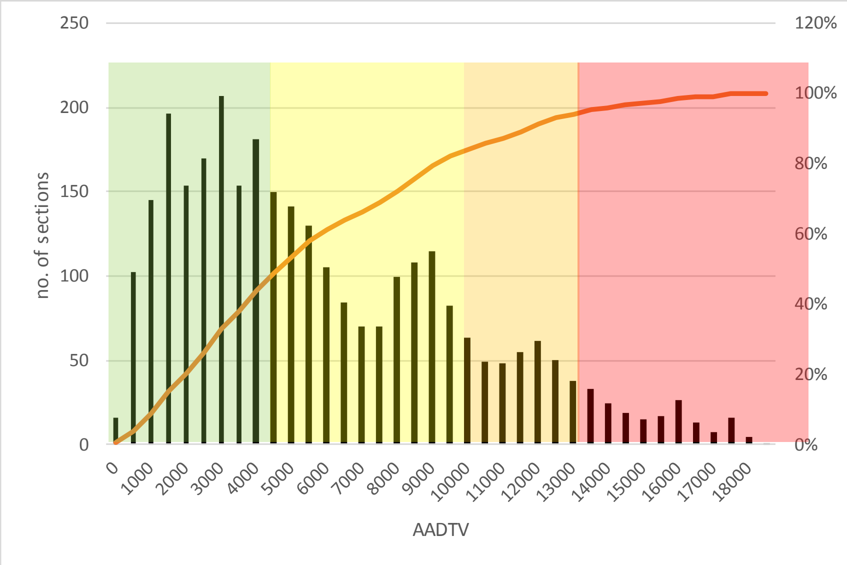
AADT-heavy vehicles
Description of the indicator
In generally, heavy goods vehicles lead to stress on the bridge structure (basic stress). Damage caused by the high temperatures can thus be intensified.
Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X < 4 000	4 000 ≤ X < 9 000	9 000 ≤ X < 12 000	12 000 ≤ X

Definition

- Regulation for the dimensioning of bridges
- Regulation for the recalculation of bridges

- Distribution within the network



Position (exposure)

Description of the indicator

Increased solar radiation (absorption) can intensify the impact of high temperature. For example, bridges on a southern slope are exposed to longer and more intensive solar radiation, which means that higher temperatures can occur on the structure than on a northern slope. Flat land is classified as "very high" in the same way as the southern slope.

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
Mountainous region and northern slope	Mountainous region and eastern slope	Mountainous region and western slope	Flat land or mountainous region and southern slope

Definition

Independent of country specific aspects

Material class

Description of the indicator

The deformation behaviour due to temperature stress is determined by the material class.

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
Wood	Concrete/ prestressed concrete	Composite-steel	steel

Definition

Independent of country specific aspects

Static system

Description of the indicator

The static system of a bridge can be either statically determined or indeterminate. The systems can react differently to temperature effects.

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
	Statically determinate	Statically indeterminate	

Definition

Independent of country specific aspects

Overall bridge condition index

Description of the indicator

The more a bridge is pre-damaged, the more vulnerable it is to further stress by high temperature.

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X<2	2≤X<2,5	2,5≤X<3,5	3,5≤X

Definition of the value of the condition index

- according to German regulations and according to DIN 1076 (RI-EBW-PRÜF)

Condition index	description
<2	good to very good condition
<2,5	satisfactorily condition
<3,5	sufficient or critical condition
≥3,5	insufficient condition

Year of bridge construction

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X≥2003	2003>X≥1985	X<1985	

Definition:

It is assumed that the consideration of new design regulations will result in a better dimensioning of the structures against to temperature stresses and thus in a longer lifespan.

- Generation of regulation
  - Prior to 1985: DIN 1072 without linear temperature gradient
  - 1985-2003: DIN 1072 introduction of temperature gradient,
  - since 2003: DIN-technical reports with advanced temperature stresses

2.2 DPC-01b Frost-related damages and restrictions at bridges (Germany, Austria)

DPC Description
Damages and restrictions at bridges caused by frost / low temperatures can be, for example:

- Brittle fractures on bridge superstructures and diffusers
- Cracks and spalling

AADT-heavy vehicles

See above chapter 2.1.

Position (exposure)

See above chapter 2.1.

Material class

See above chapter 2.1.

Statically system

See above chapter 2.1.

Overall bridge condition index

See above chapter 2.1.

Year of bridge construction

See above chapter 2.1.

2.3 DPC-01e Damages and restrictions at bridges caused by storm (Scotland)

DPC Description
Damages and restrictions at bridges caused by storm / strong wind can be, for example:

- Signs of fatigue
- Closure/restrictions to traffic

AADT-heavy vehicles

Description of the indicator

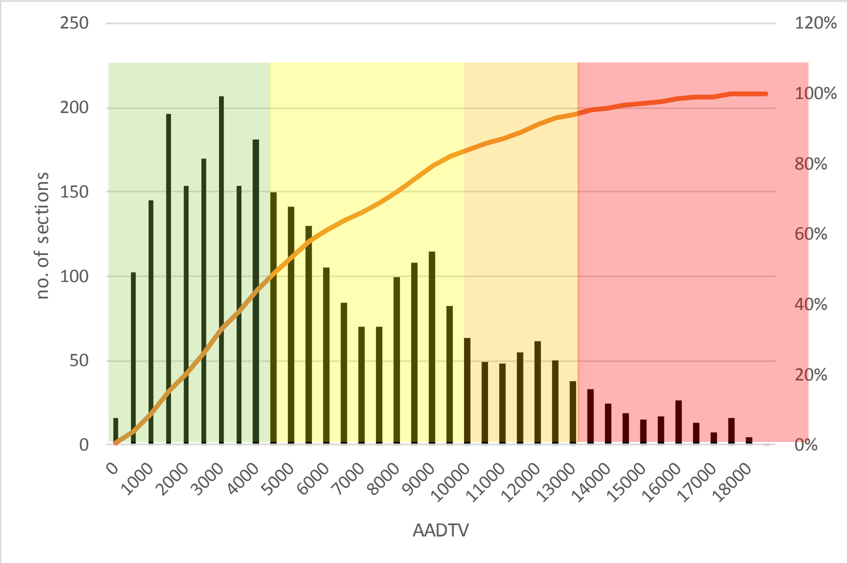
In generally, heavy goods vehicles lead to stress on the bridge structure (basic stress). Damage caused by the high temperatures can thus be intensified.

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X < 4 000	4 000 ≤ X < 9 000	9 000 ≤ X < 12 000	12 000 ≤ X

Definition

- Regulation for the dimensioning of bridges
- Regulation for the recalculation of bridges
- Distribution within the network



Overall bridge condition index

Description of the indicator

The more a bridge is pre-damaged, the more vulnerable it is to further stress by high temperature.

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X < 2	2 ≤ X < 2,5	2,5 ≤ X < 3,5	3,5 ≤ X

Definition of the value of the condition index

- according to German regulations and according to DIN 1076 (RI-EBW-PRÜF)

Condition index	description
<2	good to very good condition
<2,5	satisfactorily condition
<3,5	sufficient or critical condition
≥3,5	insufficient condition

Clearance (Height)

Description of the indicator

The higher a bridge, the stronger is the wind and therefore the higher is the stress caused by strong wind.

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X < 10m	10m ≤ X < 25m	25m ≤ X < 50m	50m ≤ X

Defined threshold values:

Expert approach

Superstructure

Description of the indicator

Increasing of the wind-exposed area at a bridge by noise protection wall. For this it is important the analyse whether the superstructure was already part of the dimensioning of the bridge or not (additional superstructure).

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
None superstructure	Superstructure considered by the dimensioning	Additional superstructure with minimal reduction of statically reserve	Additional superstructure with moderate reduction of statically reserve

Defined threshold values:

Expert approach

2.4 DPC-06a Heat-related damages and restrictions on the asphalt road surface (Germany, Austria)

DPC Description

High temperatures lead to a reduced viscosity of the asphalt, which can cause damages and restrictions, e.g. in the form of increased rut formation.

