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

Interim Report 1

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

Interim Report 1

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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 will be developed for both these areas. The risk assessment and cost-benefit 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 self-assessment tool will enable evaluation of the current level of climate change embedment in an organisation and identify areas for additional action. The first tasks of the project involved gathering and reviewing information to inform the development of the tool and guidance. This Interim Report summarises the information gathered through these initial tasks.

Information was gathered through an online survey of European NRAs, interviews and literature review. The survey provided information on NRA priorities in terms of the hazards and assets of most concern, the type of asset data collected and meteorological data used, design and planning horizons and the gaps in the current level of climate change action. For example only 30% of respondents said that they currently included climate change impacts in the economic appraisal of new projects and 26% that they used risk assessment tools or models to estimate the cost of future weather impacts.

The literature review identified research and good practice that could feed into the development of tools and guidance. The following topic areas were reviewed:

- The use of climate data and projections in road asset management
- Methods of assessing climate change risk
- Identifying and prioritising climate change adaptation actions
- Identifying and prioritising climate change mitigation actions
- Embedding climate change mitigation and adaptation in road operations
- Embedding climate change mitigation and adaptation in procurement
- Economics and climate change

A great deal of research was identified that provided an overview of the issues related to climate change, however limited practical detail or actual tools that NRAs can employ were identified. There were also few examples of approaches developed by research projects being put into practice, especially in terms of climate change adaptation. The most relevant projects for the risk assessment tool are the CEDR projects such as RIMAROCC and ROADAPT and as they are specifically aimed at NRAs, and RIVA which was based on RIMAROCC. Research was identified on aspects relating to procurement such as sustainability KPIs and LCA, but little on how to put these into practice or a general approach to procurement. The most useful sources of information for this topic were exemplar NRAs and guidance documents. The literature review was supplemented by interviews with NRAs and researchers.

The findings from the interviews, literature review and survey will be used as a basis for the development of the DeTECToR tools. The literature review was also used to develop 39 summary sheets describing key projects, and how NRAs could implement their findings. These are designed to be a stand-alone resource for NRAs and a separate output of the project.

The next step in the project is to hold a stakeholder workshop to help determine NRA requirements for the guidance and decision-support tools. This will be carried out through two interactive sessions designed to identify the types of information NRAs require and how they could use the tools. The selection of pilot NRAs and case study areas for trialling the tools will also be discussed at the workshop.

This report summarises the project findings and plans at an early stage of the project. Later during the project some aspects were changed. For example the procurement tool was changed from a self-assessment tool to a collaboration platform as a result stakeholder feedback at the workshop.

1 Introduction

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 two year project covers topics A and B in the call’s Description of Research Needs (DoRN):

A: Economic costs associated with integrating climate change into decision-making

B: Embedding climate change into practice and procurement

I. Implementing existing climate change research into practice
II. Embedding climate change into procurement processes

DeTECToR is also liaising with the Topic C project WATCH (Water Management for Road Authorities in the face of climate change) and will work with the Topic D project on driver behaviour when this project is commissioned.

1.1 *Project objectives*

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 will produce decision support tools and guidance that will enable NRAs to better integrate climate change considerations in economic and procurement decision making.

Specifically it will produce:

- 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;
- A self-assessment tool[1] that will enable NRAs to review their operations and procurement procedures and received targeted recommendations for embedding climate change mitigation and adaptation into their organisation and supply chain; 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 self-assessment tool.

1.2 *Project work packages*

The project objectives will be achieved through seven work packages as shown in Figure 1. The WPs will run across the two DoRN topics being addressed, with some sub-tasks addressing specific aspects of topic A (economics) or B (embedment in operations and

[1] Later changed to a collaboration platform.

procurement). In this way the interdependencies of the two topics can be addressed, whilst retaining sufficient focus on the individual topics when required. Project management and co-ordination will be carried out under WP1, and WP7 will focus on dissemination and implementation. There are five technical WPs:

- WP2 will gather all the information required to develop the tools and guidance. This includes reviewing literature, determining stakeholder requirements and mapping out the data requirements.
- WP3 consists of the development of the two decision-support tools, and will be carried out concurrently with WP4.
- WP4 will produce the two guidance documents to accompany the tools.
- WP5 will apply the tools and guidance in a number of pilot studies, carried out in conjunction with NRAs.
- WP6 will finalise the tools and guidance based on the feedback from the pilot studies.

Figure 1. Work package structure

1.3 Report scope

This interim report summarises the results of the activities carried out under *WP2: Evaluation of Research and Determination of Stakeholder Requirements*, which were carried out between September 2016 and February 2017. The information it contains will be refined and updated throughout the development of the tools and guidance.

The objectives of WP2 are:

- To review existing research, in order to determine the most appropriate approach for different infrastructure assets and to collate the information needed to develop the tools and guidance.
- To better understand stakeholder requirements and their existing processes, so that the tools can be tailored to their needs.

WP2 will provide the information which influences the development of the decision support tools and guidance documents; therefore, a thorough literature review of the relevant topics is critical in order to understand the requirements for the tools and guidance. WP2 also provides a catalogue of the latest research and best practises in separate project summary sheets. These sheets were developed in order to convey the key messages from the latest research related to embedding climate change into NRA operations and procurement.

WP2 is divided into three major tasks as outlined below:

Task 2.1 Review of existing tools and research
In this subtask a review of existing projects and research including tools already developed and used is performed.

Task 2.2 Identification of data sources
The goal of this subtask is to identify the data sources available for use in the decision-support tools and obtain information on the existing NRA asset management and procurement procedures (including requirements on reduction of GHG emissions). These will be collected as part of the stakeholder survey, interviews and stakeholder workshop.

Task 2.3 Review of NRA operational and procurement processes
The objective of this subtask is to identify the existing asset management and procurement procedures used by European NRAs. In addition it attempts to identify existing approaches used by NRAs to include climate change mitigation and adaptation in operational and procurement decisions and identify examples of good practice.

This report consists of deliverables D2.1 Interim Report 1 and D2.2 Summary Sheets (as described in the proposal). The main content of the report is D2.1; the summary sheets (D2.2) are included as an Appendix. The summary sheets provide information on research projects that produced tools and methodologies that could support NRA efforts to reduce carbon and adapt to climate change impacts. In addition to feeding into the development of the DeTECToR tools and guidance (WP3 and WP4), they are also a stand-alone resource for NRAs.

Interim Report 1 is divided into the following sections:

Section 1 provides an introduction to the project and sets out the scope of the report and methodology used.

Section 2 gives a brief overview of the underpinning concepts relating to the project.

Section 3 describes the existing level of embedment in European NRAs based on the information gathered from the survey and interviews.

Section 4 summarises the findings from the literature review of research and guidance on topics relating to DeTECToR.

Section 5 provides examples of climate change research and guidance being put into practice by NRAs and others.

Section 6 gives the conclusions of the information review and describes how this will be used in the next steps of the project.

1.4 Activities to-date

The main technical activities carried out to-date relate to WP2. WP2 was led by IBDiM, but all the project partners contributed to the evaluation of the existing research, development of the on-line survey and producing the summary sheets. All the partners also contributed to compiling this report.

The methodology adopted for WP2 comprises a broad ranging literature review and production of the Summary Sheets for each reviewed project, a Stakeholders Survey and interviews. Contribution from each of these components constitutes the essence of this report. The methods used in these activities are described below.

1.4.1 *Literature review*

Seven basic topics were identified to focus review activities in the effective and meaningful manner. These topics are:

- Impacts of climate change on roads
- Risk assessment methodologies
- Adaptation measures
- Actions to reduce carbon emissions
- Including climate change in road operations (incl. asset management)
- Including climate change in economic appraisal
- Including climate change in procurement

For each topic area a literature review was carried out of research projects, guidance documents and NRA examples of good practice.

1.4.2 *Summary sheets*

Key research projects relating to the topic areas were identified, and for these projects a Summary Sheet was produced. A template was developed to provide a consistent format for the sheets and to ensure all relevant points were covered. A list of the main projects

Table 1. Project Review List

Project	Funding	Duration	Impacts of CC on Roads	Risk Assesment	Adaptation Measures	Reduction of Carbon Emissions	Road Operations	Economic Appraisal	Procurement
PREDICT	FP7	2007-2013		X					
IRWIN	FP6 2008: ERA-NET ROAD I	2008-2010	X	X	X		X	X	
P2C2R2	CEDR-2008, ERA-NET ROAD I	2008-2010		X				X	
RIMAROCC	CEDR-2008, ERA-NET ROAD I	2008-2010		X	X				
SWAMP	CEDR-2008, ERA-NET ROAD I	2008-2010		X	X				
EWENT	FP7	2009-2012		X				X	
WEATHER	FP7	2009-2012	X		X			X	
FloodProBE	FP7	2009-2013	X	X	X				
SubCoast	FP7	2010-2013	X	X	X				
The Resilient Road	FEHRL	011-ongoing			X				
SUNRA	CEDR-2011	2011-2014				X	X		X
CEREAL	CEDR-2011	2011-2014				X	X		X
LICCER	CEDR-2011	2011-2014				X	X		
MIRAVEC	CEDR-2011	2011-2014				X	X		
MATRIX	FP7	2012-2014		X	X				
MOWE-IT	FP7	2012-2014			X				
KULTURisk	FP7	2012-2014			X		X		
RIVA	AdSVIS	2012-2014			X				
CliPDaR	CEDR-2012, ERA-NET ROAD II	2013-2014	X						
ROADAPT	CEDR-2012, ERA-NET ROAD II	2013-2014	X	X	X			X	
AllTraIn	EU-CIPS-2012	2013-2014	X	X	X				
RAIN-EX	EU-CIPS-2013	2014-2015		X			X		
RISC-KIT	FP7	2013-2015		X	X				
CIPRNET	FP7	2013-2017			X		X		
InfraRisk	FP7	2013-2016		X					
STREST	FP7	2013-2016		X			X		
INTACT	FP7	2013-2016	X	X	X				
Re-Gen	CEDR-2013	2014-2016		X				X	
RAIN	FP7	2014-2017			X		X		
RESILENS	H2020	2015-2018			X		X		
IMPROVER	H2020	2015-2018		X	X				
SmartResilience	H2020	2016-2019		X			X		
WATCH	CEDR-2015	2016-2018		X	X				
USE-IT	H2020	2015-2017				X			
FOX	H2020	2015-2017					X		
GreenRoads						X			X
ClimateCost	FP7	2012						X	
ECONADAPT	FP7	2015			X			X	
IMPACT2C	FP7	2011-2015	X						
LCE4ROADS	FP7	2013-2016				X	X		

considered and how they relate to these topics is included in Table 1.

During this exercise 39 summary sheets were created covering completed and ongoing CEDR, FP7 and H2020 projects that address topics such as climate change adaptation, risk management, economic appraisal and environmental indicators. This detailed review allowed specific data/information to be identified which will inform the development of the tools and guidance, as well as being a resource for NRAs. The approach taken was to specifically identify only the key information relevant to the DeTECToR remit with special emphasis on information NRAs can apply to their practises and operational strategies.

The summary sheets are intended to provide a quick overview of best practices and case studies but also gather more specific information on:

- Data availability and sources
- Methodology
- Key deliverables and outputs
- Recommendations on how NRAs can use the project findings/ outputs
- Examples of the research being put into practice or pilot studies carried out as part of the project

They also include project details such as contact details for the coordinator, partners, programme, and duration of the project.

A novel approach is the inclusion of a Road Asset/Hazard Matrix where the asset and hazard types included in the project are indicated. Figure 2 shows the matrix completed for the ECONADAPT Project as an example.

Hazard / Road element	Extreme events								Gradual changes				
	Flooding/ extreme rainfall or storm surge	High temperatures/ heat wave	Low temperatures/ ice	Landslide / mud flow	Drought	Intense snowfall/blizzard	Strong wind/ cyclone	Others (e.g. fog, lightening, hail)	Higher average temperatures	Sea level rise/ coastal erosion	Temperature fluctuation, e.g. Freeze-Thaw, diurnal	Precipitation patterns	Others (e.g. growing season)
Road as a whole / across asset types	☒	☐	☐	☐	☐	☐	☐	☐	☒	☒	☐	☐	☒
Bridges	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Culverts	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Drainage	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Geotechnics	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
ITS	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lane markings	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Pavement	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Road equipment/ furnishing	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Static signs	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Tunnels	☐	☐	☐	☐	☐	☐	☐	☒	☐	☐	☐	☐	☐
Others	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Figure 2. Road asset/Hazard Matrix

The Project Summary Sheets are included in Appendix A.

1.4.3 *Stakeholder survey*

The Stakeholder Survey aimed to provide the following:

- Information on NRA priorities regarding assets and their associated climate risks.
- An overview of data availability and use by the NRAs.
- The existing level of embedment in NRA operations and procurement processes.
- Examples of good practice.

The survey questions are included in Appendix A and results are provided in Chapter 3.

The survey was designed to be concise (less than 10 minutes to complete), but also to provide quite specific information on a number of topics relevant to the project. It was developed in an electronic format to maximise the response rate and the link sent to over 100 contacts within NRAs, research organisations and other road climate change experts in Europe. The link was also put on the DeTECToR website and distributed through FEHRL and WRA Technical Committees.

1.4.4 *Discussions*

In addition to the survey, a small number of telephone or in-person interviews were conducted.

Polish National Road Administration GDDKiA
A meeting with the Polish National Road Administration (GDDKiA) was held in November 2016 to introduce the project ideas and obtain the GDDKiA's feedback on embedding climate change into the current operations and procurement practices. GDDKiA has an environmental department which deals with ecological and climate aspects; however, this department carries out limited coordination of climate related inputs with the bridge and road construction departments.

It was found that GDDKiA considers weather conditions in their daily operations and regularly check with the National Climate Agency about any adverse weather changes to plan maintenance activities. Bridge design specifications include technical provisions for flooding events and are designed for 300-year flood event. The GDDKiA is in a process of digitising their reference system (DSR) and writing specifications for all contractors to follow.

Embedding climate change into procurement and green procurement practices is still in the planning phase. Climate change performance based related specifications can be included in technical provisions for the new construction and maintenance contracts but this will require an amendment into the legal act which regulates public procurement in Poland called: "Law of Public Procurement". Monitoring of execution of these technical provisions and KPIs would have to be established as well.

Highways England Procurement Officer
A telephone interview was held with a procurement officer in Highways England (UK NRA). The interviewee explained that he implements procurement processes, but does not set the overall procurement objectives. Managing him is a business partner which sets out the overall business case for projects. In addition, there are different portfolios on pavements, structures etc. and different directorates for major projects and maintenance contracts. EC procurement regulations were perceived to be a barrier to more innovative types of procurement. Most projects are let under framework contracts which include some sustainability specifications.

Trafikverket
A teleconference was held in November 2016 with the Trafikverket (Swedish NRA) climate change mitigation coordinator and a procurement manager. They explained the actions they had taken to embed climate change mitigation into their procurement processes. This has been driven by strong national climate policy and targets. They have recently introduced the use of carbon tool to set carbon targets for road and rail projects over a certain value. This was introduced after consultation with suppliers and an impact assessment. At each project stage more detail is required in the carbon calculation. At the end of the project the supplier submits a climate declaration stating the amount of GHG emissions produced. If this total is substantially less than the agreed target they will receive a bonus. If they fail to meet the target they will not receive any type of bonus including those for other aspects of performance such as completing on time.

Cambridge PhD student
A teleconference was held with a PhD student from the University of Cambridge in the UK, who is researching decision support tools for road adaptation. He described his Masters

thesis which compared four different tools and their approach to climate change. It was agreed that some degree of collaboration would be useful.

WATCH

Several members of the DeTECToR consortium participated in a webinar/teleconference with the WATCH project in January 2017. Each project presented their work to-date, which for DeTECToR included preliminary results of the survey. Potential synergies between the two projects were discussed, including approaches to cost benefit analysis. The DeTECToR stakeholder survey was also sent to the WATCH distribution list. Two DeTECToR consortium members participated in the WATCH Workshop on 6-7 February 2017 to further explore synergies and a member of WATCH will attend the DeTECToR workshop.

2 Project background

Section 2 provides a brief introduction to the main concepts underpinning the DeTECToR project.