AADT-heavy vehicles

Description of the indicator

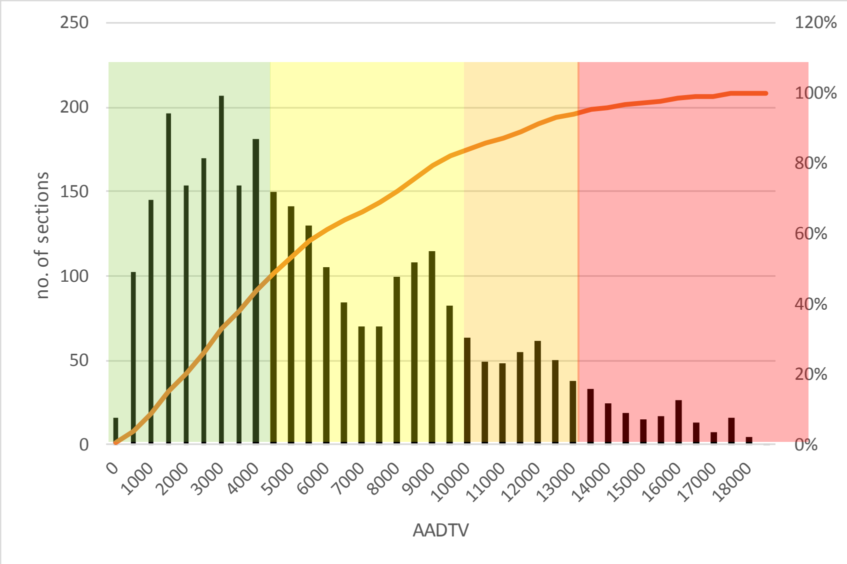
Damage or restrictions on asphalt pavement are caused in particular by the combined occurrence of high temperature and stress by heavy good vehicles. The sole occurrence of high temperature does not necessarily lead to damages on asphalt pavements. Indeed, this reduces the viscosity of the asphalt respectively the asphalt became softer, but it does not cause any damage on asphalt pavement. The softened asphalt can only be deformed by simultaneous stress by heavy good vehicles.

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X < 4 000	4 000 ≤ X < 9 000	9 000 ≤ X < 12 000	12 000 ≤ X

Definition

- The higher the heavy good vehicle traffic, the higher the stress.
- Distribution within the network



Position (exposure)

Description of the indicator

Increased solar radiation (absorption) can intensify the impact of high temperature. For example, asphalt pavements on a southern slope are exposed to longer and more intensive solar radiation, which means that higher temperatures can occur on the structure than on a northern slope. Flat land is classified as "very high" in the same way as the southern slope.

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
Mountainous region and northern slope	Mountainous region and eastern slope	Mountainous region and western slope	Flat land or mountainous region and southern slope

Definition

Independent of country specific aspects

Longitudinal slope

Description of the indicator

The speed of the traffic is lower on road sections with large gradients. This applies especially to heavy good vehicles. The lower speed leads to longer stress on the heated and softened asphalt pavement.

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X<2%	2%≤X<5%	5%≤X<7%	7%≤X

Definition

The higher the gradient of the slope, the lower the speed of heavy good vehicles and therefore the longer the stress.
Independent of country specific aspects

Cracks

Description of the indicator

The poorer the condition of the pavement the more vulnerable it is to further stress by high temperature.

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X<2	2≤X<3	3≤X<4	4≤X

Definition

- Note, Index 'ZWRISS' of the German regulation ZTV ZEB-StB

Layer type

Description of the indicator

For asphalt pavements different construction methods and bitumen types as well as different layer thicknesses are used. The choice of the bitumen type (layer type) influence the viscosity behaviour of the asphalt when temperature changes.

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
	PA (OPA), MA (GA)	SMA, AC (AB)	

Definition

- for the definition of the German indicator set, two categories of layer types depending on viscosity behaviour determined
- depends on country specific used layer types

Rut depth

Description of the indicator

The more the pavement is pre-damaged, the more vulnerable it is to further stress by high temperature. Already existing ruts leads to different thickness of the asphalt layer and leads to further cracks or damages on the asphalt pavement at high temperatures. In addition, existing ruts are a kind of 'guideline' for the traffic (lane driving traffic) and thus the stress of the already pre-damaged section is increased.

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X<4 mm	4≤X<7 mm	7≤X<10 mm	10≤X mm

Definition

- German regulation ZTV ZEB-StB

Thickness of asphalt layers

Description of the indicator

There is a correlation between resilience of the road structure and layer thickness. The thinner the asphalt pavement, the higher the stress of the underlying layer (without binder). Layer thickness means the sum of layer thicknesses of the top layer, binder layer and of the base layer.

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X ≥ 30 cm	30 > X ≥ 25 cm	25 > X ≥ 22 cm	X < 22 cm

Definition

- experience
- expert knowledge

2.5 DPC-06b Frost-related damages and restrictions on the asphalt road surface (Scotland, Germany, Austria)

DPC Description

Frost-related damages and restrictions on asphalt road surfaces are caused, for example, by the penetration of water into small cracks and the increase in water volume during freezing. In addition, low temperatures lead to an increase in the viscosity of the asphalt structure, which means that compressive stresses in the asphalt structure resulting from the increase in volume cannot be reduced and cracks or spalling can occur.

AADT-heavy vehicles

Description of the indicator

Damage or restrictions on asphalt pavement are caused in particular by the combined occurrence of low temperature and stress by heavy good vehicles. The sole occurrence of low temperature does not necessarily lead to damages on asphalt pavements. Indeed, this increases the viscosity of the asphalt respectively the asphalt became stiffer, but it does not cause any damage on asphalt pavement. The softened asphalt can only be deformed by simultaneous stress by heavy good vehicles.

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X < 4 000	4 000 ≤ X < 9 000	9 000 ≤ X < 12 000	12 000 ≤ X

Definition

- The higher the heavy good vehicle traffic, the higher the stress.

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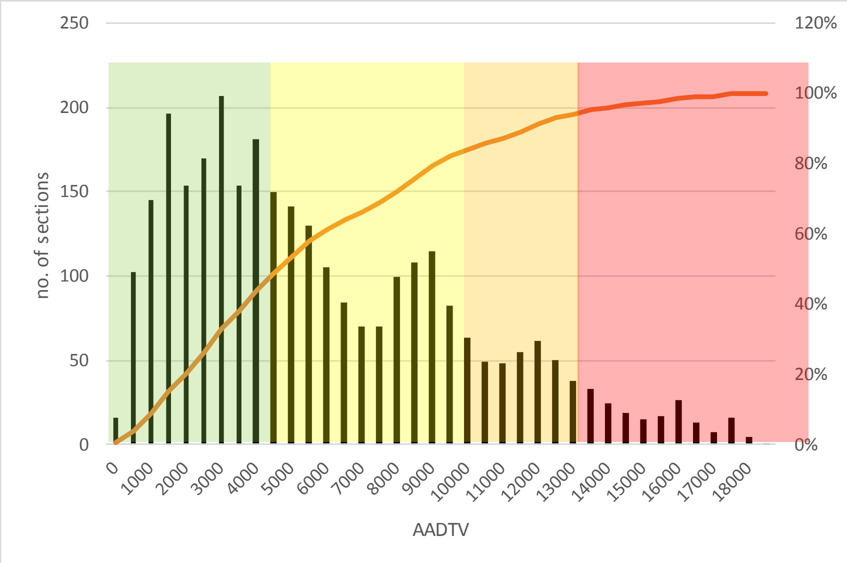
- Distribution within the network



Position (exposure)

Description of the indicator

Increased solar radiation (absorption) can reduce the impact of low temperature. For example, asphalt pavements on a southern slope are exposed to longer and more intensive solar radiation, which means that higher temperatures can occur on the structure than on a northern slope. Flat land is classified as "low" in the same way as the southern slope.

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
Flat land or southern slope	western slope	eastern slope	northern slope

Definition

Independent of country specific aspects

Cracks

Description of the indicator

The poorer the condition of the pavement the more vulnerable it is to water penetration.

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X<2	2≤X<3	3≤X<4	4≤X

Definition

- Note, Index 'ZWRISS' of the German regulation ZTV ZEB-StB

Layer type

Description of the indicator
For asphalt pavements different construction methods and bitumen types as well as different layer thicknesses are used. The choice of the bitumen type (layer type) influence the viscosity behaviour of the asphalt when temperature changes.

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
	PA (OPA), MA (GA)	SMA, AC (AB)	

Definition
- for the definition of the German indicator set, two categories of layer types depending on viscosity behaviour determined
- depends on country specific used layer types

Age

Description of the indicator
Change of material characteristics with increasing age, for example reduced viscosity.

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X < 5 years	5 ≤ X < 15 years	15 ≤ X < 25 years	25 ≤ X years

Definition
- experience
- expert knowledge

Mends / Patches

Description of the indicator
The materials of patches differ from the origin asphalt pavement. The different materials have different thermal characteristics. In addition, insufficient bonding with the origin pavement facilitate the penetration of water, which freezes at lower temperatures.

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X < 2%	2% ≤ X < 6%	6% ≤ X < 10%	10% ≤ X

Definition
- German regulation ZTV ZEB-StB

Thickness of asphalt layers

Description of the indicator

There is a correlation between resilience of the road structure and layer thickness. The thinner the asphalt pavement, the higher the stress of the underlying layer (without binder). Layer thickness means the sum of layer thicknesses of the top layer, binder layer and of the base layer.

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X ≥ 30 cm	30 > X ≥ 25 cm	25 > X ≥ 22 cm	X < 22 cm

Definition

- experience
- expert knowledge

2.6 DPC-07a Heat-related damages and restrictions on the concrete road surface (Germany, Austria)

2.7

DPC Description

High temperatures lead to constrained stresses on concrete pavements as a result of expansion processes. The expansion can be so large that blow-ups occur. Blow-ups occur when two concrete slabs press against each other so strongly due to their respective expansion that they break open in the joint area.

AADT-heavy vehicles

Description of the indicator

In generally, heavy goods vehicles lead to stress on the concrete pavement (basic stress). Damage caused by the high temperatures can thus be intensified.

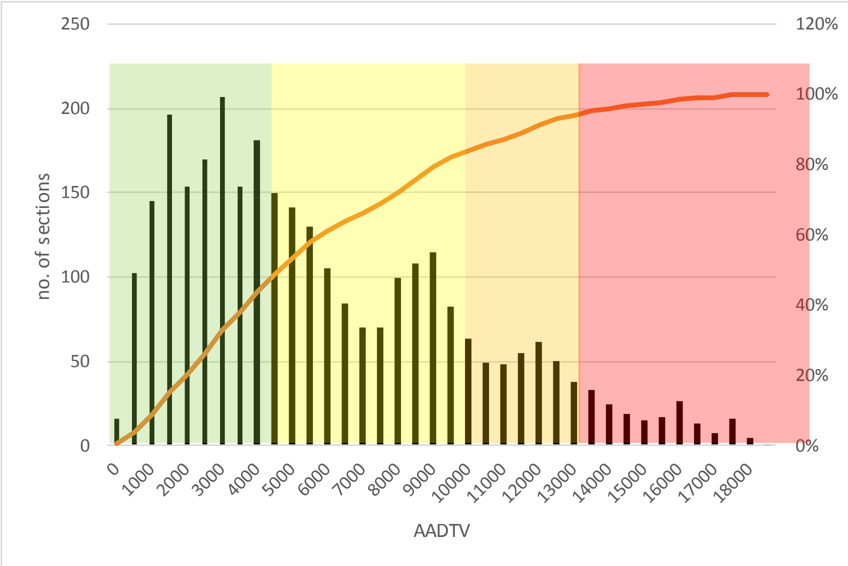
Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X < 4 000	4 000 ≤ X < 9 000	9 000 ≤ X < 12 000	12 000 ≤ X

Definition

- The higher the heavy good vehicle traffic, the higher the stress.

- Distribution within the network



Longitudinal slope
See above chapter 2.4.

Position (Exposure)
See above chapter 2.4.

Structural Condition Index
The more a concrete pavement is pre-damaged, the more vulnerable it is to further stress by high temperature.

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X<2	2≤X<3	3≤X<4	4≤X

Definition

- German regulation ZTV ZEB-StB

Patched spots, partial replacements with asphalt
Description of the indicator
The materials of patched spots differ from the origin concrete pavement. The different materials have different thermal characteristics.

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X≥5%	5%>X≥10%	10%≤X<15%	15%<X

Definition

- German regulation ZTV ZEB-StB

Voids / Spalling

The poorer the condition of the pavement, the more vulnerable it is to further stress by high temperature.

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X ≥ 5%	5% > X ≥ 10%	10% ≤ X < 15%	15% < X

Definition

- German regulation ZTV ZEB-StB

Thickness of concrete layers

Description of the indicator

There is a correlation between resilience of the road structure and layer thickness. The thinner the concrete pavement, the higher the stress of the underlying layer (without binder). Layer thickness means the sum of layer thicknesses of the top layer and of the base layer.

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X ≥ 60 cm	60 > X ≥ 50 cm	50 > X ≥ 40 cm	X < 40 cm

Definition

- experience
- expert knowledge

2.8 DPC-07b Frost-related damages and restrictions on the concrete road surface (Germany, Austria)

DPC Description

Frost-related damages and restrictions on concrete road surfaces are caused, for example, by the penetration of water into small cracks and the increase in water volume during freezing which can lead to spalling.

AADT-heavy vehicles

See above chapter 2.6.

Longitudinal slope

See above chapter 2.6.

Position (Exposure)

Description of the indicator

Increased solar radiation (absorption) can reduce the impact of low temperature. For example, asphalt pavements on a southern slope are exposed to longer and more intensive solar radiation, which means that higher temperatures can occur on the structure than on a northern slope. Flat land is classified as "low" in the same way as the southern slope.

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
Flat land or mountainous region and southern slope	Mountainous region and western slope	Mountainous region and eastern slope	Mountainous region and northern slope

Definition

Independent of country specific aspects

Structural Condition Index

See above chapter 2.6.

Patched spots, partial replacements with asphalt

See above chapter 2.6.

Voids/Spalling

See above chapter 2.6.

Thickness of concrete layers

See above chapter 2.6.

3 Adjustment of climate indicators

3.1 DPC-01a Heat-related damages and restrictions at bridges (Germany, Austria)

Number of hot days (TX>30°C) - increase compared to current climate period

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X<0	0≤X<5	5≤X<10	10≤X

Definition

Depends on the current number of hot days.

Maximum temperature [Tmax in °C]

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X<37°C	37°C≤X<40°C	40°C≤X<43°C	43°C≤X

Definition

Reference has been made to the Euro-code for the derivation of the thresholds. Within the Euro-code a maximum temperature of 37°C is assumed for the temperature stress. Accordingly, 37°C is classified as "low" and a temperature of more than 43°C is classified as "very high".

Maximum daily spread [K] TX and TN per year – change compared to current period

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X<-25%	-25%≤X<0%	0%≤X<25%	25%≤X

Definition

- experience
- expert knowledge

Maximum daily temperature [Tmax in °C]

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X<37°C	37°C≤X<40°C	40°C≤X<43°C	43°C≤X

Definition

Reference has been made to the Euro-code for the derivation of the thresholds. Within the Euro-code a maximum temperature of 37°C is assumed for the temperature stress. Accordingly, 37°C is classified as "low" and a temperature of more than 43°C is classified as "very high".

Number of hot days with PR>20 mm (temperature drop)

The combination of hot days and strong rainfall events leads to heavy temperature drops and thus to thermal stress.

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X<0,1	0,1≤X<0,2	0,2≤X<0,3	0,3≤X

Definition

- depends on the current climate period

3.2 DPC-01b Frost-related damages and restrictions at bridges (Germany, Austria)

Maximum spread [K] TX and TN per year
see above chapter 3.1.

Minimum daily temperature [Tmin in °C]
Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X ≥ -20°C	-20°C > X ≥ -24°C	-24°C > X ≥ -28°C	X < -28°C

Definition
Reference has been made to the Euro-code for the derivation of the thresholds. Within the Euro-code a minimal temperature of -24°C is assumed for Germany. Accordingly, -24°C is classified as "medium" and a temperature of lower than -28°C is classified as "very high". A temperature of more than -20°C is classified as "low", in order to consider the expected reduction of low temperature of the projections.

Number of frost days [d] per year – change compared to current climate period
Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X < -15	-15 ≤ X < 0	0 ≤ X < 15	15 ≤ X

Definition
Depends on the current number of frost days.

3.3 DPC-01e Damages and restrictions at bridges caused by storm (Scotland)

Not defined in the RIVA project.

It is assuming, that a bridge is designed for the individual wind situation, then the change of the intensity of the wind should an indicator and the number of days with strong wind.