2.1 Climate change

Climate itself is a complex statistical property of the ever-changing atmosphere. It emerges from highly variable daily weather processes. The challenge lies in the definition of time and space scales for which representative and robust information on the atmosphere can be obtained. However, it should be kept in mind that, even without a climate change, there are already hazards for infrastructure due to extremes as they presently occur.

For DeTECToR the focus is on an evolution of the climate which exceeds the development of the recent past. This evolution includes several climate properties, e.g. changes in mean values as well as changes in the extreme behaviour. Concerning extremes it is important to gain knowledge about changes in their frequency of the occurrence (e.g. if there will be a 100mm rain per hour event more often in the future) and their magnitude (e.g. will a 100mm rain per hour event become a 150mm event in the future).

There are two main complicating factors at work: (i) the future pathways of the atmospheric development can be highly diverse due to other developments, such as economy, demography, geopolitics and geophysics. These are collated in scenarios which aim at telling plausible, congruent stories of different futures rather than providing a definite answer; (ii) climate models, being the feasible source of information on influences as well as impacts, reflect those developments in an approximating way. Moreover, climate projections by these models have a certainty that diminishes the further into the future they are extending.

The way forward, nevertheless, is to use climate model projections to understand climate-exerted hazards to transportation infrastructure under the conditions of a changing climate. It is an established approach to assess the future climate not using one single model but an ensemble of models which improves the resilience of the results.

2.2 Types of climate change action

There are two types of action related to climate change:

> **Climate change mitigation** - Human intervention to reduce the sources or enhance the sinks of greenhouse gases (GHGs).
>
> **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.

It should be noted that the definition of mitigation strongly depends on the context, since this term is understood differently in different communities. While this commonly used definition proposed by the IPCC relates to mitigation of climate change, a different definition is used in the context of disaster risk reduction:

> **Mitigation** - The lessening or limitation of the adverse impacts of hazards and related disasters.

This definition of climate change adaptation addresses the concerns of climate change and is sourced from the secretariat of the United Nations Framework Convention on Climate Change (UNFCCC). The broader concept of adaptation also applies to non-climatic factors such as soil erosion or surface subsidence. Adaptation can occur in autonomous fashion, for example through market changes, or as a result of intentional adaptation policies and plans. Many disaster risk reduction measures can directly contribute to better adaptation (UNISDR, 2009).

The adverse impacts of hazards often cannot be prevented to the full extent, but their scale or severity can be substantially lessened by various strategies and actions. Mitigation measures encompass engineering techniques and hazard-resistant construction, as well as improved environmental policies and public awareness (UNISDR, 2009).

With respect to disaster risk reduction, these two concepts are closely linked and complementary to each other. Effective mitigation measures entail lesser impacts and thus a lower requirement for adaptation, while effective adaptation measures allow for coping with more severe (i.e. less mitigated) impacts. In many cases, boundaries between mitigation and adaptation are fluid. Measures and actions taken may intertwine and contribute to increasing both adaptation and mitigation. In this context, it has to be emphasized that both terms are not clearly defined in many projects. Thus, the terms “adaptation” and “mitigation” are used interchangeably in several projects dealing with adverse weather or climate change impacts on roads.

In DeTECToR, the IPCC definition of mitigation as used in the context of climate change policy is employed, thus referring to reduction of greenhouse gas emissions that are the source of climate change.

2.3 Impact of climate change on roads

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**:** Extremely high temperature poses a number of threats to infrastructure, such as degradation of road surfaces or stability problems of bridges and other supporting structures due to thermal expansion. Moreover, prolonged episodes of very high temperature cause health stress on road workers and travellers delayed in traffic.

Extremely low temperature is also a hazard, freezing temperatures can damage pavements and the threat of icing requires expensive winter service action. In addition, bridges and other structures suffer from stability problems due to the negative thermal expansion. Low temperature is a health issue as well. It should be kept in mind that days with freeze-thaw-cycles and their immense expansion-contraction stress are particularly hazardous for road surfaces.

Climate projections show an increase of heat stress but also an increase in variability. This means that the temperature range to which the infrastructure is exposed increases. As a derived consequence, it should be added, a future climate will not only exhibit fast increase in high temperature threats but also a rather slow decay of the low temperature threats. Furthermore, areas which remained in a subfreezing temperature range during the winter months almost entirely will face an increase in the freezing-thawing cycles.

Precipitation: Extremely high amounts of rainfall pose a severe threat to transport infrastructure as it causes excessive runoff with ensuing flooding and also can cause inundation from nearby rivers. It also indirectly can result in landslides which lead to traffic disruptions and high repair costs. Large amounts of snow leads to hazardous usage conditions of the infrastructure and is another cause for traffic disruptions. Moreover, they necessitate the deployment of equipment to deal with winter conditions.

Droughts, on the other hand are a hazard to ecosystems surrounding the transportation infrastructure and can inflict fire or contribute to the degradation of landscape surfaces which, in turn, exacerbates runoff problems, should they be followed by heavy precipitation. Large changes in moisture content can also cause subsidence and heave.

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. This includes a superimposed large-scale effect which causes areas around the Mediterranean Sea to become generally drier. Yet, the climate projections also point towards an increase in variability. Consequently, the probability of extreme precipitation occurring will be of similar, if not higher magnitude.

Wind: Large-scale motion of the atmosphere in combination with topographical features in the landscape can cause high-wind threats to transportation infrastructure. This encompasses storm-related damage to infrastructure and the disruption of traffic, e.g., by uprooted trees. High winds can also cause reduced visibility. 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.

Another impact of climate change is ***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.

2.4 The contribution of roads to climate change

Roads also contribute to climate change through the GHG emissions produced by construction, maintenance, operation and use of roads. Transport produces around 26% of global carbon emissions, with around 90% of this being generated by the road sector. Decarbonisation of road transport is a major challenge in meeting international agreements to keep the global temperature rise below 2°C.

The majority of road emissions (62%) are directly generated from the use of fossil fuel powered vehicles. NRAs can influence this through providing supporting infrastructure for electric vehicles and non-motorised transport, effective traffic management and consideration of rolling resistance. However the main types of emissions within their control are those associated with the construction, maintenance and operation of infrastructure which accounts for around 10% road emissions (the remaining 28% is manufacturing of the vehicles). The main component (70%) of the construction and maintenance emissions is the embodied carbon in materials (Itoya *et al*., 2015). Materials commonly used in road construction such as cement (in concrete) and steel are very energy intensive to produce. Safety barriers alone contribute a large proportion to a project's carbon footprint.

The carbon footprints of the components of different types of road vary; for example, expressways/motorways and national roads have higher carbon footprints than local roads (Table 2). Tunnels have high operational energy consumption due to the need for lighting, ventilation etc. (see Figure 3).

Table 2. Breakdown of GHG by road component (World Bank, 2010)

Emissions (tCO_2 eg./km)	Expressway	National Road	Provincial Road	Rural Road-Gravel	Rural Road-DBST
Earthworks	161	16	12	3	3
Pavement	13334	425	157	72	86
Culverts	238	51	17	12	12
Structures	1068	119	21	3	3
Road Furniture	432	182	0	0	0
Total	3234	794	207	90	103

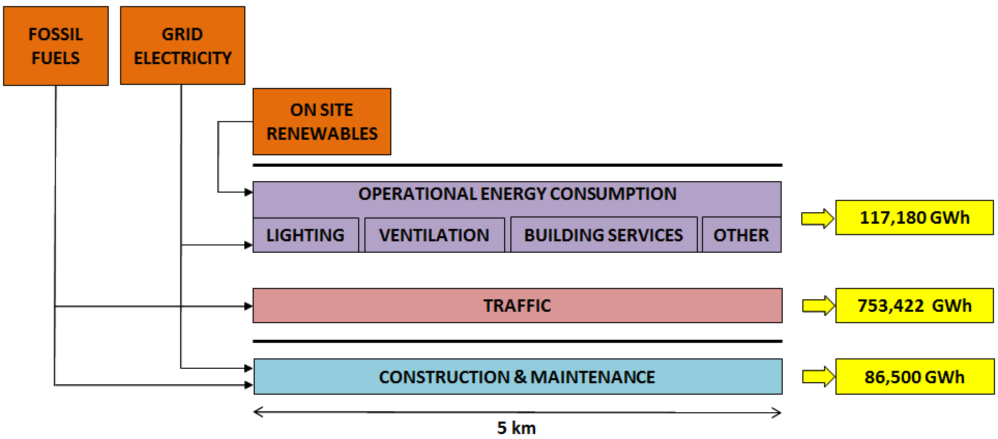

Figure 3. Energy consumption over a 120 year lifetime of a single bore, 5 km drill and blast road tunnel (Wayman *et al.*, 2016)

The USE-iT project identified the following challenges relating to reducing transport carbon emissions, which are relevant to NRAs (Peeling and Reeves, 2015):

- Phasing out the use of fossil fuels to power vehicles.
- Reducing the embodied carbon of infrastructure (e.g. use of lower carbon materials and design).
- Improving the efficiency of transport operations (e.g. smart lighting, improved traffic management).
- Generating renewable energy/harvesting energy from transport (e.g. installation of photovoltaics).

- More efficient asset management (e.g. sustainable procurement, more durable materials).
- Influencing customer behaviour (e.g. high occupancy lanes).

2.5 Including climate change in asset management

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 mitigation and adaptation actions is in asset management strategies. In this section, the definition of the asset, asset management and asset management system will be briefly described and possibilities for integration of risks resulting from extreme weather events will be shown. This unification is necessary in order to prepare a common understanding for the whole project. The definitions are taken form international literature and are already in use by some NRAs.

The international standard ISO 55000 defines and describes the most important approaches in the field of asset management. An integral part of the standard is risk management. A potential approach to risk management can be found in ISO 31000.

2.5.1 *What is Asset Management?*

An **asset**, according to ISO 50000, is defined as an *“item, thing or entity that has potential or actual value to an organisation”*. Although the use of asset management for all types of asset is possible, most applications focus on tangible assets, including infrastructure asset, such as roads, airports, municipal infrastructure or railways.

The term **asset management** is defined as *“the coordinated activity of an organisation to realize value from asset”*. Furthermore, it was added that the “realisation of value will normally involve a balancing of costs, risks, opportunities and performance benefits”.

The function of an **Asset Management System** is to investigate and establish the asset management policy, and strategy and asset management objectives (see Figure 4). Climate risk and planning of adaptation and mitigation actions should be taken into consideration when developing an Asset Management Plan.

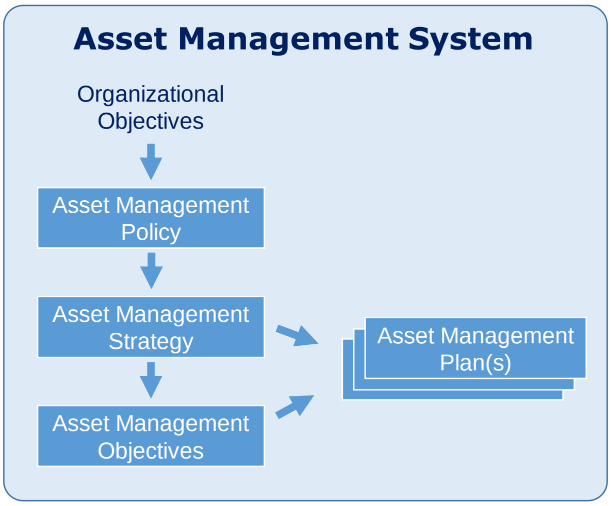

Figure 4. **Asset Management System**

The **Asset Management Plan** is defined as *"Documented information that specifies the activities, resources and timescales required for an individual asset or a grouping of asset to achieve the organisation's asset management objectives"*.

2.5.2 *Including climate related risks in Asset Management Plans*

The inclusion of climate change in an NRA Asset Management Plan is a multi-step processes. Many countries have defined political and governmental goals or requirements related to climate change and have developed action plans on how to deal with uncertainties coming from weather and reduce carbon emissions. The goals at this level are related not only to road infrastructure. The NRA needs to tailor governmental goals to their needs and implement the appropriate action into their Road Asset Management Plan. Figure 5 provides an overview of the process of preparing an Asset Management Plan – commencing with initial data collection and using this to establish a picture of the status of the existing infrastructure (such as condition, criticality, value, extent).

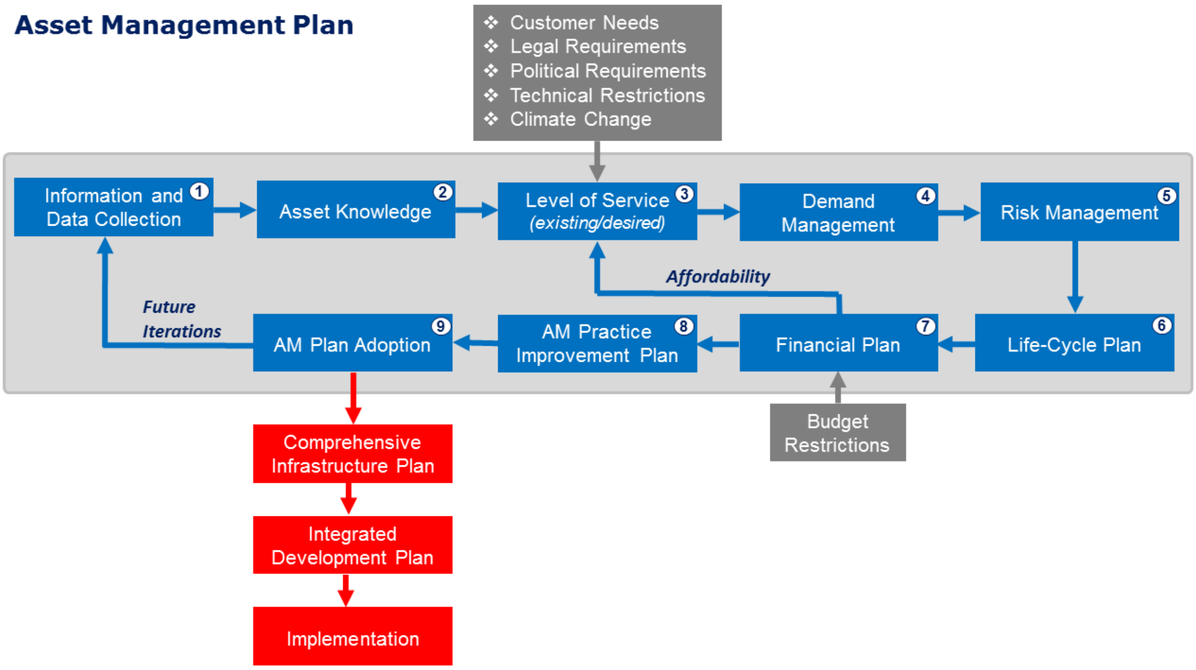

Figure 5. Asset Management Plan (Boshoff *et al.*, 2009)

The resilience of road assets to climate hazards is expressed by defining the desired **Level of Service** (Step 3). Level of Service defined parameters characterise the essential service delivery requirements for a particular service, against which performance may be measured. Criteria can relate to availability of the service, quality/condition, quantity, reliability, responsiveness, environmental acceptability and financial implications. Resilience against weather hazards is usually not expressed directly, but is included in criteria such as availability of service, life cycle performance or environmental acceptability. Table 3 shows an example of Level of Service related to road infrastructure. These criteria can be significantly affected by climate change if appropriate actions are not taken. For example Highways England state that typically 2 fatalities and 10 serious injuries per annum are related to surface flooding (Highways Agency, n.d.), so an increase in flooding due to more frequency intense rainfall events could potential affect safety. Increased incidents of flooding would also affect the availability of the network, potentially damage infrastructure affecting the quality of the road surface and if action was not taken ultimately impact on asset value.

Table 3. Road Transport Level of Service (Boshoff *et al.*, 2009)

Key service criteria		Service level characteristic	Performance indicator	Target value
1	Availability	Vehicular access of residential and business even to the road network	% of total with level of service of grade 3 or greater	100% have vehicular access
2	Quality	Extent of road failures and distresses	Annual review of percentage of roads in a poor or worse condition	Less than 10%
3	Safety	Bridge condition	Condition grading less than poor	No bridges
		Fatality rates	Number of fatalities in the road network per year	Less than X per year
		Vehicle and pedestrian accident levels	Number of accidents reported per year	Less than X per year
4	Asset value	Change in value of assets	5 year rolling average increase or decrease in immovable asset value	In accordance with development vision

Demand management (Step 4) covers the identification of the current and forecasting of the expected demand. In order to better forecast the impact of demand factors, the following key trends need to be considered:

- Economic trends
- Social trends
- Environmental trends which include issues such as climate change and extreme weather events
- Technological trends
- Other future changes.