Change (%) of wind speed compared to 1971-2000
Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X < 20%	20% ≤ X < 35%	35% ≤ X < 50%	50% ≤ X

Definition
- experience
- expert knowledge

Change (%) of number of days with strong wind
Strong wind above a defined threshold for wind speed
Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X<20%	20%≤X<35%	35%≤X<50%	50%≤X

Definition

- experience
- expert knowledge

3.4 DPC-06a Heat-related damages and restrictions on the asphalt road surface (Germany, Austria)

Number [n] of hot days [d] per year
Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X<10	10≤X<20	20≤X<30	30≤X

Definition
Depends on the current climate period (current value is classified as "medium")

Number [n] of summer days [d] per year
Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X<35	35≤X<50	50≤X<65	65≤X

Definition
Depends on the current climate period (current value is classified as "medium")

Number of [n] heat waves per year
Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X<1	1≤X<2	2≤X<3	3≤X

Definition
Depends on the current climate period (current value is classified as "medium")

Number [n] of tropical nights per year
Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X<1	1≤X<3	3≤X<5	5≤X

Definition
Depends on the current climate period (current value is classified as "medium")

Maximum daily temperature [Tmax in °C]
Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X<33°C	33°C≤X<37°C	37°C≤X<41°C	41°C≤X

Definition
Depends on the current climate period (current value is classified as "medium")

3.5 DPC-06b Frost-related damages and restrictions on the asphalt road surface (Germany, Austria, Scotland)

Number [n] of frost days [d] per year
Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X<10	10≤X<20	20≤X<40	40≤X

Definition
Depends on the current climate period (current value is classified as "medium")

Change (%) number of frost days per year against 1971-2000
Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X<20%	20%≤X<35%	35%≤X<50%	50%≤X

Definition
- experience
- expert knowledge

Number [n] of Ice days [d] per year
Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X<5	5≤X<10	10≤X<20	20≤X

Definition
Depends on the current climate period (current value is classified as "medium")

3.6 DPC-07a Heat-related damages and restrictions on the concrete road surface

Number [n] of hot days [d] per year
See above chapter 3.4.

Number [n] of summer days [d] per year
See above chapter 3.4.

Number [n] of heat-periods per year
See above chapter 3.4.

Number [n] of tropical nights per year
See above chapter 3.4.

Maximum daily temperature [Tmax in °C]
See above chapter 3.4.

3.7 DPC-07b Frost-related damages and restrictions on the concrete road surface (Germany, Austria)

Number [n] of FTA-days [d] per year
Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X < 30	30 ≤ X < 40	40 ≤ X < 50	50 ≤ X

Definition
Depends on the current climate period (current value is classified as "medium")

Number [n] of frost days [d] per year
Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X < 10	10 ≤ X < 20	20 ≤ X < 40	40 ≤ X

Definition
Depends on the current climate period (current value is classified as "medium")

Change (%) of frost days number compared to 1971-2000
Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X < 20%	20% ≤ X < 35%	35% ≤ X < 50%	50% ≤ X

Definition

- experience
- expert knowledge

Number [n] of ice-days [d] per year

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X<5	5≤X<10	10≤X<20	20≤X

Definition

Depends on the current climate period (current value is classified as "medium")

number of days [d] within a frost-period (TM < -5°C) per year

Defined threshold values:

Low	Medium	High	Very high
1	2	3	4
X<4	4≤X<8	8≤X<12	12≤X

Definition

Depends on the current climate period (current value is classified as "medium")

Appendix B: Manual for country specific cost data provision

CEDR Transnational Road Research Programme
Call 2015: Climate Change: From desk to Road

funded by Germany, Netherlands, Ireland, Norway, Sweden and Austria

Decision-support Tools for Embedding Climate Change Thinking on Roads (DeTECToR)

Manual
Country specific cost data provision

August, 2018

Prepared by TRL, AC, HI, IBDiM, CEC and AIT

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CEDR Call 2015: Climate Change
DeTECToR
Decision-support Tools for Embedding Climate Change Thinking on Roads

Manual
Country specific cost data provision

Start date of project: 01/09/2016 End date of project: 31/08/2018

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Table of contents

1 Introduction CBA module

The DeTECToR-Analysis Tool consists of two modules; the risk assessment module which provides information on the level of risk for different time periods and emission scenarios; and the CBA module which compares the costs of different adaptation options and a “no adaptation” option. The CBA module is described in detail in DeTECToR-deliverable 5.1 (Interim Report 2). The CBA module will be implemented in the DeTECToR-Analysis tool. For the description of the risk-assessment module see DeTECToR-deliverable 5.1 (Interim Report 2).

Within the cost-benefit analysis direct costs and indirect costs will be calculated. However, it should be noted that the benefits will be expressed as a reduction in indirect costs and the differences between the different options/measurements compared in the CBA-module. Direct costs are the costs incurred by the NRA such as (re)construction costs, repair costs and the initial costs of implementing the adaptation actions and additional operation/maintenance costs of adaptation action. The indirect costs are the costs associated with increased journey times, accidents, and congestion during and after a climate event (see also the 5 stages of the temporal sequence of socio-economic evaluation of a "network problem" described in ROADAPT Guidelines Part D – socioeconomic impact assessment). The optimal solution in terms of cost-benefit analysis is the one with the lowest sum of direct and indirect costs over the appraisal period. The calculation is based on the risk potential of hazard calculated in the risk module and the cost information and criteria provided by the NRA (for further information see deliverable 5.1).

It should be noted that the DeTECToR-Analysis tool will provide indicative costs for the specified options selected by the user. A significant number of assumptions and estimations are made in the calculations, so the results cannot be taken as an accurate costing. This document will give recommendations how to define these assumptions and estimations.
The CBA-module reflects the lifecycle of the asset/elements. Depending on the lifespan of an asset/element several lifecycle periods can occur during the analysis period. Therefore, costs are calculated on an annual basis and assume a development of lifecycle depending on changing vulnerability indicators (used for the calculation of Risk Potential of Hazard (RPH)). Hence, the RPH-value increases during a life cycle as the condition deteriorates and the asset becomes more vulnerable to climate change impacts and decreases when a routine renewal of the asset is performed. The RPH-value affects the cost calculation in two ways. Firstly, the initial lifespan (provided by the NRA) is reduced depending on the RPH value to account for the impact of climate. In principle, it is assumed that climate events have a negative effect on the lifespan of an asset/element. The extent of lifespan reduction is an exponential function of RPH-value. This is used for the calculation of the reduced lifespan and for the depreciation of reconstruction costs, as well as of the calculation of the indirect costs during reconstruction sites at the end of a lifecycle.
Secondly, the RPH value is used to estimate the annual occurrence that a climate event leads to damages or interruptions. The Level of Occurrence used is a function of the RPH-value. The Level of Occurrence influences both repair/restoration costs after a climate event (direct costs) and indirect costs such as monetarised costs of additional journey times as a result of the event.

The annual discounted direct and indirect costs are added up separately (net present value). The total sum of the discounted direct and indirect costs is being presented to the user for each of the three climate projection periods. Furthermore, results are shown for RPH-value related quartile areas of the investigated section of the network in order to give the NRA the possibility to choose – if appropriate – different adaptation measure depending on both the vulnerability respectively the hazard potential (RPH) and the climate projection period (near and/or far future). The results will be presented to the user in an appropriate way as relative value to the no adaptation variant.

The representational document gives an overview of the assumption / estimations needed for the calculation within the CBA-module. Some of these assumption / estimations were determined by the DeTECToR research team due to the lack of further information. Other assumptions were based on available sources or based on the expertise of the DeTECToR research team. During the pilot study phase these assumption / estimations will be discussed with the NRAs.

The objective of this manual is to guide the discussions with the pilot study NRAs by providing an explanation of the assumptions related to cost, highlighting the types of cost information required and providing a basis for discussions with the NRAs.