Changes in climate could affect how often and where people travel or where they prefer to live (e.g. hotter summers may increase the desirability of cooler coastal destinations). Actions to reduce greenhouse gas emissions could also affect when and how often people travel.

The **risk management** process (step 5) needs to be tackled at two levels, as follows:

- At the network level events that could impact on the performance of the service need to be identified. There should be a focus on identifying risk events that will have a major consequence (if there is no separate corporate risk plan, the exercise should include some key corporate risks); and
- At the asset level the most significant events that could cause critical assets to fail (or cease to function adequately) need to be identified.

The common approach to address asset management related risks is to:

- identify risk events;
- determine the exposure to each risk event; and
- determine an appropriate response to each risk event.

Additional information on the steps of risk management is provided in Section 2.5.2.

The results of this step are often documented in the form of risk register. The risk register includes each identified risk event and an assessment of risk exposure before and after the proposed risk mitigating action is taken.

The **life-cycle plan** (step 6) is a considered response to the needs identified in the preceding elements of the Asset Management Plan (i.e. the strategic vision of the NRA, the Level of Service, the pattern of future demand and demand management interventions, and proposed risk responses). The plan will indicate the approach adopted by the NRA in managing the lifecycle of each asset type (e.g. when replacement/renewal is carried out, how new projects are identified and prioritised, operation & maintenance, contracted out or in-house resources, adopted standards etc.). Additionally, the life-cycle plan considers how standards for operation or maintenance need to be altered to reduce the risk of failure. Therefore in order to be robust this plan needs to take account of the projected changes in the climate.

A **financial plan** (step 7) will illustrate all the expenditure to be incurred during the asset's lifecycle, and all revenue that will be realised as a result of the asset's operation. This should also include consideration of the resources needed to carry out the climate change adaptation and mitigation actions that are necessary to meet with the overall strategic objectives of the NRA.

By combining the income and expenditure requirements of all infrastructure assets across the major services the surplus income generated by some services, and the extent to which those surpluses can be used to subsidise expenditure in other services can be determined. All capital projects from the Asset Management Plan will typically require an investment plan. Typically it includes the following elements:

- Construction costs
- Life cycle costs
- Details of sources of funding
- Operation & maintenance forecasts
- Renewal forecasts and replacement costs

Improving upon **infrastructure management practices** (Step 8) is not a once-off activity, but rather a continuous process that requires commitment at all levels of the organisation. In planning for improvement the NRA should pursue reasonable milestones that can be achieved. This means that these milestones should be coupled to realistic timeframes, with sufficient budget allocation, if there is a financial implication. Typically, improvements in management practices are split into several milestones. Every milestone has to be clearly planned and budgeted, and the evaluation criteria need to be defined.

The final **Asset Management Plan** (Step 9) could be created as a combination of all plans developed in previous steps.

2.5.3 *How to conduct Risk Management in Asset Management*

Many authors emphasise that risk management should always be addressed within asset management (Williams, n.d.).

Risks can impact an organisation in the short, medium and long term, and they are related to operations, tactics and strategy respectively. Asset management cannot be operated without risk management (AIRMIC *et al.*, 2010). ISO 31000:2009 Risk Management provides guidance on developing a sound risk management process. The **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 6.

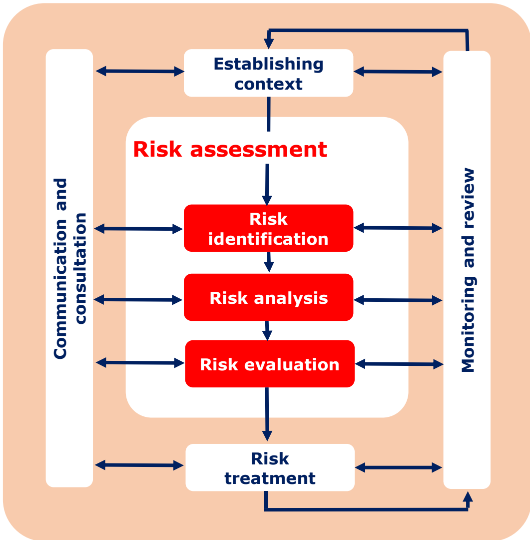

Figure 6. Risk Management process

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. An example of risk matrix is shown in Figure 7.

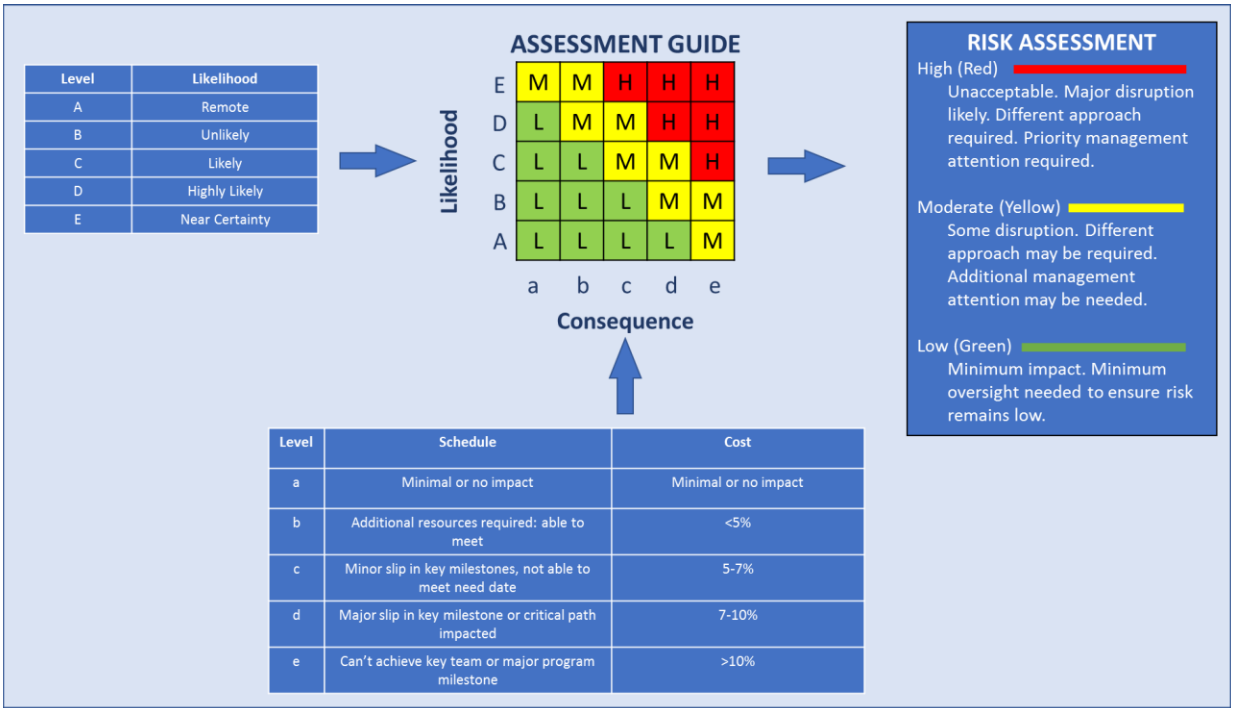

Figure 7. An approach for considering risk in decision making (Source Federal Highway Administration, 2012)

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. Complete avoidance of risk is not possible, and therefore cannot be the aim of risk management.

Risk impact mitigation is action taken to minimise the consequences of an adverse event to an acceptable level. This may include both preventive measures and improvements to the efficient handling of events when they occur, in order to quickly return the system to its previous (or desired) state.

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. The level of acceptable risk will differ by NRA and asset type. For example a bridge or a busy junction is likely to have a lower level of acceptable risk than a less trafficked section of road where there are viable alternative routes. The level of acceptable risk will also be affected by political pressure, customer acceptance and available budget.

2.5.4 *Risk Management in Road Authorities*

Road authorities are constantly confronted with various risks and the integration of risk management into all relevant Road Asset Management processes is thus indispensable.

Risk management is carried out at three levels:

- **Organisation** (i.e. road authorities, road stakeholders, service providers): an activity to properly manage the various risks related to the road authorities; in order to realise the given tasks efficiently and sustainably.
- Road **Networks:** here the aim is to provide an optimal (or at least the minimum acceptable) level of service. There should be a sufficient safety margin with regard to the consequences of damage to the asset. It is also assumed that the expected costs over time for the community and the road authority should have a sufficient safety margin with regard to the consequences of damage to the facility. This should include the impact of climate change and both dimensions of risk (i.e. probability and consequence) need to be assessed.
- Road **Projects:** the goal of risk management at the project level is to evaluate the likelihood and impact of not achieving time or budget demands. Furthermore, for projects in inhabited areas there is a risk of damage to a range of third party persons and property. Finally, there is a risk that the problems which the project causes to the public will cause public protests and political reactions affecting the course of the project. To be successful, the road authorities should address the management of risk proactively and consistently throughout the project. This action involves identifying and describing risk, defining risk ownership and assigned responsibilities, response strategies and specific actions, symptoms-warning, fall-back plans and contingency reserves of time and cost to provide for the risk owners tolerance of risk.

The risks associated with the impact of climate change needs to be included in all three levels, at appropriate levels of detail. An example of organisational level risks for UK roads is presented in Table 4.

Table 4. Example of organisational level risks (Highways Agency, 2011)

Highways Agency high-level climate-related risks to corporate objectives	
Risk	Examples
Reduced asset condition and safety	Assets deteriorate more quickly due to changes in average climatic conditions; assets are more badly damaged as a result of more extreme climatic events.
Reduced network availability and/or functionality	Need for restrictions on the network to maintain safety; increased need for road works.
Increased costs to maintain a safe, serviceable network	Construction/maintenance/repairs/renewal required more often; more extensive construction /maintenance/repairs/renewal required; new (more expensive) solutions required e.g. designs and materials /components/ construction costs.
Increased safety risk to road workers	Increased risk to construction and maintenance workers and Traffic Officers as a result of climatic change e.g. if need to work on the network more often; if required to work on the network during extreme climatic events or if climate change requires them to perform more 'risky' activities.
Increased programme and quality risks due to required changes in construction activities	More onerous design requirements; new technical solutions required with higher uncertainty, affecting project programmes and/or quality.
Current Highways Agency internal operational procedures not appropriate	Effects of climate change require new ways of working - changed or new business processes, new skills/competences.
Increased business management costs	Need for more staff; more frequent (expensive) incidents to pay for; need for more research into ways of coping with climate change.

Crisis Management can also be considered as a particular risk management level.

Crisis management is a situation-based management system that includes clear roles, responsibilities and processes related to organisational requirements. The aim of crisis management is to be well prepared for crisis, ensure a rapid and adequate response to the crisis, maintaining clear lines of reporting and communication in the event of crisis and agreeing rules for crisis termination (Groh, 2014).

Among the types of crises for which road authorities must be prepared, natural disasters including incidents of extreme weather play a particular role. Therefore, the impact climate change on the occurrence and magnitude of natural disasters needs to be considered. It is essential for the development of a country to reduce the impact of climate change on the road network. In order to achieve this, decision-makers and road operators must understand the weaknesses in transport systems and their sensitivity to climate impact caused and/or amplified by climate changes.

The ongoing climate change leads to variation and uncertainty of the maintenance periods and to unpredictable treatments. The risk level is increased or decreased depending on the world region. As a result, risk management in the road sector is considered as a common global task.

2.6 *Including climate change in procurement*

2.6.1 *Contract types*

In order to identify where (i.e. what mechanisms are available) and how (e.g. use of KPIs) climate change can be included in procurement processes, there needs to an understanding of the different types of project delivery, procurement and financing options used for road infrastructure projects. Figure 8 demonstrates the wide range of approaches used by infrastructure owners to procure construction and maintenance services (Gransberg et al., 1999).

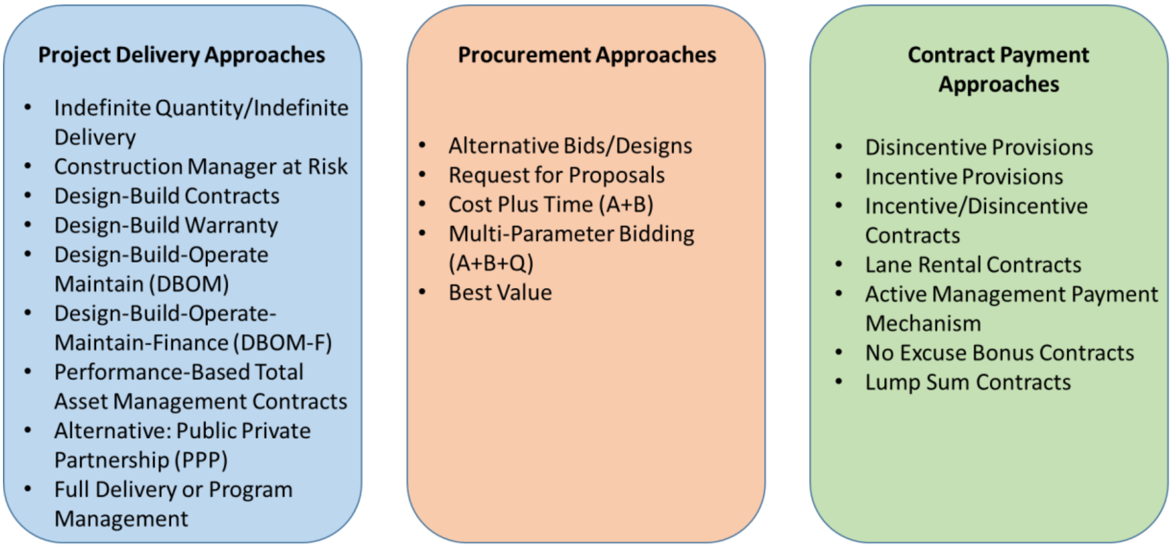

Figure 8. Infrastructure project delivery, procurement and contract payment approaches (Gransberg et al, 1999)

The type of project, expectations, and many other criteria are inputs into the process the road agency/administration uses to decide the project delivery method. Also, as part of a NRA procurement strategy it would be wise to consider a healthy mix of project types for flexibility, maintaining competition, and project duration. Increasingly infrastructure owners are using the Design-Build procurement approach for new construction projects and are also seeking innovation in procurement methods (Pekkala, 2002) in order to achieve a wide range of objectives in a cost-effective manner.

There are two types of contracts relevant to this discussion: capital projects (large scale construction projects) and maintenance contracts.

Capital projects

Examples of innovative capital project procurement approaches are:

- Design-Build (DB)
- Design-Build Operate Maintain (DBOM)
- Design-Build Finance Operate (DBFO)
- Build Own Operate (BOT) & Build Own Operate Transfer (BOOT)

Procurement methods that can be used to minimising road user impacts are:

- Multi-parameter bidding known as A+B and A+B & Quality (warranty)
- Lane rental

- Incentives & disincentives

Other approaches that can be employed in capital projects include:
- Partnering
- Constructability reviews
- Value engineering
- Performance & outcome-based criteria
- Full Delivery or Program Management

Maintenance contracts
Increasingly NRAs are outsourcing road maintenance to private industry, rather than using their own staff to carrying out maintenance. A range of different procurement approaches are utilised. The Finnish Road Enterprise (Pekkala, 2002) identified an increasing use of long-term maintenance contracts. The most innovative include the following parameters:
- Long-term agreements - greater than 7 years
- Partnering (both client & sub-contractors)
- Lump sum contracts
- Using quality-based contractor selection criteria
- Provide some of the sub-contractors with the same long-term agreement or at least sharing the risks/rewards
- Utilising outcome-based criteria
- Ability to use climate change requirements throughout the length of the contract

Changing from an organisation where maintenance is carried out in-house to a client-based organisation usually requires a significant cultural change and is not a simple process. An industry-wide cooperative effort is required with new partnering relationships forged. Trust needs to be developed and bold champions in the decision-making process are needed in order to achieve successful long-term maintenance contracts. It also means the client needs to develop new, appropriate contracting systems to be used in the public delivery process.

Examples of capital project services that can be outsourced by the NRAs include:
- Design/Engineering
- Construction & Construction Management
- Supplies & end products for the road assets (Lighting, guard rails, line marking, etc)
- Design, Construction, & Maintenance & Finance
- Asset Management
- Research & Development
- Administration Services
- Road Management Services
- Traffic Services
- Computer and Data Systems & Services
- Customer Service

For maintenance contracts the outsourced services can be sought in:
- Winter maintenance
- Summer maintenance
- Maintenance products & services
- Road Weather Information Systems (RWIS)
- Pavement Management Systems (PMS)
- Information Technology (IT) applications

2.6.2 *Performance Specifications and outcome based criteria in maintenance contracts*

The use of performance specifications and outcome-based criteria is quite a recent development, especially in capital and maintenance contracts for the road sector. Their use has increased in response to the trend for greater outsourcing of construction and maintenance activities, and consequently the need to infrastructure owners to have a suitable audit and quality processes.

Performance criteria have been widely used in capital projects in other infrastructure sectors, for example in the building technology sector. The performance criteria for capital projects can be quite easily incorporated into Design-Build delivery methods or their related Design-Build models (Design-Build Operate Maintain and Design-Build Finance Operate). For pavements these might take the form of a minimum level in a condition indicator such skid resistance or may include a warranty for a specific time period. Sometimes these performance specifications have been developed from other industries that have successfully implemented them. Among the reasons for the progression to performance specifications are the potential for cost savings, risk transfer, and providing the contractor with more flexibility to utilise innovative and more efficient means of producing the desired performance results. If a NRA uses "Outcome-Based Criteria" in maintenance contracts, the process is somewhat different, as the NRA specifies the desired "outcomes" and the contractor needs to provide the proper strategy to meet these stipulated levels. A significant failure or risk would be to apply inappropriate "Outcome-Based Criteria" which could result in poor quality or failed roads, or even the reverse scenario producing expensive over-engineered roads.

Performance specifications related to climate change considerations can be embedded into the technical specifications for maintenance. Care must be taken in determining the satisfactory or desired levels so that there is neither a large increase in cost nor a large decrease in the quality and performance of the roads. Some examples of outcome-based road maintenance criteria where climate change impacts on KPIs or could be included in KPIs are:

- For pavements:
    - Roughness (IRI)
    - Rutting
    - Skid resistance
    - Deflection
    - Cracking
    - Texture
- Signs - visibility & structural fastening
- Road markings - visibility & skid resistance
- Lighting - % in working order & no two consecutive not working
- Vegetation (grass) - None greater than prescribed height
- Bridges
- Guard rails
- Sound barriers
- Drainage systems

The NRAs need to define the outcome-based criteria that meet or exceed the quality requirements in the contract. Also, the contractor is then responsible for performing the work and activities that meet these requirements. It is very important that there is a mutual understanding between the industry and the procuring road agency organisation on what repercussions or end results might occur.

2.6.3 *Embedding climate change in procurement*

As much of road construction and maintenance is now outsourced to private contractors, embedding climate change in procurement is vital to addressing both climate change mitigation and adaptation. The key issue is how to incorporate the contracting authority's needs for climate change mitigation and adaptation into procurement processes (including through development of output specifications, project requirements, evaluation criteria & approaches) in a way that is objective and not challengeable (Cambray, et al., 2009). Procurement processes are heavily regulated at a national and European level in order to encourage a fair, competitive market, which can create restrictions or perceived restrictions on NRA procurement processes. In broad terms, requirements can only legally be included in public procurement if it can be shown that they are clearly linked to the subject matter of the procurement and within the control of the supplier. This is not always as easy to achieve with sustainability and climate change adaptation requirements, where specific targets can be difficult to set.

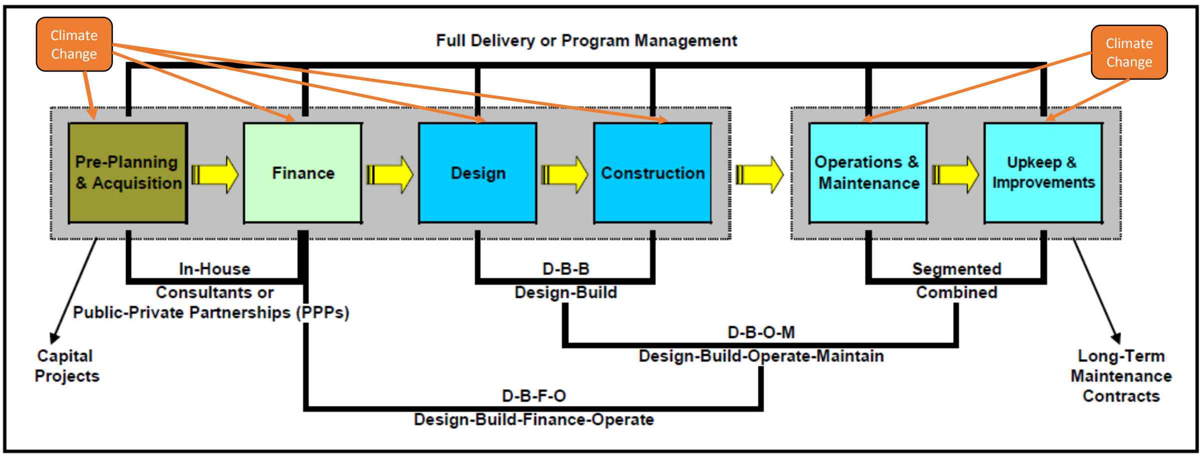

Figure 9. Embedding climate change in procurement programs for NRAs (Based on Pakkala, 2002)

Key messages for contracting agencies/NRAs in terms of including climate change in procurement are provided in Figure 10.

Sharing good practice	1. A stronger mechanism is needed for sharing this. Contracting authorities should make best use of the full range of public sector networks on climate change and procurement, including collaborative procurement opportunities. 2. NRAs should seek and share good practice case studies. This should include examples of specifications and evaluations, and capture the full range of adaptation measures (i.e. not just design features, but end-user behaviour measures too).
Guidance and support	1. Need to develop a programme of support for local authorities on sustainable procurement (based on national program). This is expected to include workshops, training, good practice examples and access to expert panels. It is important that climate change adaptation is fully integrated into this. 2. Guidance needs to be made available about the different ways in which climate change adaptation can be embedded in the procurement process. This should include the importance of the specification and evaluation criteria, investment in skills to manage the process and recruitment of an expert evaluation panel. 3. Guidance could also be explored on how to best distribute risk between the NRAs and contractors and how contracting authorities should reflect their risk acceptance in the procurement process.
Engage the contractors	1. NRAs should include climate change adaptation in the vision for the project from the outset. In many contracting authorities this means raising awareness and training people in service directorates that adaptation needs to be a core principle, rather than an "add-on" by the central procurement team at a later stage. 2. NRAs then need to develop clear objectives (in consultation with the contractors market), benchmarks and indicators, and communicate this to stakeholders and potential bidders. Adaptation should be written into procurement documents and contracts.
Define and apply the vision	1. NRAs need to engage the market early and openly to develop a shared understanding with bidders. The market needs to know the authority is serious about adaptation by weighting the evaluation criteria such that it is a significant part of the project. 2. NRAs need to be open to challenge and ready to enter dialogue about relative priorities (e.g. in striking a balance between carbon management and adaptation). 3. Detailed specifications can be overly prescriptive; instead the market should be allowed to innovate based on the contracting authority's defined outcomes.
NRA Priority	1. Increasing numbers of NRAs have some level of climate change strategy including adaptation. The next step is to embed this throughout the internal decisions making process so those involved in the project commissioning, budget approval and the procurement process itself have the understanding, resources and skills required to deliver climate change and resilience in practice. Adaptation should be written into standard procurement codes and guidance within the NRAs.
Long term thinking	1. NRAs should consider the impacts of climate change on the design over the estimated lifetime of the project, taking account of potential future refurbishment and changes of use, not just the initial length of the contract.

Figure 10. Recommendations for embedding climate change in procurement (Based on (Pekkala, 2002))

Inclusion of climate change into NRA procurement processes is a key element of controlling negative effects of road operations, maintenance and future construction. However, a concern of many NRAs is that including climate change in performance and outcome-based contracts will result in an increase in the proposal costs submitted by tenderers. The experiences of Trafikverket and ProRail who both implemented measures to reduce carbon through their procurement processes suggest that if costs rise, this is a small and short-term effect as competition acts to decrease prices. With adaptation actions the situation is more complex; as whilst some adaptation measures do not increase the overall price, others require additional investment with the economic benefits being realised in the long term. Also depending on the type of contract and delivery methods risk may be shifted from the NRAs towards the contractor, i.e. DBOM contracts.

In summary, the embedment of climate change mitigation and adaptation needs to be based on the individual characteristics and needs of the NRA. It needs to take into account the agency’s ability and propensity to accept the risks resulting from climate change impacts, reflect their asset management approach (worst first, preservation, optimisation) and their type(s) of procurement processes. It is recommended that a holistic, long term perspective is taken in procuring maintenance and future infrastructure construction and that long term benefits such as increased road safety, less disruption, lower maintenance costs, wider socio-economic benefits and environmental protection are taken into account.

3 Current status of embedment in European NRAs

The status of embedment of climate change mitigation and adaptation in European NRAs varies considerably; depending mainly on national legislation, policy and targets driving NRA behaviour. For example, Sweden has a target to have no net GHG emission by 2050 and the Swedish NRA has introduced carbon reduction measures driven by this. The UK Climate Change Act 2008 required important national organisations including road operators to report to the government on their adaptation actions, which drove UK NRAs to address adaptation issues. To provide an overview of the status of embedment across European NRAs and to gather information NRA priorities, availability and use of data in an online survey was developed.

3.1 Survey questions

The survey questionnaire was designed to capture relevant information to create baselines for the DeTECToR consortium to move forward with the tool requirements and prepare ground for the stakeholder workshop in April 2017. The survey was divided into two thematic parts Section A: Asset Management and Section B: Procurement. The survey included questions where there were pre-defined answers to choose from, as well as some open questions. A total of 12 technical questions were asked along with administrative questions to provide country, type of organisation, and name and contact if agreed by the respondent. The survey questions are provided in Annex B.

3.2 Survey results

3.2.1 *Responses*

A total of 44 responses were received during the seven week online survey duration period. These came from 24 separate countries (22 European and two outside of Europe (USA and Australia)), with additional responses from separate regions within countries and different roles within NRAs. Figure 11 shows the geographical spread of the responses.

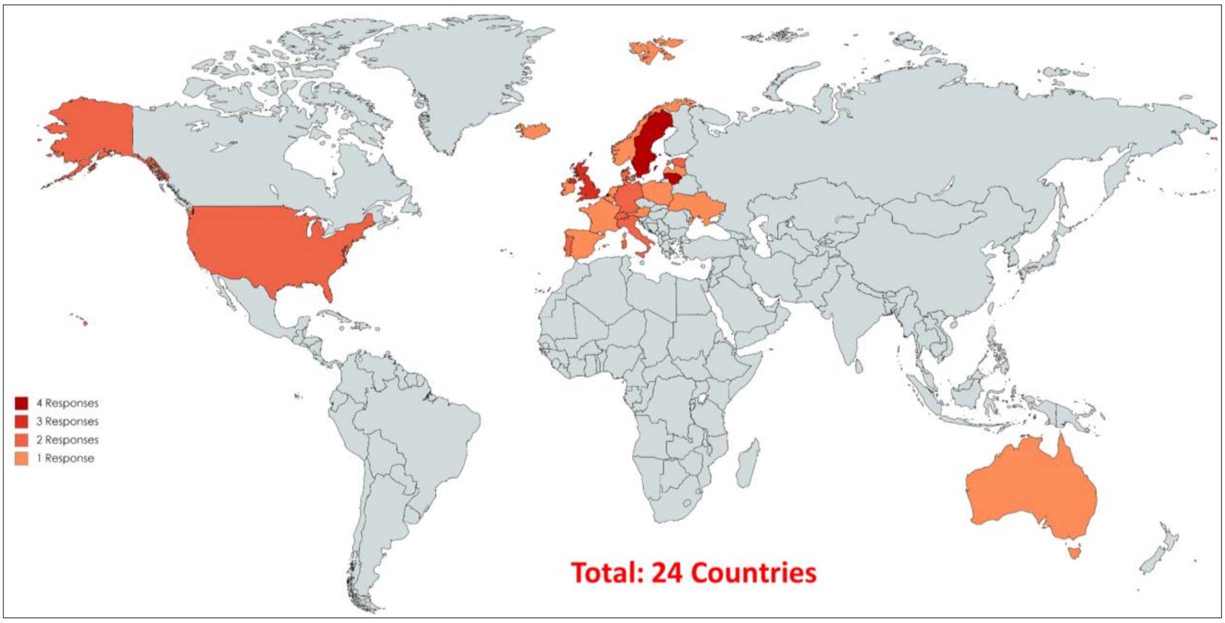

Figure 11. Map of Surveyed Countries

The survey was designed for and targeted at NRAs; however, input from other organisations such as contractors, research institutions and consultants are also important. Responses by types of organisation are included in Figure 12. Around 76% of the responses were from the target responders; road administrations.

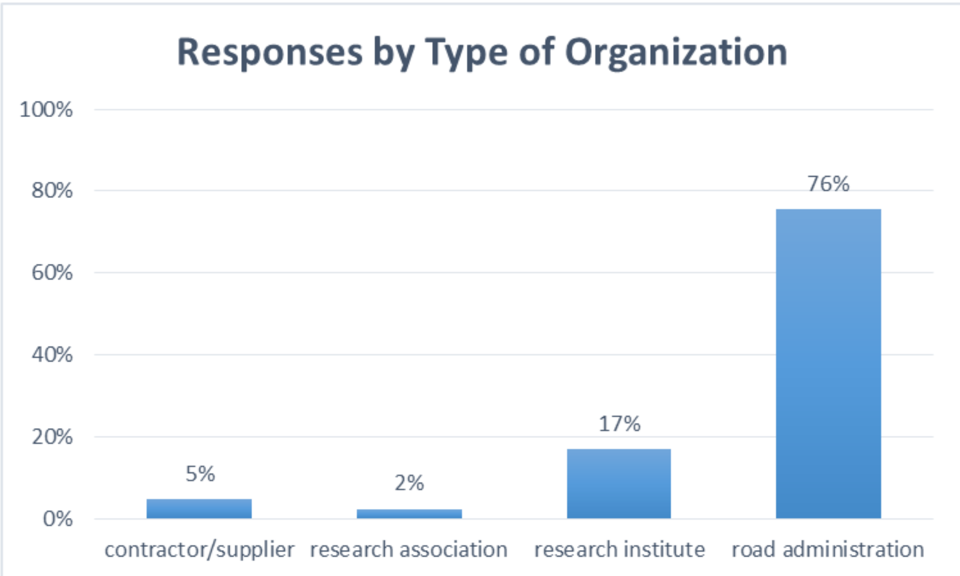

Figure 12. Responses by Type of Organisation Surveyed

3.2.2 *Priorities hazards and asset types*

The surveyed countries cover a variety of climates (with some countries experiencing more than one type of climate). For the European countries, six major climate types were defined:

- Continental
- Maritime
- Polar
- Temperate
- Subtropical
- and combination of the above

For Australia the climate was characterised as Subtropical and for USA the climate was described as continental to maritime and from subtropical to temperate, with polar influences in northern and central areas.

The survey responders were asked to identify the types of weather hazards which caused them most concern and which asset types where affected. Figure 9 shows the six climate types and how the respondent priorities correspond with these. The priorities are also summarised in Table 5.