2 Risk potential of hazard related assumptions

2.1 Reduction of lifespan function

In principle, it is assumed that climate change will have a negative effect on the lifespan of an asset/element. However, in this context it should be noted, that not every single climate event leads to a collapse or failure of the asset, rather it is a gradual process, where climate events with a smaller extend means only that the asset/element will be stressed. The extend/impact of a climate event is described in the RIVA-methodology as Risk potential of hazard. Therefore, it is assumed that the extent of lifespan reduction could be described as a function of the Risk Potential of Hazard - RPH-value. The RPH is a result of the combination of climate (projection) data[2] and vulnerability data[3] of the asset. The RPH-value can have an assume range of values between 1 and 4. The higher the RPH-value the higher the effect/impact of the climate event on the asset/element. Furthermore, the authors of this report assume that low RPH-values do not affect the asset. On the other side, the authors assume, that a RPH-value of 4 leads to a collapse/failure of the asset/element, and consequently to a lifespan reduction of 100%. An exponential function will describe this in the best way. The influence of different power-values of the exponential function shows **Figure 4**. Based on this,

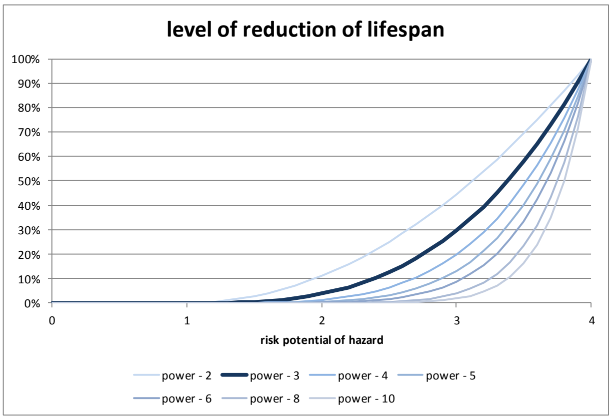

Figure 42: Reduction of lifespan as a result of climate change

[2] Calculated as the combination value of climate (CVC), which merges all the information of the dimension climate for a damage pattern category of the considered asset. The combination value of climate is determined through the aggregation of the individual assessments of climate indicators for the period under consideration and can assume a value between 1 and 4.
[3] Calculated as the combination value of vulnerability (CVV), which merges all information of the dimension vulnerability for a damage pattern category of the considered asset / element. The combination value of vulnerability is determined through the aggregation of the individual assessment of the vulnerability indicators and can have an assume range of values between 1 and 4.

the authors suggest a power value of 3, with very slightly increasing lifespan reduction values above a RPH-value of 1.5, and stronger increasing values above a RPH-value of 2.5.
It could also be possible that the power-value of the exponential function depends on the type analysed asset/element. However different power-values for the exponential function for the different damage pattern categories or assets/elements leads may not produce comparable results. Hence, one power-value for all damage pattern categories must be defined. The authors suggest a power-value of 3.

These assumptions will be discussed during the pilot-study phase. The project consortium proposes to calculate scenarios with different power-values, to analyse the influence of these and confirm the selected scenario is sensible with the NRAs.

2.2 Level of occurrence function

In the risk assessment module the RPH-value is calculated for climate projection periods of 30 years, i.e. not for each single year of the projections periods but as one value for the whole per period. However, the calculation within the CBA-module needs to be done on an annual basis. Therefore, the periodical results of the risk assessment have to be interpreted/transferred to an annual value representing the likelihood of an event occurring. This was done by defining a level of event occurrence for a period of 10 years and setting an RPH-value of 4 to correspond to an occurrence of the climate event of one times per ten years.

For the calculation of the occurrence of a climate event per 10 years an exponential function is used.

Similar to the approach described in Section 1.1 the following assumptions are made for the exponential function. It has a power value of 4 and at a RPH-value of 4 the occurrence-value is 10. This means that there is a probability of occurrence of 100% within 10 years, if over the entire 10 years period the RPH-value is 4. In a comparison to the power-value of the exponential function for the lifespan reduction a higher power-value is suggested by the authors. The reason behind this is, that the function of the reduction of lifespan shall consider the gradual process (see above), whereas the function of the level of occurrence shall represent the occurrence of an event which could leads to a failure.

These assumptions will be discussed during the pilot-study phase. The project consortium proposes to calculate scenarios with different power-values, to analyse the influence of these and confirm the selected scenario with the NRAs.

3 Traffic related assumptions (indirect costs)

3.1 Introduction into the assessment of indirect costs

As the suggested in the *ROADAPT Guidelines Part D – socioeconomic impact assessment* the different stages of the temporal sequence of socio-economic evaluation of a "network problem" should be considered. The Guidelines Part D divided the temporal sequence into the following 5 stages:

- Stage 1 - Initial situation before the event: network is operating normally before the event occurs.

- Stage 2 - Occurrence of the traffic event: network problem occurs, but no action has yet been implemented by the operating organisation. Vehicles continue to arrive on the scene of the incident:
- Stage 3 - Managing the problem. It is the situation after taking direct response measures. Emergency services and operators are involved for the return to a temporary situation with degraded conditions.
- Stage 4 - Operation in degraded conditions: take operational measures in order to return to initial stage, during which traffic conditions are deteriorated. The network is operating in a degraded mode for a certain period.
- Stage 5 - End of the incident: back to the initial situation. (Stages 1 and 5 are identical).

Since the CBA-module calculates additional direct and indirect cost stages 1 and 5 are not relevant within the calculation. Therefore, the CBA-module considers traffic interruptions during the climate event and after the event until the reason for the traffic interruption is removed as well as during the work to repair the damage caused by the event.
The CBA-module calculates indirect costs caused by:

- prolongation of the journey time,
- congestion, and
- accidents.

3.1.1 *Loss of journey time after climate event*

Traffic disruption leads to longer journey durations, and therefore to time losses for the road users. The delay time is calculated separately for passenger cars and for heavy good vehicles (HGVs). In the first step the average days of disruption per annum as function of the Level of Occurrence (see 2.2) are determined, in order to calculate the time losses in hours per year for HGVs and passenger cars. In order to calculate the journey time losses further assumptions are need e.g. regarding the average of number of days of an interruption caused by a climate event (which could be DPC-specific), the normal average speed and the average speed reduction.

The time losses are calculated as differences in journey time with and without traffic interruptions.

The approach includes delay costs as a result of speed reduction and/or partly lane closure and not just the complete closure of the section.

3.1.2 *Loss of journey time during regular reconstruction*

Traffic interruption also occurs during the regular reconstruction at the end of the lifecycle. The time losses are calculated separately for passenger cars and for HGVs. Firstly, the days of interruptions per annum are determined, in order to calculate the time losses in hours per year for HGV and passenger cars. The interruption caused by reconstruction occurs only in the last year of a life cycle period.

An assumption of the average days need for reconstruction is required for the calculation. The time losses will be calculated as differences in journey time with and without traffic interruptions. For the calculation it is assumed that traffic interruptions mean only speed reduction and/or partly lane closure and not the closure of the section.

3.1.3 *Costs of loss of journey time*

After ascertaining the time losses caused by climate and / or reconstruction the indirect costs of these time losses are be calculated. The time losses per year are summarised; and this sum multiplied with the time cost rates (standard costs approach).
Different time cost rates are considered for HGV and for passenger cars.

3.1.4 *Congestion costs*

Congestion costs (as part of indirect costs) will be calculated as a function of the days with traffic interruption both caused by reconstruction works or after a climate event. The days of interruption per year are summarised; and this sum multiplied with the congestion cost rates (standard costs approach).

One congestion cost rate is considered for HGV and for passenger cars.

3.1.5 *Accident costs*

Traffic interruptions leads to a higher possibility of accidents. This type of accidents costs (as part of indirect costs) are be calculated as a function of the days with traffic interruption caused by both reconstruction-works or after climate event. The days of interruption per year are summarised; and this sum multiplied with the accidents cost rates (standard costs approach).

One accident cost rate is considered for HGV and for passenger cars.

In addition to this, accident costs caused during the climate events are be considered. The annual average level of occurrence is used for the calculation. The accident cost rate depends on the DPC-specific kind of accidents.

3.1.6 *Aggregation of indirect costs*

For the comparison of the different adaptation measures and these with the 'do nothing strategy' the annual indirect costs (calculated as described above) are discounted and aggregated.

3.2 Number of days of traffic interruption after event

Traffic disruption leads to longer journey durations, and therefore to time losses for the road users. The delay time is calculated separately for passenger cars and for heavy good vehicles (HGVs). In the first step the average number of days of disruption per annum as function of the Level of Occurrence (*see chapter 2.2*) is determined, in order to calculate the time losses in hours per year for HGVs and passenger cars. This requires assumptions to be made on the average number of days of an interruption that are caused by a specific climate event. This needs to be defined for each damage pattern category.

The determination of the number of days shall consider not only the average duration of such a climate event but also the duration for investigations and repair works (in addition to the planned reconstruction at the end of a life cycle period – see below). Therefore, the number of days will be vary for the different damage pattern categories, since the number of days depends on the asset/element affected, the damage inflicted, type of traffic interruption (partial or total closure, speed restriction etc.) and the climate event.

As part of the pilot studies we need estimates from the NRAs on the average number of days for traffic interruption for each climate event being considered. Please note, that some climate events for example storms may not lead (immediately) to infrastructure damage, but will only result in traffic delay.

3.3 Days for reconstruction

Within the CBA-module regular reconstructions at the end of an asset lifecycle are considered. During the regular reconstruction traffic interruptions occur. Therefore, the general duration of regular reconstruction sites have to be ascertained.

The definition of the number of days for traffic interruption in case regular reconstruction sites should made in relation of the length – such as Number of days per kilometre or metre depending on the kind of asset/element. The basis for this is the engineering expertise and should discussed during the pilot studies.

How many days takes a construction for example on road surfaces to rebuild one kilometre? Please consider here only the construction site itself and do not include the planning phase.

3.4 Average speed heavy goods vehicles

The normal average speed of heavy goods vehicles without interruption is needed for the calculation of time losses as reference value in comparison for the average speed in case of interruption (during regular reconstruction and in case of climate event). The basis for the determination is the speed limit on the section.

For example in Germany the general speed limit on the trunk road network for heavy goods vehicles is 80km/h and in UK 90km/h (60miles/h).

What is the average speed of heavy goods vehicles for the analysed road section? Do you have a data base for speed limit on the road section?

3.5 Reduction of speed limit for HGV

In case of construction sites a speed limit on the section is implemented. In general, the speed limit is determined by regulations. For example in Germany the majority of construction sites have a speed limit of 80km/h or sometimes 60km/h. For constructions sites in the UK 50 miles/hr (80km/hr) is most common. Therefore, the authors assume only slightly speed reduction in case construction for heavy goods vehicles. However, the speed reduction is country specific, so that it should be discussed during the pilot studies.

What is the average speed of heavy goods vehicle for the analysed road section in case of restricted traffic routing because of a construction site on the road?

3.6 Average speed passenger cars

The normal average speed of passenger cars without interruption is need for the calculation of time losses as reference value in comparison for the average speed in case of interruption (during regular reconstruction and in case of climate event). The basis for the determination is the speed limit on the section. For example in Germany, many sections of the trunk road network are without any speed limit for passenger cars. However, because of the traffic volume and other cars or heavy goods vehicle an average driving speed of 120km/h is assumed. Exceptions were made, where a speed limit exists. In the UK, the maximum speed limit on the trunk road network is 70miles/hr (109km/h) and some sections may have lower speed limits.

What is the average speed of passenger cars for the analysed road section? Do you have a data base for speed limit on the road section?

3.7 Reduction of speed limit for passenger cars

In case of construction sites a speed limit on the section is implemented. In general, the speed limit is determined by regulations. For example in Germany in the majority of construction sites the speed limit is 80km/h and sometimes 60km/h. For constructions sites on the UK trunk road; 50miles/h (80km/h) is most common. Therefore, in comparison to the original speed of passenger cars without construction sites the authors assume a moderate speed reduction. However, the speed reduction is country specific, so that it should be discussed during the pilot studies.

What is the average speed of passenger cars for the analysed road section in case of restricted traffic routing because of a construction site on the road?

3.8 Time costs passenger cars

In order to assess the indirect costs, time costs for passenger cars are needed. The time costs were multiplied with the time losses based on the assumption above.

In general, in European countries, cost benefit analyses are conducted during the planning process of new roads or extension of existing roads. These analyses based on country specific methodologies, approaches and assumptions. The times costs will differ from one country to another because of the different gross domestic product and will change over time.

For example, in Germany the German Federal Transport Plan set assumptions for the time costs for passenger cars and in the UK this is provided in the government's Transport Appraisal Guide (WebTAG). Other European countries prepare also transport plans comparable to the Germany Federal Transport Plan. Such assumptions (e.g. share of commercial traffic, time costs, occupation ration per car) can be used to derive time cost rates for passenger cars [for the German pilot study – 15.06 EUR/(h*car) | for the Scotland pilot study – 14.00 EUR/(h*car) (£11.97)].

What values you use for cost benefit analysis during the planning process of new roads or for the extension of existing roads, in order to calculate the benefit of time savings of the users?

3.9 Time costs heavy goods vehicles

In order to assess the indirect costs, time costs for heavy goods vehicles are needed. The time costs were multiplied with the time losses based on the assumption above.
In general, in European countries, cost benefit analyses are conducted during the planning process of new roads or extension of existing roads. These analyses based on country specific common methodologies, approaches and common assumption. However, the assumptions differ from one country to another because of the gross domestic product.
For example, in Germany the German Federal Transport Plan set assumptions for the time costs for heavy goods vehicles and in the UK this is provided in the government's Transport Appraisal Guide. Other European countries prepare also transport plans comparable to the Germany Federal Transport Plan. Such assumptions (time costs) can be used to derive time cost rates for heavy goods vehicles [for the German pilot study – 34.00 EUR/(h*car) | for the Scotland pilot study – 18.63 EUR/(h*car) (£15.92)].

What values you use for cost benefit analysis during the planning process of new roads or for the extension of existing roads, in order to calculate the benefit of time savings of the users?

3.10 Mean (additional) accident cost rate [interruptions]

The mean (additional[4]) accident cost rate is used for the assessment of the costs of accidents both in case of construction sites of reconstruction works as well as in case of climate events. Therefore, it is multiplied by the number of days of interruption due to reconstruction works as well as in case of the climate event.

Within the German Federal Transport Plan assumptions for accident cost rates are made. However, these assumptions count only for roads without traffic interruption caused by construction sites. Therefore, for the German pilot study, the assumption for the cost rate for additional accident in case of construction sites based on a research work for construction sites within the German trunk road network: economic feasibility analysis of temporary traffic routes at motorway.[5] Based on this, an average value of 7.10 €/1000 cars/km/event for (additional) accidents cost in case of construction sites is derived for the German pilot study.

To assess such a (additional) cost rate, we need information about:

- **accident cost rates for various severity of accidents on trunk roads**
- **the average number of accidents per 1,000 cars for various severity of accidents with and without roadworks on trunk roads**

[4] Additional to those which are estimated for the road without construction sites.
[5] Fischer, Wirtschaftlichkeitsuntersuchungen von Behelfsverkehrsführungen an Autobahnquerschnitten unter Berücksichtigung der Querschnittsabmessungen, Dissertation, Bauhaus-Universität Weimar, 2009, S. 111

3.11 Mean (additional) accident costs per accident

The mean (additional[6]) cost per accident is used for the assessment of the costs of accidents in case of climate event. The costs are multiplied with the Level of occurrence. Therefore, these costs consider only the accidents which occurs immediately during the climate event. However, the value depends on the severity of accidents. For example, in case of DPC damages or restriction on concrete surfaces it is assumed, that the severity of an accident is high. Therefore, a mean value of costs for fatal and serious injury accidents is used.
For the German pilot study, the assumption for the accident cost is based on a research work of the BASt: Economic costs of traffic accidents in Germany, 2010.[7]

To assess such a (additional) cost rate, we need information about:

- **accident cost rates for various severity of accidents**

3.12 Reduction of accident cost rate (adaptation measure)

An adaptation measure could either reduce the risk potential of hazard (the infrastructure is less vulnerable) or the severity of the consequences (e.g. less traffic disruption). In order to consider the secondary effects of an adaptation measure it is necessary to make an assumption on the level of reduction in the frequency and severity of accidents the adaptation measure provides. That means, if it assumed, that a damage pattern category leads to severe accidents with fatalities but through the implementation of the adaptation measure e.g. traffic management system the frequency of such accidents can be reduced (the users are warned), an assumption of the share of reduced accident costs is needed.

The reduction of the accident rate depends on the change of the severity of accidents because of the implementation of the adaptation measure. Therefore, for each adaptation measure an assessment of the change of the severity and the frequency of such accidents is needed. Please note: For many DPC there will be no changes of the severity and the frequency. However, the indirect costs are influenced also by the (reduced) Level of Occurrence.

4 Cost related assumption (direct costs)

4.1 Introduction into the assessment of direct costs

4.1.1 *Regular reconstruction costs*

As the CBA calculation considers the lifecycle of the asset/element, direct costs for the reconstruction of the asset/element at the end of a lifecycle period has to be ascertained (the residual value). Within the CBA-module the reconstruction costs are calculated as linear depreciation based on a standard costs approach. This is necessary because the analysis period contains – depending on the duration of lifespan of the asset – several lifecycle periods, which do not end simultaneous with the end of analysis period.

[6] Additional to those which are estimated for the road without construction sites.
[7] Volkswirtschaftliche Kosten durch Straßenverkehrsunfälle in Deutschland BASt-Bericht M 208.