Table 5. Summary of climate type and hazards identified by NRAs

Climate type	Main hazards	Assets affected
Scandinavia and northern Baltic region with climate change characterised as strong temperature increase in the winter and increase of precipitation in winter and summer (corresponding to dark blue colour on the map).	Flooding and precipitation	bridges, tunnels, geotechnics, pavements, and drainage
West Scandinavia with climate change characterised as particularly strong temperature rise in the northern parts of Norway (corresponding to light blue colour on the map),	Flooding and precipitation	tunnels, geotechnics, pavements, and drainage
Iceland Arctic climate with particularly strong future temperature rise in the winter and also subject to summer and winter increases in precipitation (corresponding to purple colour on the map).	Sea level rise and flooding	drainage and pavements
Western Europe: Atlantic/Maritime climate with temperate, continental to polar influences in general characterised with summer decrease and winter increase of precipitation (corresponding to yellow colour on the map).	Flooding, landslides, precipitation	drainage, pavements, bridges, geotechnics and tunnels
Southern Europe: Mediterranean with climate change characterised as summer and winter decrease of precipitation (orange colour on the map) and particularly strong future temperature rise in Spain (dark red colour on the map).	High temperature, wild fire and flooding	bridges, tunnels, geotechnics, pavements, and drainage
Central and Eastern Europe: Continental, temperate and polar influences, subject to increased precipitation in winter and summer (light green colour on the map) and particularly strong temperature rise in the summer in Ukraine (dark green colour on the map).	High temperature, flooding and precipitation	drainage, pavements and geotechnics

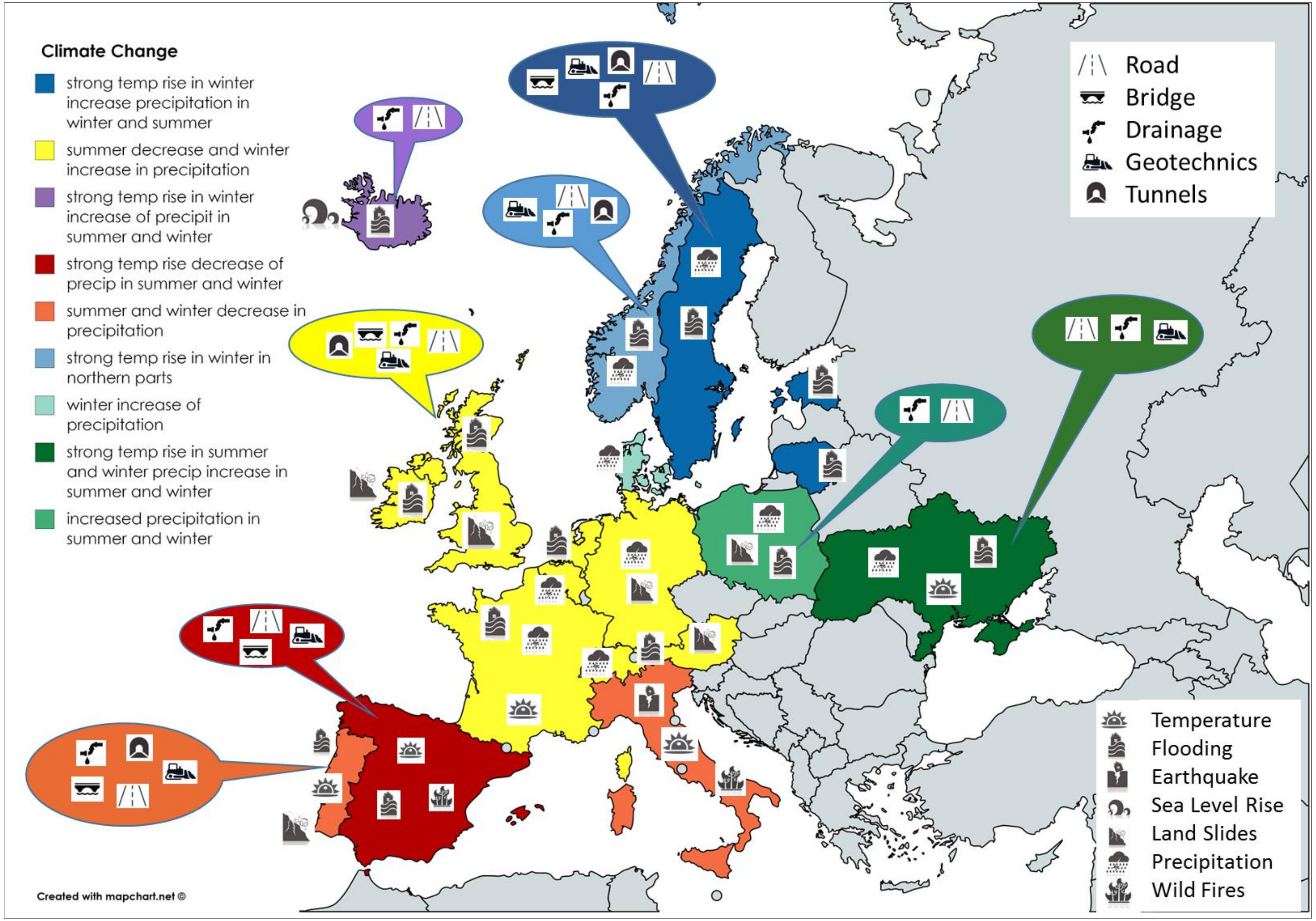

Figure 13. Climate change, asset and priority risks map by region

It can be seen that in southern, central and eastern Europe the major hazards include high temperature and wild fire, whereas in Scandinavia flooding and precipitation are the main priorities. The most vulnerable assets were reported to be drainage, pavements and geotechnics (Figure 14). Of those who responded to this question 84% identified drainage and pavements as vulnerable assets. The least vulnerable was pavement lane markings and ITS (5%). The major hazards for all assets were identified as flooding, storms, and precipitation, which are in line with the climatic changes observed and projected for Europe.

The major weather hazards per asset are the following:

- Geotechnics – precipitation
- Tunnels – flooding
- Pavements – temperature
- Bridges – flooding
- Road furnishing and equipment and Intelligent Transport Systems (ITS) related equipment, static signs – storms
- Drainage – precipitation

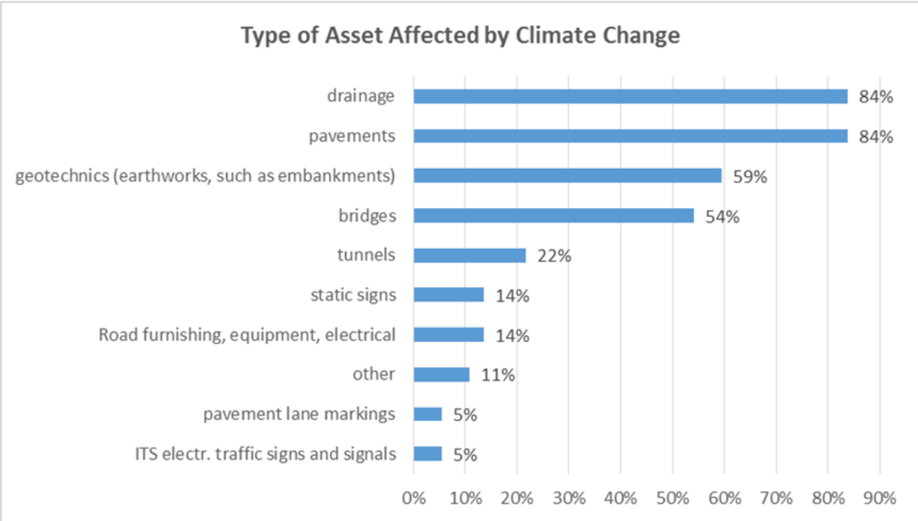

Figure 14. Type of Asset Affected by Climate Change

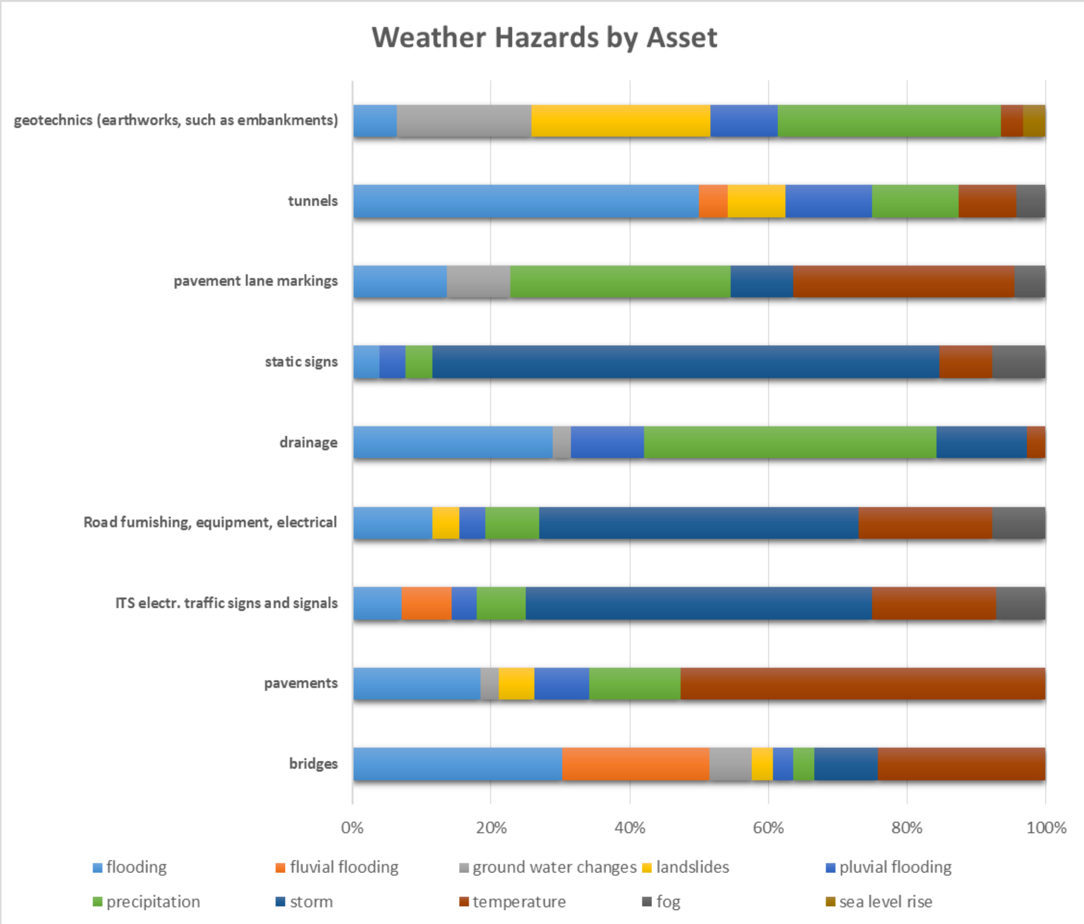

Figure 15. Types of Weather Hazards by Asset

3.2.3 *Data collection and use*

Figure 13 shows that the most commonly collected asset data is location, all those who responded to this question 98% said that this information was collected. Condition and incidents of failure were less likely to be recorded.

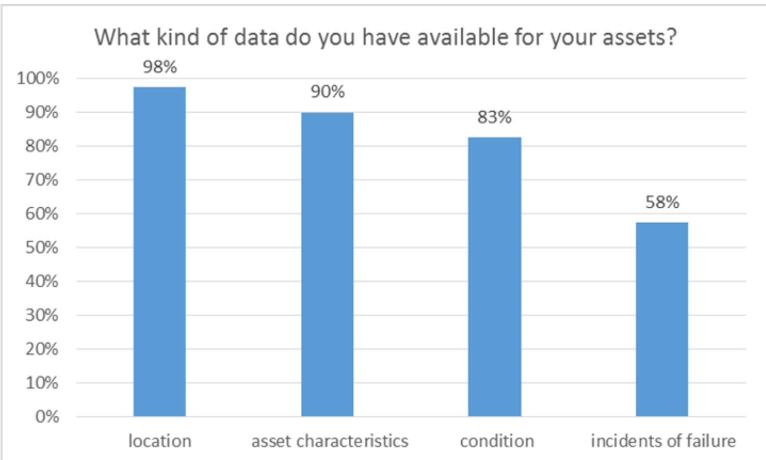

Figure 16. Types of Available Asset Data

Figure 17 shows that type of meteorological data most used is historical weather data (83%), followed by real time data collected from field sensors such as RWIS (76%). This was mostly used for winter maintenance activities. Just under half of respondents said that they use climate projections.

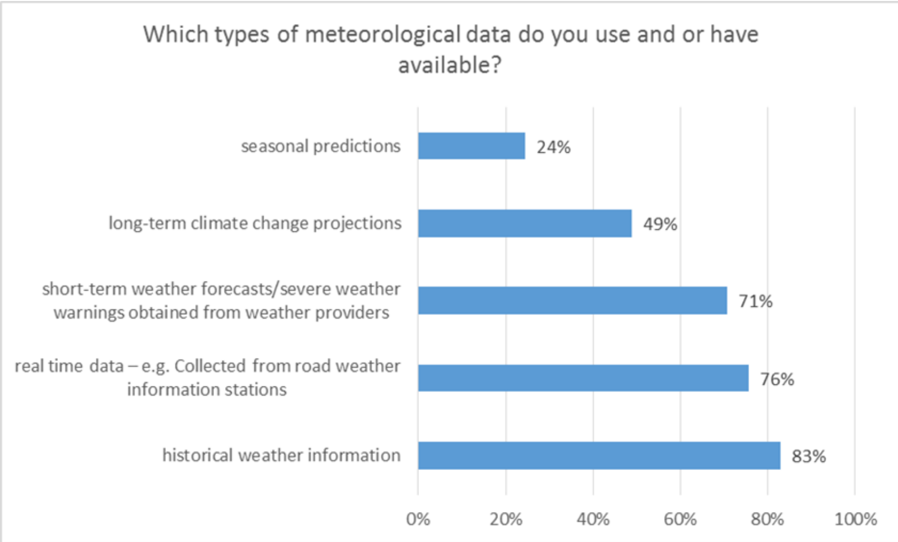

Figure 17. Types of Meteorological Data Used

3.2.4 *Design and planning horizons*

Figure 18 provides the design period per asset. The average time frame per asset is the following:

- Bridges substructure: <5 years
- Bridges superstructure: 21-50 years
- Geotechnics (earthworks, embankments): 51-100 years
- Tunnels: >100 years
- Pavement lane markings:<5 years
- Pavement surface: 11-20 years
- Pavement Substructure: 21-50 years
- Drainage: 21-50 years
- Road furnishing: 5-10 years
- ITS: 5-10 years

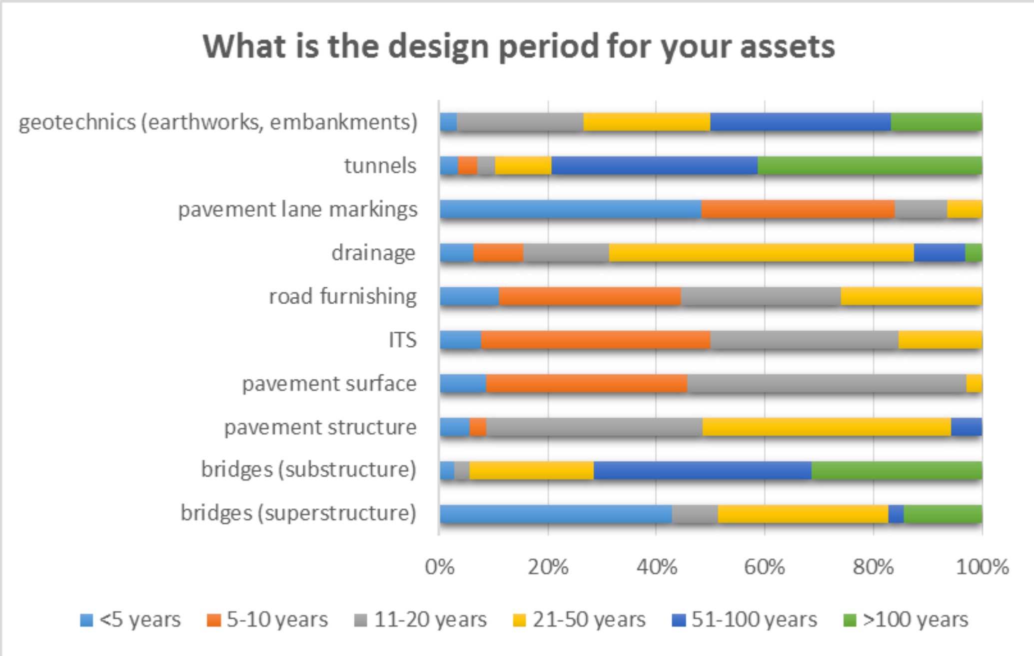

Figure 18. Design Period per Asset Type

Figure 19 shows the typical planning horizon for different asset types. This average asset maintenance planning horizon is between 2 and 5 years.