The depreciation of reconstruction costs is determined through a standard cost approach as function of the dimensions (e.g. square metre) of the analysed asset. The standard costs are based on engineering experiences and derived from average costs depending on the asset type. Since, the depreciation value depends not only on the reconstruction costs itself, but also on the duration of the lifecycle period influenced by climate event, a longer lifespan leads to lower depreciation values and therefore – in case of same reconstruction costs – to lower total direct costs as part of the comparison of different adaptation measure scenarios. In other words, the shorter the lifecycle period (respectively the higher the reduction of the lifecycle) the higher the annual depreciation value, and therefore the higher the costs of reconstruction as part of direct costs.

4.1.2 *Repair costs (caused by climate event)*

The CBA-calculation considers repair costs after a climate event occurred. One basis for the repair cost calculation is the Level of Occurrence (see 2.2). The other basis is the standard cost approach for repair costs as percentage of the initial construction costs (already used for the calculation of the reconstruction costs.

4.1.3 *Additional direct costs for the implementation of adaptation measures*

The implementation of adaptation measures has associated direct costs. The kind of these direct costs depends on the type of adaptation measure. The CBA-calculation differs three different categories of adaptation measures:

1. modification of the infrastructure (e.g. design or material);
2. modification to operations/ maintenance; and
3. installation of additional infrastructure (e.g. traffic management).

The different adaptation categories are associated with different kinds of direct costs, which are included in the CBA-calculation as follows:

- for category 1 - additional construction/implementation costs and operation/maintenance costs are added as percentage of initial costs of the asset
- for category 2 - additional operation / maintenance costs are added as percentages of the asset
- for category 3 - implementation costs and operation/maintenance costs of the additional infrastructure are added

For the purposes of the calculation it is assumed that only the additional costs are those caused by implementing the adaptation measures will be considered. For category 1 adaptation measures this means the additional construction / implementation costs are the difference between the entire construction / implementation costs and the initial construction costs of the current asset which are already considered in the calculation.

4.1.4 *Aggregation of direct costs (discounted direct costs)*

For the comparison of the different adaptation measures and these with the 'do nothing strategy' the annual direct costs (calculated as described above) are discounted and aggregated.

4.2 Initial construction and regular reconstruction costs

The DeTECToR-CBA-module calculates direct costs for different types of assets/elements of the trunk road network. In order to do so, the CBA calculation considers the lifecycle of the asset/element, calculating the direct costs for the reconstruction of the asset/element at the end of its life and any residual value. Within the CBA-module the reconstruction costs are calculated as linear depreciation based on a standard costs approach. This is necessary because the analysis period contains – depending on the duration of lifespan of the asset – several lifecycle periods, which do not end simultaneous with the end of analysis period.

The depreciation of reconstruction costs is determined through a standard cost approach as function of the dimensions (e.g. square metre) of the analysed asset. The standard costs are based on engineering experiences and derived from average costs depending on the asset type. The depreciation value depends not only on the reconstruction costs itself, but also on the duration of the lifecycle period (which is influenced by climate event) A longer lifespan leads to lower depreciation values and therefore – if the reconstruction costs are the same – to lower total direct costs. In other words, the shorter the lifecycle period the higher the annual depreciation value, and therefore the higher the costs of reconstruction as part of direct costs.

Class	**Sub-class**
Road surface courses	
	Asphalt
	Concrete
Bridges	
	Arch bridge
	Cable stayed bridge
	Suspension bridge
	….
Tunnels	
	With Less than 3 Lanes
	With 3 Lanes
	With more than 3 Lanes
retaining structures	
	Earthwork
	Anchor wall
	safety nets, catching fences
	…
….	

Table 4: asset/elements-cluster for direct costs (examples)

The basis for the assumption of the initial construction cost could be for example values derived from a networkwide analysis of the costs for construction works for the different cluster of assets/elements. The *Table 4* gives a short overview of possible asset/element-cluster.
For the German pilot study the applied standard cost approaches were derived from report on road infrastructure costs of Federal Ministry of Transport and digital Infrastructure[8].

What cost categories should be used and what are the average costs for each category? (€/m²)

[8] Korn et.al.: Berechnung der Wegekosten für das Bundesfernstraßennetz sowie der externen Kosten nach Maßgabe der Richtlinie 1999/62/EG für die Jahre 2018 bis 2022, final report Berlin, 2018

4.3 Initial life cycle duration

The CBA-module reflects the lifecycle and the therefore the lifecycle costs of the asset/elements. Depending on the original lifespan of an asset/element several lifecycle periods (LCP) can occur during the analysis period (separately calculation for each climate projection period). Therefore, the calculation within the CBA-module is performed on an annual basis and assumes a development of lifecycle depending on the vulnerability indicators.

Class	Sub-class
Road surface courses	
	Asphalt
	Concrete
Bridges	
	Concrete
	Steel
	Stone
	….
Tunnels	
	Mined tunnel
	Open cut tunnel
retaining structures	
	Earthwork
	Anchor wall
	safety nets, catching fences
	…
….	

Table 5: asset/elements-cluster for direct costs (examples)

By merging the reduction of lifespan function and the initial life cycle duration/period the reduced lifecycle period is calculated. The reduced lifecycle period is the base for further calculation within the CBA-module. The calculation is based on the assumption that the RPH gets the best (lowest) value at the beginning of a lifecycle period (LCP) and the worst (highest) value at the end of a LCP. Between the beginning and the end of a LCP a linear interpolation of the RPH-value is assumed. For the first year (1st calculated LCP) the current RPH-value of the climate projection periods is used. For LCP=1 a linear interpolation is assumed between the current RPH (cRPH) and worst RPH of the first LCP. For LCP>1 the starting point of the interpolation is the best RPH-value and the ending point of the interpolation is the worst RPH-value. However, the best and/or worst values depends also on the climate projection period. Furthermore, as described above, for the CBA-calculation respectively for the depreciation the initial lifecycle duration respectively the calculated reduced lifecycle duration is needed. The (theoretical/design) lifecycle duration is determined by the material and the type of asset. The different analysed asset/elements should, therefore, clustered in homogenous classes – for example see *Table 5*.

What should the asset categories be and what is the average lifespan of these (in years)?

4.4 Repair / refurbishment costs after event

After a climate event which leads to infrastructure damage, repair / refurbishment works is necessary. Within the CBA-module the costs are determined in percentages of the initial construction costs. Therefore, the proportion has to be assumed depending on the typical damages on the asset / element which occurs as consequence of a harmful climate event and how much of the selected asset section is typically affected. For example for bridge related damage pattern categories the proportion will be higher than for road surface related damage pattern categories, since often the whole bridge is affected whereas for road surfaces often only part of the whole road surface is affected. But it should be noted – especially for road surface related damage pattern categories, that the determination of proportion has to consider the dimension of the analysed asset. The dimension is determined by the resolution of the asset data available. For example, if the asset data for the road surface are available in very small units (for each 100m section, for each lane – as in

Germany), the proportion could higher. Whereas, if the data only available in a larger scale, the proportion could be smaller, since the affected share is smaller.

Please provide an estimate of the proportion of the initial construction costs that the repair costs should be for the different DPC analysed for your pilot region.

4.5 Adaptation measure related assumptions

It should be noted that the CBA-module has the following restrictions:

- Comparison of max. three adaptation measures
- Consideration of three types of adaptation measures
  - Type 1 - modifications of the construction
  - Type 2 - modifications to operation or maintenance
  - Type 3 - implementation of additional infrastructure e.g. traffic management systems (or additions to existing traffic management systems)
- It is not possible to change from one DPC to another DPC (e.g. from concrete surface to asphalt surface)

The results will always be related to the initial asset/element and DPC.

[Note: in case of amendment of the construction (type 1) the calculation within the CBA-module implements the new construction only after the current lifecycle of the asset is ended.]

4.5.1 *Prolongation of lifespan of the initial asset*

The different types (1-3) of adaptation measures (see list above) have various influence to the lifespan (lifecycle duration) of the asset/element. For example, a re-construction of the road surface with a larger layer thickness (adaptation measure type 1) will extend the lifespan of re-constructed surface. Whereas, the implementation of an additional infrastructure e.g. ITS will not influence the lifespan of the analysed asset.
Please note, that – using the same example (type 1) – the higher layer thickness can adjust the vulnerability values (see below) in case of the layer thickness is a vulnerability indicator. The prolongation of the lifespan is specified in percentage in relation to the initial lifespan.

Please provide estimates of the prolongation of the lifespan of the initial asset through the implementation of the adaptation measure. This is needed for each analysed DPC and for the type of adaptation measurement.

4.5.2 *Initial implementation costs of Action*

In the case of an adaptation measure type 1, which intends amendments/modification of the construction, the calculation applies the adaptation measure only at the end of the first (current) lifecycle. The implementation costs of the adaptation measure are added to the cost of reconstruction without adaptation. In the case of adaptation measure type 2 (amendment of operation or maintenance) no implementation costs occur (see also chapter below). For type 3 the cost of implementation is applied at the start of the analysis period.
For the derivation of the (additional) implementation costs the same basis as used for the derivation of the initial construction costs can be used (see above).

What categories should be used for the costs of implementation and which average costs (€/m²) should be assigned to each of these categories?

4.5.3 *Additional annual operation / maintenance costs (additional)*

As part of the lifecycle concept of the CBA-module, operation and maintenance costs are also considered in the calculation. However, the calculation considers only the additional operation/maintenance costs of the adaptation measure. Because of the fact, that the costs of adaptation measures will be compared with those costs of the so-called do-nothing option (without adaptation), the calculation of the operation/maintenance costs of the initial asset/element is not necessary, since they accrue in all variants anyway. Therefore, assumptions only for the additional operation/maintenance costs of the various adaptation measure are needed.

The additional operation/maintenance costs are specified in percentage in relation to the initial construction costs respectively to the implementation costs of the adaptation measures.

For example, for the German pilot study the annual average operation / maintenance costs is 2.0% of the initial construction costs (without winter services and landscaping) for asphalt surfaces.

Please indicate the annual average operation / maintenance costs as percentage of initial construction costs.

4.5.4 *Lifespan of the additional infrastructure*

Here only assumption for the lifespan of the additional infrastructure (adaptation measure type 3) are needed. In case of type 1 and 2 the lifespan already considered by the assumption of the prolongation of the lifespan (see above).

What are the categories for the (theoretical) lifespan for the infrastructure elements and which lifespans (years) should be used for these?

4.5.5 *Adjustment of vulnerability values – impact on vulnerability indicators*

The *Figure 43* shows assumption regarding the impact on vulnerability values for the three types of adaptation measure examples.

Impact on vulnerability indicators		Note: the model check the assumption, depending of the type of Action					
	weighting	Action 1 [amendment of construction]		Action 2 [Amendment of services or maintenance]		Action 3 [Implementation of additional infrastructure e.g. ITS]	
		at the beginning of LCP [best]	at the end of LCP [worst]	at the beginning of LCP [best]	at the end of LCP [worst]	at the beginning of LCP [best]	at the end of LCP [worst]
AADT-heavy goods vehicles:	20%	not adjustable - calculated					
tendency:	5%	not adjustable - calculated					
position (exposure):	10%	not adjustable - calculated					
condition:	30%	1	4	1	2		
mends [share]:	10%	1	4	1	2		
spalling [share]:	10%	1	4	1	2		
layer thickness [cm]:	15%	1	1				

Figure 43: impact on vulnerability indicators – DPC specific

For each of the adaptation measures the impact on the vulnerability indicators has to be analysed. For example, in case of type 1, because of the higher layer thickness the vulnerability value for the indicators gets the value of 1. Or, in case of type 2, the layer thickness will not be changed only better operation/maintenance will be conducted, which leads to better condition values; and this in turn leads to lower possible worst vulnerability values at the end of a lifecycle period (LCP). Or, in case of type 3, only additional infrastructure or measurements will be implemented without any changes of the construction or the operation/maintenance of the initial asset/element itself. Therefore, there is no impact on the vulnerability values – but on the effects/impacts (see below).

[Note: With the CBA-module it is possible the compare three different adaptation measures of the same adaptation type (type 1-3, see above). The different options could have various costs, various life span reductions or various impacts on the vulnerability indicators.]

4.5.6 *Adjustment of effect/impact values – impact on effect indicators*

The *Figure 43* shows assumption regarding the impact on effect/impact values for the three types of adaptation measure examples. However, adjustments of the assumption are limited to some of the indicators.

upper level	sub-level	categorie	weighting	classification - current	classification - Action 1	classification - Action 2	classification - Action 3
refurbishment			20%				
	refurbishment		80%				
		refurbishment	50%	2	2	2	2
		frequence of occurence	50%	2	1	1	2
	construction costs		20%	calculated			
maintenance			30%				
	maintenance		75%				
		maintenance	50%	3	3	3	3
		reduction of life cycle	50%	3	1	1	3
	construction costs		25%	calculated			
operation			5%				
	operation		80%				
		operation	100%	3	3	3	3
	construction costs		20%	calculated			
accidents			10%				
	frequence		50%	1	1	1	1
	type / severity		50%	3	3	3	1
traffic			35%				
	kind of interruption		50%				
		duration	40%	2	2	2	2
		frequence	40%	3	1	2	3
		extent	10%	3	1	3	3
		accidents (above)	10%				
	criticality		50%				
		traffic volume	35%	calculated			
		traffic volume heavy goods vehic	35%	calculated			
		occupancy rate (calculated)	20%	calculated			
		part of TEN-network	10%	calculated			

Figure 44: impact on effect/impact indicators – DPC specific

For each of the adaptation measures the impact on the effect/impact indicators has to be analysed. For example, in case of type 1, because of the higher layer thickness the effect value for the indicators gets the value of 1, since a prolongation of the refurbishment frequency is assumed. Or, in case of type 2, the layer thickness will not be changed only better operation/maintenance will be conducted, which leads to better condition values; and this in turn leads to longer possible refurbishment frequency. Or, in case of type 3, the additional infrastructure e.g. ITS will reduce the severity of accidents, therefore, the effect/impact value can also be reduced.

[Note: With the CBA-module it is possible the compare three different adaptation measures of the same adaptation type (type 1-3, see above). The different options could have various costs, various life span reductions or various impacts on the vulnerability indicators.]

5 Summary table

Information required	***Source***	***NRA input***	***Integrated in the tool or example user input***
assumption of the power value of the reduction of lifespan function (2.1)	*Proposed by consortium*	*Validate*	*Integrated in the tool*
assumption of the power value of the level of occurrence function (2.2)	*Proposed by consortium*	*Validate*	*Integrated in the tool*
average number of days for traffic	*Proposed by*	*Validate*	*Integrated in the*

interruption caused by a specific climate event (3.2)	*consortium*		*tool*
average number of days for reconstruction (3.3)	*NRA*	*Provide values*	*Integrated in the tool*
average speed of cars (HGV - 3.4 / passenger cars - 3.6)	*NRA*	*Provide values*	*Integrated in the tool (data base)*
average speed of cars because of construction sites (HGV - 3.5 / passenger cars - 3.7)	*NRA*	*Provide values*	*Integrated in the tool*
Time saving costs for users (passenger cars - 3.8 / HGV - 3.9)	*NRA*	*Provide values*	*Integrated in the tool*
accident cost rates for various severity of accidents on trunk roads (3.10 / 3.11)	*WebTAG / NRA*	*Provide values and validate*	*Integrated in the tool*
the average number of accidents per 1,000 cars for various severity of accidents with and without roadworks (3.10)	*WebTAG / NRA*	*Provide values and validate*	*Integrated in the tool*
reduction of the accident rate (3.12)	*Proposed by consortium*	*Validate*	*User input*
Cost categories and construction costs (4.2)	*NRA*	*Provide values*	*Integrated in the tool*
Lifespan of the asset (4.3)	*NRA*	*Provide values*	*Integrated in the tool*
Costs for repair as proportion of initial construction costs (4.4)	*Proposed by consortium*	*Validate*	*Integrated in the tool*
Estimates of Prolongation of lifespan (adaptation measure)	*Proposed by consortium*	*Validate*	*User input*
Adaptation measure's implementation costs (4.5)	*NRA*	*Provide values*	*User input*
Operation / maintenance costs as percentage of initial construction costs (4.5)	*NRA*	*Provide values*	*User input*
Adaptation measure's impact on vulnerability indicators – depends on DPC and adaptation measure (4.5)	*Proposed by consortium*	*Validate*	*User input*
Adaptation measure's impact on effect/impact indicators – depends on DPC and adaptation measure (4.5)	*Proposed by consortium*	*Validate*	*User input*