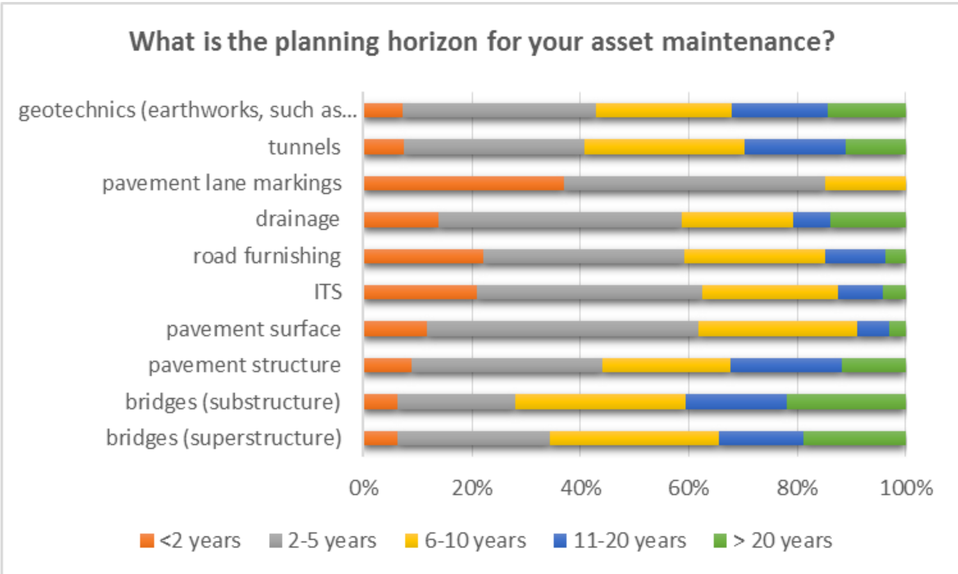

Figure 19. Planning Horizon for Asset Maintenance

3.2.5 *Embedment of climate change adaptation*

Figure 20 illustrates that many NRAs do not currently include consideration of climate change in their major decisions. It is most often considered in the development of technical standards and the design of new infrastructure. The majority of NRAs said they do not consider climate change in asset management plans or in business cases for construction or maintenance projects.

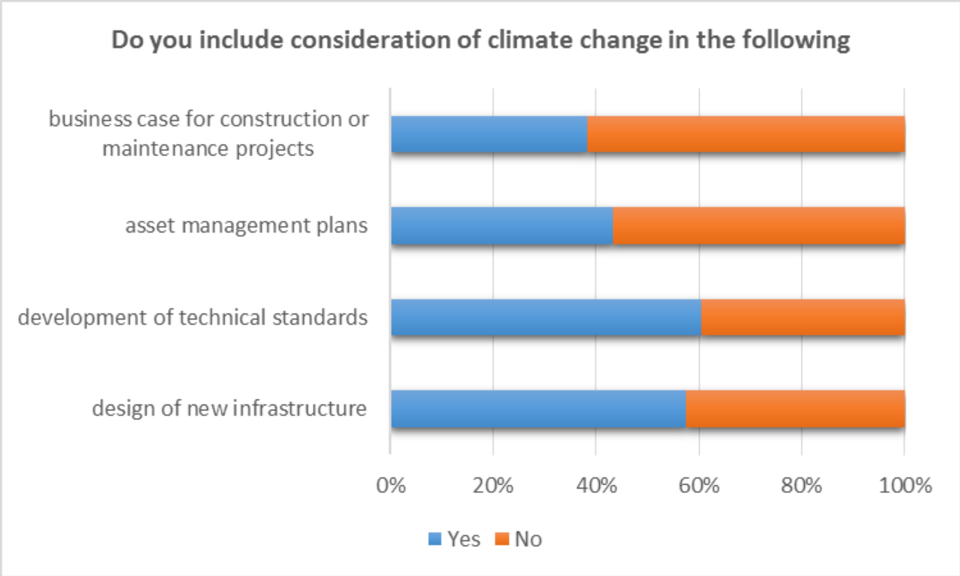

Figure 20. Considerations of Climate Change in Selected NRAs Procedures

As can be seen in Figure 21 76% of respondents stated that they do not include climate change impacts in the economic appraisal of potential construction projects or future plans and 74% said they do not use climate risk assessment tools.

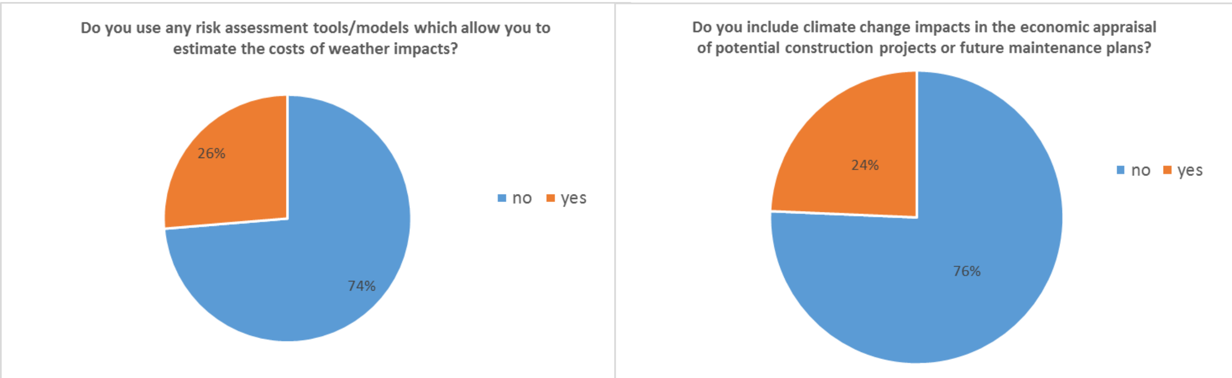

Figure 21. Usage of Risk Assessment Tools and Inclusion of Climate Change in Economic Appraisal

Figure 22 shows that the majority are NRAs are considering climate change risks in their operations in some way – only 34% said they did not include it any of the options given. The two most common areas for considering climate change related risks where when preparing emergency response plans, project specifications and contracts, and developing business cases for funding projects (37%).

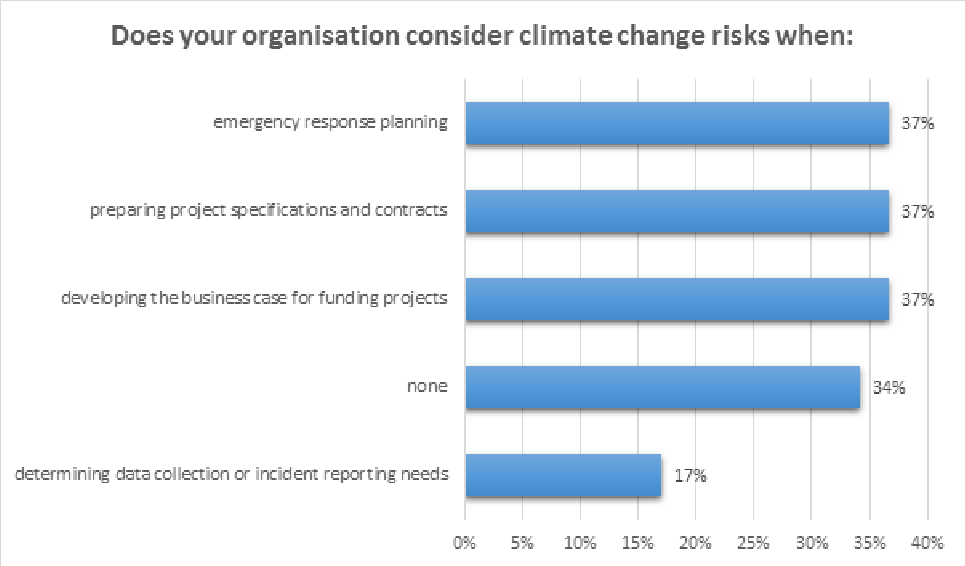

Figure 22. Considerations of Climate Change Risks

3.2.6 *Embedment of climate change mitigation*

In comparison to the adaptation response, 39% of those who responded to this question indicated that they were not undertaking any of the listed procurement approaches related to reducing climate change. This implies that the majority of NRAs are using some form of tools or measures to control CO_2 emissions in their procurement processes (see Figure 23). Around 34% of the NRA respondents said that they are including requirements relating to carbon reduction in their tender evaluations and 32% consider carbon emissions when making a decision on which project to fund. However, only a small percentage of respondents (10%) are currently using carbon related KPIs in projects and maintenance contracts.

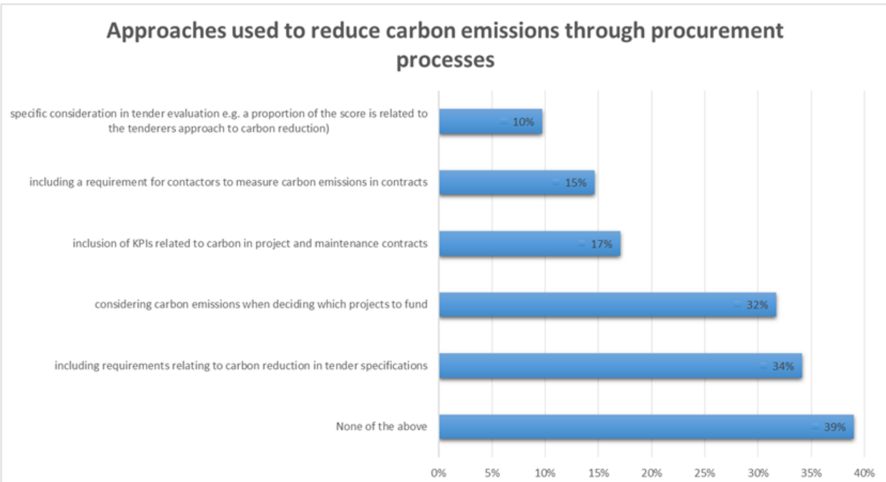

Figure 23. Reductions of Carbon Emissions through Procurement

Figure 24 shows that the most commonly used approach for encouraging suppliers to reduce carbon was promoting the use of renewable energy (38%). Other approaches such as the use of carbon calculators, setting carbon reduction targets for the infrastructure projects, industry awards and incentive programs for those contractors who perform well and above the targets were also employed by a small number of respondents.

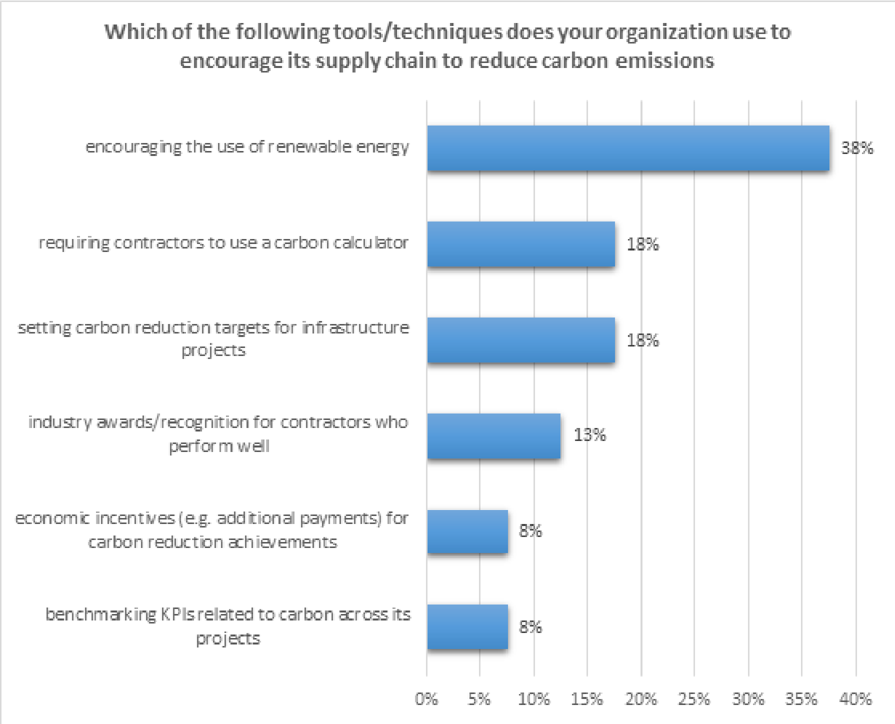

Figure 24. Tools used to Reduce Carbon Emissions

3.3 Discussion

3.3.1 *Response*

The survey had a high response rate including a broad range of countries with various types of networks and climates. Thus it can be concluded that the survey results are based on a reasonable sample size. A few difficulties were raised by respondents; for example, some NRAs had difficulty finding one person able to answer all the survey questions. This also provides an indication that the information needed to address climate change can be spread across organisations. The roles and responsibilities within NRAs are also divided differently in different countries; for example, in Sweden there is a climate change mitigation and adaptation coordinator to deal with climate change issues, whereas in others there is an environmental role which covers both aspects of climate change, along with other types of environmental issues.

3.3.2 *NRA priorities*

The survey helped to identify the priorities for the NRAs in terms of assets and hazards, and this was correlated with climate type. Flooding (including fluvial) is a high priority for most of the central and western European countries; increased precipitation (including snow and storms) and landslides are priorities in mountainous and coastal regions, and extreme heat is an issue in Mediterranean countries including wild fires and earthquakes in Italy.

3.3.3 *Data*

The majority of NRAs collect data on the location and type of asset; however not all have information on asset condition. Respondents also said that the quality of data varies between asset types; for example, data on drainage can be difficult to obtain. Historical climate and short term forecast data is the most used meteorological data, sometimes in addition real time data collected from road field sensors. It is most often used for winter maintenance purposes or warning drivers of local conditions. Fewer NRAs use climate projections or seasonal forecasts.

3.3.4 *Design life and planning horizons*

Design life varies from 100 years or more for structures to less than five years for road markings. There is quite a large variation between countries. Planning horizons are often quite short, even for long life assets. This could be a challenge when integrating climate change impacts.

3.3.5 *Embedment*

More actions are carried out on climate change mitigation than adaptation. Only 30% of respondents said that they included climate change impacts in the economic appraisal of new projects or future maintenance plans. Around 26% of respondents said they used some kind of risk assessment tools or models to estimate the cost of weather impacts.

3.4 Conclusions

The main conclusions from the survey are that:

- Climate change related events have the highest impact on drainage, geotechnics, pavements, bridges and tunnels.
- Precipitation, flooding and storms are the major risks which are mentioned by the majority of countries and in reference to almost all asset types.
- There are some differences in priorities depending on climate, but flooding is a universal issue.
- Most NRAs include some aspects relating to climate change mitigation in their procurement processes, but many do not.
- Most NRAs do not include climate change related impacts in the economic appraisal, nor use it in the risk assessment models for their potential construction projects and future maintenance contracts.

The general message is that there are some countries which do include elements of climate change in their procurement and operational processes; this is normally relates to climate change mitigation. Climate change is not included in the majority of European NRA operations and procurement processes, and most do not address climate change adaptation.

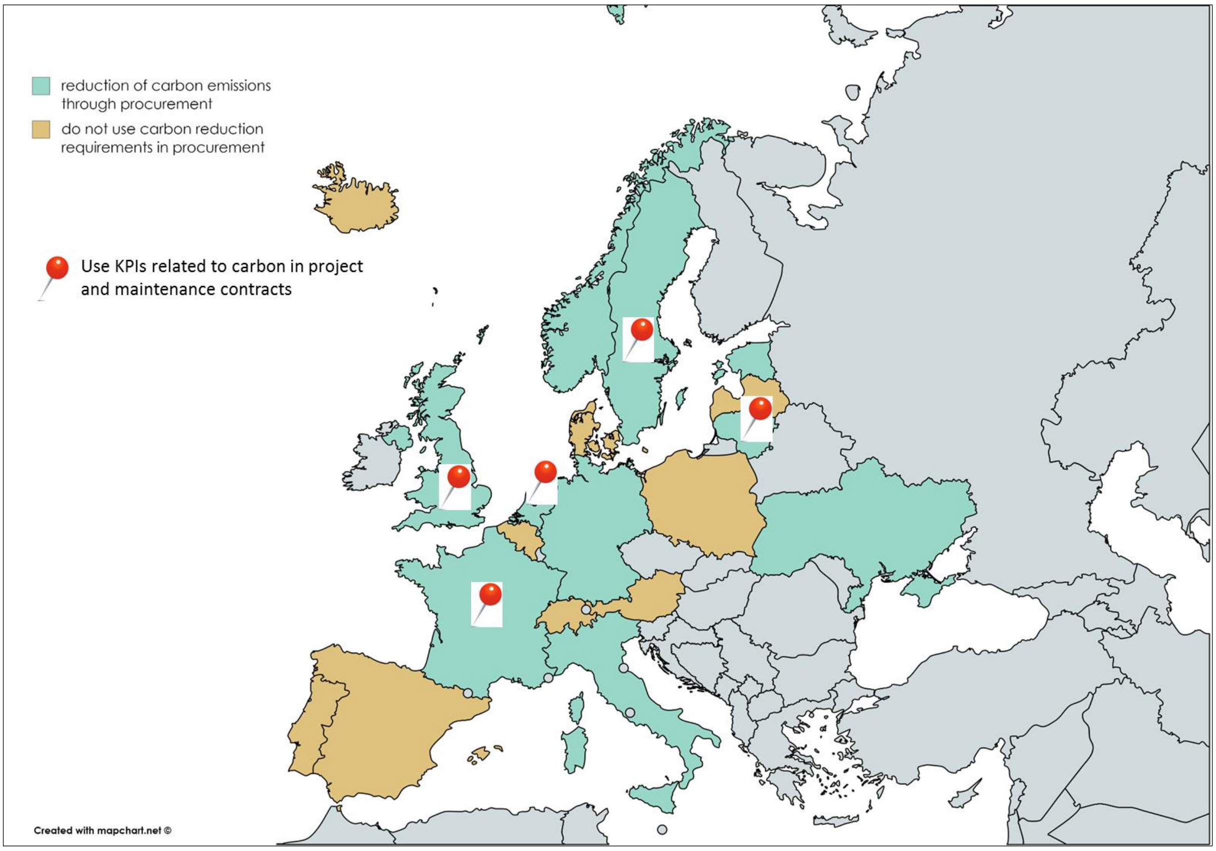

Figure 25. Map of countries where the NRAs are including carbon emission reductions in their procurement

4 A review of the latest research and good practice

In Section 4 the findings from a review of published research and guidance relating to the aspects of climate change mitigation and adaptation covered by the DeTECToR project are given.

4.1 Understanding the impacts of climate change on roads

4.1.1 *Climate data and projections*

Adaptation of transport infrastructure is a huge endeavour, since the existing European transport network is extensive and diverse. Adaptation actions may involve the use of different materials which would better withstand the changing climate conditions and extremes, but in some cases roads may need to be relocated to safer areas, which is extremely costly. It is therefore important that adaptation action is evidence based and actions can be prioritised. This necessitates an understanding of the projected climatic changes and how these could impact on road networks.

According to projections, as they are for example compiled in the IPCC Reports, climate change and extreme events will damage a range of critical infrastructure, including transport infrastructure which is particularly vulnerable. The main drivers of climate change are temperature (including frost/thaw cycles in winter and road deformation in summer), precipitation (leading to flooding and landscape erosion) and storm intensity (leading to various transport disruptions). Impacts can be exacerbated by other factors such as changes in population, wealth, urbanisation, and regulation or consumer behaviour. Consequently, the necessary effort and the ensuing costs of maintaining transport infrastructure are likely to increase due to a combination of these drivers.

The entire infrastructure will be affected, but the threat is more pronounced in coastal areas. Changes in weather and climate extremes, and sea level rise may impact on coastal roads, especially when locate on low lying land. It is important to also note that major infrastructure such as ports, power stations etc. are often built on European coastlines and even though these may not be directly affected, the access roads to them could be. Additionally, transport systems are critical for effective disaster response, be it concerning evacuation pathways or concerning the provision of food, water, and emergency services to affected populations.

4.1.2 *Use of climate data and projections by NRAs*

An exemplary study was carried out in the CEDR project CliPDaR on the use of climate projections in the road sector. It offered results from state-of-the-art climate modelling and focused on three essential extreme factors with a high hazardous potential for transportation infrastructure. This selection is by the same token of high relevance to NRAs.

To begin with, it should be noted that average conditions are better captured by a climate model than extreme condition – therefore the selection needed to be underpinned by the aim to identify extreme factors that offer a chance to be acceptably reproduced by climate models. Those were the factors and indicators identified in CliPDaR:

- Frost-thaw-cycles – days which exert high stress to transport infrastructure as well as to traffic itself; a day is defined to belong to a frost-thaw-cycle if a temperature is recorded as above freezing, as well as a temperature below freezing. In CliPDaR the definition of such cycles was modified in a user-relevant way, since it was prescribed that the daily temperature should range from -2°C or less to +2°C or more. This is the so-called “distinct zero temperature crossing” indicator.

- Extreme precipitation – in order to identify events with a high impact for runoff and flooding, a threshold of daily precipitation totals of 30 mm was used.
- Days with particularly high day and night temperature conditions – these so called "rutting days" which constitute stressful conditions, e.g., for road surfaces or bridges were defined as having a maximum temperature above 30°C and a minimum in the subsequent night that did not occur below 20°C.

Moreover, the analysis encompassed a selection of 20 urban areas (transport spots) in Central Europe located at different elevations. It made a survey of the occurrence of those indicators under current climate conditions and analysed their development using climate projections.

4.1.3 *Implications for DeTECToR tools and guidance*

The findings of CliPDaR are an adequate basis for further investigations in DeTECToR; however it needs to take account of the following points:

- NRAs will need similar information as in CliPDaR, but for more locations than the 20 Central European transport spots which CliPDaR analysed.
- There is the need for similar information for areas outside of Central Europe.
- It may be necessary to analyse different precipitation threshold than 30 mm – surpassing such a fixed limit may exert a major threat in low lying areas, but for higher elevations, prone to heavier rainfall, it does not pose the same level of threat.
- CliPDaR made use of the then-available greenhouse gas scenarios which are linked to emissions; meanwhile successor generations of global climate models, regional climate models and greenhouse gas scenarios has been developed. The latter uses concentrations of greenhouse gases instead of emissions. DeTECToR investigations should be taking those updates into account.

4.2 Assessing climate change risks to roads

At first glance, a broad range of projects touch issues with regard to assessing climate change risk and roads are often mentioned to be part of the projects' context.

However, many studies are on a more or less rough and abstract in scale. They therefore look on climate related risks in terms of macroeconomic parameters and macrosocial challenges.

As NRAs are responsible for the development and operation of national road networks or sub-nets, risk assessment approaches need to refer concretely to a particular network segment/road section or even to a concrete road element or building to support NRAs' decision-making processes. That is why, although risk assessments are part of a number of the rough scale studies, risk assessment results are often of a rather limited information value for NRAs since they do not correspond to the level of detail and issues mattering in the NRAs' actual decision-making.

With a closer look it becomes apparent that only few studies do actually refer to questions of risk assessment in a level of detail that matches perspective, concerns and information needs of NRAs. In particular, for the assessment of climate related risks to road infrastructure, concrete approaches potentially suitable for NRAs' scopes of responsibility are rare.

4.2.1 *State-of-the-art*

The analysis of studies which have a significant relation to climate related risks to road infrastructure and provide an adequate level of detail were reviewed. The main findings are as follows:

- The studies display differences regarding how climate change is reflected. Some projects focus more or less 'only' on extreme weather events (heavy rain, hot spells etc.). Other projects take on a broader view and therefore look at the change of the actual climate parameters. This allows them to reflect on not only extreme events (which are reflected if climate parameters take on respective extreme values) but also enables them to reflect on the gradual parameter changes (such as changes in numbers of 'summer days' or of freeze-thaw-cycles etc.). This broader view is assumed to be more comprehensive in view of the NRAs' need for information.
- Studies often focus on qualitative assessment methods as they experienced problems in the availability of comprehensive data. However, a couple of approaches do include quantitative evaluation steps.
- The studies differ regarding whether and how climate projections are carried out and included in the risk assessment. All projects use historical weather data. However, some studies have also conducted climate projections to reflect future climate scenarios. This makes assessment approaches more meaningful.
- The projects differ regarding the size of study area and display different levels of detail with regard to the examined (road) infrastructure.
  (network/subnets/road sections; road as a whole versus differentiation according to road elements; focus on specific technical components, e.g. drainage)

The following <u>sources which discuss single sub-aspects</u> with regard to assessment of climate related risks to roads are worth mentioning:

- SWAMP (focus on drainage)
- P2R2C2 (focus on pavement)
- Re-Gen (focus on asset management for ageing structures)
  The project aimed at presenting an overall approach, considering performance aspects such as structural degradation, increasing loads, and natural hazards in the decision making process for management of ageing structures.

The framework proposed in the Re-Gen project consisted of three modules – module one is concerned with degradation modelling and considers ageing, traffic volume and environmental conditions, as potential factors in the degradation process; module two considers an integrated risk analysis, while module three considers maintenance strategy optimisation.

- **RAINEX** (Risk-based approach for the Protection of Land Transport Infrastructure against Extreme Rainfall)
  The project focused on identification and assessment of transport infrastructure towards extreme rainfall. This was based on expert knowledge and included both qualitative and quantitative analyses for the assessment of the vulnerability and criticality of relevant transport infrastructure.

Noteworthy sources which focus on roads as a type of critical infrastructure, that have a clear focus on roads and apply a more or less comprehensive risk catalogue (such as climate related risks) includes:

- **AllTraIn (All-Hazard guide for Transport Infrastructure)**
  The project aimed to develop a comprehensive and structured all-hazard guide for critical transport infrastructures in Europe (i.e. including both natural and man-made hazards). The guidebook enables owners and operators of transport networks to identify relevant threats for its infrastructure and types of infrastructures in the network which are susceptible to a specific threat. This approach supports the prevention and preparedness of critical infrastructure by stimulating and supporting risk assessment and developing methodologies for the protection of critical infrastructure.

Noteworthy sources which discuss concrete assessment approaches for climate related risks and are on a sufficiently detailed level, have a clear focus on roads and apply a more or less comprehensive risk catalogue are:

RIMAROCC (Risk Management for Roads in a Changing Climate)

The main focus of the project was translating the steps of a common risk management process into the explicit context of climate change induced risks to roads. This also includes conceptual considerations for risk assessment. Therefore, the project provided important methodical basic work. Results have been refined with respect to practical applicability in the follow-up projects for ROADAPT and RIVA, which built upon the RIMAROCC methodology.

ROADAPT (Roads of today, adapted for tomorrow)
The project outcomes per se can be understood as a further concretisation of RIMAROCC, particularly with regard to the guidelines A (use of climate data), C (vulnerability assessment) and E (adaptation strategies), ROADAPT clearly adds value.

However, with regard to guidelines C (QuickScan), it is questionable whether the workshop based approach would be applicable for the handling of complex networks, such as national road networks or comprehensive subnets. The proposed approach for impact assessment only considers potential loss of time for evaluation of the various climate change related threats. Hence, cost impacts on the road infrastructure itself due to prompt or gradual damages are not taken into account. However, from the NRA point of view, impacts on their direct infrastructure costs (reconstruction, maintenance and operation) are also of substantial relevance. Therefore, the added value of the ROADAPT impact assessment is limited from NRAs' perspective.

In addition, the ROADAPT overall approach so far does not provide for a systematic merging of cause related and effect related assessments towards an overall risk value per threat. This impedes comparability of risk potentials.

EWENT (Extreme Weather impacts on European Networks of Transport)
The project includes all transport modes and takes on a European-wide view. As road transport is only one subject of investigation amongst others, respective findings and examinations are on a rather coarse scale. Furthermore, the risk assessment method does not involve actual characteristics of a road/road subnet but does apply a nationwide uniform infrastructure quality index (susceptibility). Hence, the risk indicators derived do not allow for the level of differentiation needed to support NRAs in their concrete decision making with regard to a particular road/road subnet.

Additionally, the inclusion of coping capacity (measured by GDP per capita, purchasing power adjusted) into the calculation of a vulnerability index leads to increased vulnerability values in case of low GDP and lowers vulnerability values in case of high GDP. This follows the concept, that the macroeconomic perspective GDP could be an indicator for the restore capacity.

However, from a NRA's point of view, vulnerability is clearly not determined by a macroeconomic figure but depends on technical characteristic of the particular infrastructure and its actual exposure to the respective climate impact (extreme event or changing climate parameter). The concept of vulnerability and hence the concept of the risk indicator in the context of the EWENT project therefore does not correspond with the NRAs' perspective.

RIVA (Risk analysis of key goods and transit axes including seaports)
The project focuses on risk assessment for the German motorway network and aimed to develop a methodology as well as a pilot tool for assessing risks for current and future time periods for a complex road network.

Attributes of climate and infrastructure are incorporated into a hierarchic structured indicator model. Accordingly, the model takes into account climate events, vulnerability of risk elements, characteristics of potential effects and criticality of infrastructure as the four dimensions of attributes.

The project defined the 'damage pattern category' as unit for investigation. This copes with the fact that climate induced damages often relate to more than one climate event/parameter (combination or sequence). At the same time this allows for aggregation and structuring of the range of various potential effects on infrastructure elements to a reasonable and workable set of investigation units. The method provides evaluation for the potential exposure to hazards (sphere of cause), for the potential of effects (sphere of effect) and for the overall risk potential as a function of cause and effect.

The inclusion of characteristics of the potential effects, as well as of criticality, allows for the display of different potentials of effect; this enables the validation of risks from the economic perspective. The modular structure of the tool allows for integration of further/changed damage pattern categories and for expansion/change of parameter sets; therefore, it is able to include future findings.

4.2.2 *Implications for DeTECToR tools and guidance*

Overall objectives which need to be taken into account for the development of tools and guidance that suit 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

Hence, in the course of the further project progress, particular attention should be paid to the following aspects:

Varying understandings of the term ‘risk’ and implications for assessment methods

With regard to the set of studies dealing with risk assessment approaches, it must be noted that they, to some extent, display different understandings of the term “risk” in the context of the project matter. However, this is not only a matter of definition or academic discussion but needs to be kept in mind when interpreting assessment results and choosing methodical approaches.

For example, ‘risk’ can be interpreted as mainly related to cause. Accordingly, assessment concepts focus on climate parameters (potential hazards) and vulnerability of infrastructure which together constitute the potential exposure to hazards of the infrastructure. For this kind of risk understanding, risk values generated do not allow for conclusions with regard to potential of effects.

However, the understanding of ‘risk’ in terms of risk effects is just as important since risks differ with regard to their inherent way and intensity of impacts on traffic flow and damages to structure/road elements. Hence, an adequate reflection of effect related risk understanding in assessment approaches is of particular importance from the NRAs’ economic perspective.

As a consequence, risk assessment methods have to integrate the sphere of cause as well as the sphere of effect appropriately to suit perspective and information needs of the NRAs. Furthermore, it is important to allow for a systematic merging of cause related risk evaluation (potential of hazard) and effect related risk evaluation (potential of effect) up to overall risk potential values.

Therefore, the understanding of ‘risk’ which should be reflected in the DeTECToR tools and guidance needs to be as follows:

$$RP_O = f(RP_H; RP_E)$$

with:
RP_O =*overall risk potential*
RP_H =*risk potential of hazard*
RP_E =*risk potential of effect*

Approaches should provide for a step by step evaluation of risk indicators from the cause side, as well as from the effect side along a clear hierarchical structure. This will enable NRAs to evaluate risk indices on different aggregation levels.

Technical implementation of methods and meaningful presentation of results

In regards to technical implementation conclusions from the respective studies indicate that it is absolutely essential to conceive assessment tools in a way allowing for systematic and routine computer aided application. Requirements to be met include, for example:

- Suitability for involvement of existing data
  (e.g. technical parameters of roads/road components, traffic data, data collected anyway with regard to status and dimensioning of elements etc.)
- Affordable resource requirements
  (no excessive computer resources needed, software features usually available or obtainable at manageable efforts etc.)
- Meaningful presentation of results, preferably presentable in tabular form and map view

Integration of data from existing data bases by means of standardised data interfaces is worth to be aimed at in the future. However, this is not achievable in the context of DeTECToR.

Availability of necessary data

All studies experienced issues in regards to availability of applicable data on an adequate level of detail. It is assumed for DeTECToR that availability of data will also be challenging. Hence, the availability of data will be essential criteria for selection of the case studies. In addition, proposals for how to obtain the required data must be included in the DeTECToR guidance.

4.3 Climate change adaptation measures

4.3.1 Introduction

Adaptation measures with respect to road infrastructure can be subsumed in three major categories:

1. Early warning systems (Alfieri *et al.*, 2011):
   This includes all measures and systems that raise preparedness towards weather-related hazards, e.g. weather prediction/forecasts or flood warning systems.
2. Non-structural prevention measures (Ranzi *et al.*, 2011):
   This includes (deterministic or probabilistic) hazard mapping, land use and urbanization planning as well as risk transfer practices.
3. Structural prevention measures (Brilly *et al.*, 2011):
   This includes all types of structural measures and geotechnical engineering, e.g. retaining walls, check dams or snow bridges.

This entails two different levels of actions to be distinguished regarding time-scale and immediacy of adaptation measures:

- Strategic level: These are any actions implemented within the scope of maintenance or reconstruction work, e.g. adapting asphalt types or pipe diameters to withstand more extreme events. The planning horizon for these measures is medium to long-term.
- Operational level: Any short-term action to flexibly respond to possible hazardous events, such as using variable message signs for providing warning messages and traffic control.

Considering various alternatives with respect to type and immediacy of adaptation measures is thus of core importance for efficient and effective planning of adaptation strategies.

4.3.2 Status quo of applied research

Research projects
Even though many projects deal with climate change adaptation for roads to some extent, specific recommendations related to adaptation measures are rare. This section provides a short overview of the adaptation measures proposed in recent projects:

ECONADAPT (Roads of today, adapted for tomorrow)

ECONADAPT has developed adaptation economic methods for assessing adaptive capacity by considering costs and benefits of adaptation. The ECONADAPT data repository contains 54 adaptation measures and 249 adaptation sources, grouped by policy area. The project shows the merits of adopting cost-benefit analysis and multi-criteria analysis in the economic appraisal of road projects.

SUNRA (Sustainability – National Road Administrations)

The project dealt with understanding, measuring, improving, managing and reporting of sustainable development from an NRA perspective.

SUNRA covers 26 different aspects of sustainability performance including climate change adaptation and mitigation. Under the climate change adaptation topic area there are questions relating to processes and policy, flooding, drought, wind speed and growing season, habitat and species. Under climate change mitigation there are questions relating to processes and policy, traffic emissions, operational energy, materials, transport of materials and wastes and construction plant.

SUNRA provided methods to make cost effective choices and interventions with respect to sustainable development and improve the long term choices of NRAs.

CEREAL (CO_2 Emission REduction in RoAd Life cycles)

CEREAL aimed at enhancing Europe wide carbon foot printing of road construction and pavement maintenance. The project's main output is a tool for assessing CO_2- emissions in different phases of a road pavement life cycle (design, construction, maintenance and rehabilitation).

IRWIN (Improved local winter index to assess maintenance needs and adaptation costs in climate change scenarios)

The application of climate indices (derived from a climate database containing downscaled climate data) to depict potential changes in need of maintenance activities is advocated.

SWAMP (Storm Water Prevention, Methods to Predict Damage from the Water Stream in and near Road Pavements in Lowland Areas)

A Geographical Information System (GIS) is used to detect the most vulnerable parts of the road network concerning floods ("blue spots"). In order to take into account future climate change impacts, the use of a "climate factor" is proposed. This "climate factor" is incorporated into the assessment of future climate risks by simply multiplying design events (floods) with a certain constant.

EWENT (Extreme Weather impacts on European Networks of Transport)

Focus is on adaptation policies and related concepts (effectiveness, effectivity and acceptability) rather than on specific adaptation measures.

Potential strategies in mitigating extreme weather risks are related to three different contexts: (a) European Union, (b) Member States and (c) Mode-specific considerations, mainly drafted by international umbrella organisations and bodies acting with one single transport mode.

Focus is on non-structural prevention measures and early warning systems. Stakeholder interviews indicated that continuous cooperation with national weather services and environmental authorities with persistent development of specific warning services is the most effective way to mitigate weather risks. These measures also fulfil the requirement of cost-effectiveness.

Education and training of transport managers and users are considered to be important adaptation measures. In addition, it was noted that better monitoring systems and forecasting methods are required for coordinating immediate actions.

KULTURisk (Knowledge-based Approach to Develop a Culture of Risk Prevention)

The focus of this project is on social and economic benefits of risk prevention, i.e. the reduction of potential (flood) losses due to the implementation of prevention measures.

Results show that the implementation of early warning systems, as well as structural and non-structural prevention measures, and combinations thereof, can significantly reduce potential flood damage.

ROADAPT (Roads of today, adapted for tomorrow)

A (draft) version of a database of adaptation measures is one of the core outputs of the project. Depending on climate parameter and threat type, a policy matrix containing adaptation measures related to the resulting specific combinations can be queried. Recommendations in the matrix cover all stages of the risk-management cycle as well as different categories of adaptation measures and are depicted as combinations thereof. In addition, results are attributed to one of four different strategies: (a) do minimum / develop contingency plans" strategy, (b) future-proof designs / retrofit solutions / update operating procedures strategies, (c) monitoring strategy and (d) research strategy.

AllTraIn (All-Hazard guide for Transport Infrastructure)

The project AllTraIn aimed to develop a comprehensive and structured all-hazard guide for critical transport infrastructures in Europe. Adaptation and mitigation measures are presented for specific phenomena (e.g. extreme wind, extreme rainfall) in so-called hazard fact sheets.

4.3.3 *Implications for DeTECToR tools and guidance*

Implications derived from a review of existing research refer to two areas.

As far as procurement processes are concerned, several projects have shown the benefits (for both economy and environment) of incorporating the effects of climate change impacts into procurement. The merits of using sustainable performance indicators for making cost effective choices and interventions with respect to sustainable development are a core contribution to improving the long term choices of NRAs. Adopting cost-benefit analysis and multi-criteria analysis in the economic appraisal of road projects provides valuable information for decision-making. These efforts, with respect to incorporating climate change and environmental effects into decision making by means of economic methods, provide a sound basis for the DeTECToR project to build upon.

Several projects have already assessed the impacts of a changing climate on changes on roads and road networks. However, concise recommendations with respect to adaptation and mitigation measures are difficult to derive and thus hard to find. Only a few projects have attained to establish prototypes of adaptation measure databases targeted at certain impacts and assets. Regarding the implications for the DeTECToR project, it should be noted that recommendations have to be precisely targeted at combinations of specific hazards and road assets (cause-effect relationships), while providing an inclusive overview at the same time. Generic recommendations that do not consider this relationship are probably not very useful for road authorities.

In DeTECToR, the consideration of cause-effect relationships between hazard types and effects on specific infrastructure assets is of core importance for developing viable tools and guidance documents. Both non-structural measures, such as hazard mapping, methods to raise awareness and early warning systems, as well as solutions related to geotechnical engineering and other structural measures are considered in this project. Based on the draft version of the database for adaptation measures created in the ROADAPT project, as well as the Hazard Fact Sheets designed in AllTrain, a decision support tool containing refined adaptation measures is developed in DeTECToR. The DeTECToR cost-benefit tool consists of two modules, a planning module and an asset-management module.

The planning module provides a framework to assess the likely exposure to climate hazards for a specific route and asset design, thus displaying the aforementioned cause-effect relationship. Since risks relate to failure and deterioration rates, and costs are associated with aspects such as construction, future maintenance, delays, accidents, different adaptation measures can be considered for both risk and cost estimation. Different risks to various assets along the routes under consideration will be aggregated in order to provide a holistic risk estimate. Instead of using “climate factors”, proper estimates derived from climate projections will be used.

The asset management module produces estimates of maintenance and management costs under different climate change scenarios and timeframes. With respect to adaptation measures, this module is also designed to consider both engineering options (e.g. alternative materials and designs, improved drainage) and non-structural methods (e.g. effective asset management, innovative ITS solutions, green construction materials). These rehabilitation treatments are evaluated together with their impact expressed in cost factors.

The DeTECToR guidance documents provide additional information about the economic appraisal of climate change into cost-benefit analysis. In this context, adaptation actions are discussed against the background of data requirements, uncertainty, assumptions made and how they could be eventually assessed using the tool.

4.4 *Reducing carbon emissions*

4.4.1 *State-of-the-art*

Road transportation is responsible for 26% of total energy consumption which relates to about 24% of all CO_2 emissions (the main greenhouse gas) in the EU, with passenger cars being responsible for more than half of these emissions (European Commission, 2010). Despite manufacturers reducing CO_2 emissions, increasing numbers of vehicles of the road means that emissions have been continuously growing by about 2% per year. Therefore, to fulfil the EU obligations with target 20-20-10 and tackle climate change, CO_2 emissions from vehicles need to be reduced (European Commission, 2011).

Environmental goals that fall into the NRAs responsibilities also include actions which contribute to carbon emission reductions. These include:

- Managing traffic so there is less idling time for vehicles
- Objective to reduce GHG emissions from domestic transport (emission targets)
- Enforcing use of low carbon intense construction materials for roads (also including technical requirements in for green procurement).
- Enforcing and encouraging low carbon intense maintenance techniques.

According to research done by the Swedish Road Administration, the majority of GHG emissions from infrastructure is generated by concrete, machineries and trucks (fuel), steel and asphalt (Figure 25).

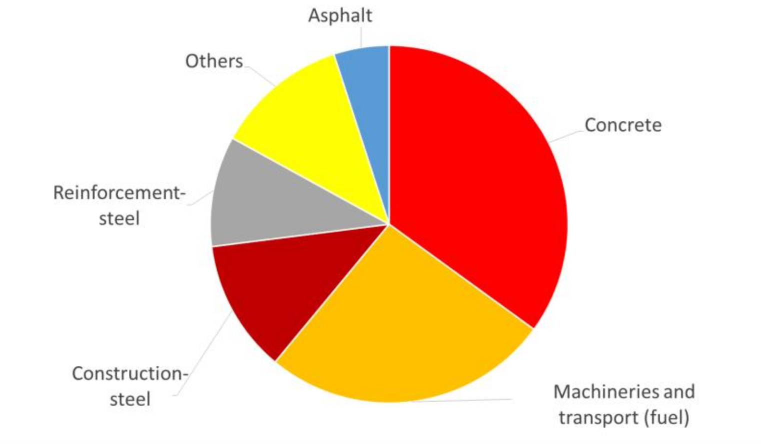

Figure 26. Sources of GHG from infrastructure based on Swedish national projects, source: Trafikverket, 2016

Basic principles in the development of climate requirements regarding GHG emissions include the following:

- Long term targets
- Technical neutral
- Monitoring
- Incentives for achieving more than required
- Penalty for not fulfilling requirements
- Impact assessment

Requirements on GHG emission should be included in all four phases of the project:

- Measurement selection study
- Planning Phase: Requirement on consultant to present measures in the planning phase
- Design Phase: Quantitative requirement on reduced GHG emissions on consultant or turnkey (design) contract
- Building Phase: Climate declaration to control compliance of requirements to reduce GHG emissions

Relevant projects and examples of tools used by the NRAs and other infrastructure operators (rail) are described below.

Klimatkalkyl

This is a model developed by the Swedish Transport Administration (Traffikverket) for efficient and consistent calculation of the energy use and potential climate impact of transport infrastructure. The model can be used to make climate and energy calculations for individual investment projects, or for parts of investment projects, and as a tool for systematic and effective improvements in climate and energy efficiency of infrastructure. The Swedish Transport Administration guideline TDOK 2015:00071 specifies when and for what measures climate calculations are to be carried out using the Klimatkalkyl model (Trafikverket, 2016). The model is based on a life cycle assessment (LCA) methodology and uses emission factors with an investment's project-specific resource use, or resource-use templates for standard measures, to calculate energy use and emissions of greenhouse gases (CO_2 equivalents). The emission factors used in Klimatkalkyl have been defined by the Swedish Transport Administration.

CEREAL (CO_2 Emission REduction IN roAd Lifecycles)
The project aimed at enhancing Europe wide carbon footprinting of road construction and pavement maintenance. A tool was developed for the prediction of CO_2 emissions in the construction and maintenance phase of roads called Carbon Road Map. Default data is available in the tool or report and part of the database is fed by LICCER. A benefit of this model structure is that it can be tailored to the local situation.

LICCER (Life Cycle Considerations in EIA of Road infrastructure)
The project developed a model including a framework and guidelines. This was based on existing tools and methodologies for Life Cycle Assessment (LCA) and GHG emissions of road infrastructure that can be used within an EIA process in the early stage of transport planning. The LICCER model includes site-dependent aspects of the planning such as the choice of a plain road, bridge or tunnel. The life-cycle model focuses on energy use and contribution to climate change. The LICCER model calculates the annual cumulative energy (consumption and greenhouse gas emissions) of the involved road corridor alternatives using default values. The model enables NRAs and other stakeholders to compare different road corridor alternatives in the decision-making process. The model is based on LCA methodology following the ISO 14040 standard. It was applied for verification in two case studies in Sweden and Norway.

MIRAVEC (Modelling Infrastructure Influence on RoAd Vehicle Energy Consumption)
The project developed a spreadsheet tool based on simplified fuel consumption models that allowed the comparison of the effects of different infrastructure-related measures on fuel consumption and CO_2 emissions. The model requires data about the most widely available pavement and road layout parameters, and uses information about traffic flow and vehicles as background information. While the tool can be applied even with limited data, the strong influence of these background data found in the analysis may supersede the infrastructure effects in some cases.

The MIRAVEC tool estimates the average vehicle speed from the road geometry, the level of rutting, ride quality, the level of traffic and the split of heavy to light vehicles. In addition, a simple method for estimating the effect of idle time due to traffic congestion has been developed and implemented. It further enables users to estimate vehicle fuel consumption associated with a specific route and to explore the effects of various changes to the road infrastructure on the fuel consumption. This spreadsheet tool has been used to assess the potential benefits to be gained from making improvements to the infrastructure (i.e. the capacity for NRAs to provide energy reducing road infrastructure) by considering different scenarios and using statistical data available from national road networks.

CO_2 Performance Ladder
ProRail, the Dutch Rail Operator, has developed a procurement tool called the CO_2 Performance Ladder, which compares contractors' approaches to carbon reduction (Doree *et al.*, 2011 and University of Exeter, 2013). Contractors are evaluated on the following:

- Insight into where emissions are generated;
- Reduction targets and monitoring of these;
- Transparency and communication of their carbon reduction actions;
- Participation in sector initiatives to reduce carbon.

Contractors are encouraged to share their carbon reduction ideas as they are evaluated on their joint ventures and work with environmental Non-Governmental Organisations (NGOs). The company's self-assessment is certified by an accredited Conformity Assessment Body. The company evaluations contribute towards a virtual discount on any tenders they submit. Depending on the evaluation category (0 to 5), this can be up to 10% of the tender value.

Although the use of this tool initially resulted in ProRail paying 0.3% more for projects, quickly all the contractors worked to achieve level 5, so that their competitors would not have an advantage and that the costs would be reduced within six months. In the longer-term this encouraged contractors to reduce energy use, which also reduced project costs and encouraged collaboration and innovation. The contractors passed the sustainability requirements on to their supply chains, cascading the effect. The tool has been adopted by contractors and has successfully improved carbon management in the Dutch rail industry. Its use has also spread to other construction sectors including road.

Improving Transport System Efficiency on the network level is one of the key responsibilities of NRAs which can lead to the reductions of CO_2 emissions generated by road transport. System efficiency improvements can reduce GHG emissions significantly and generally produce valuable co-benefits such as reduced traffic congestion, improved air quality, and lower costs. NRAs can play a major role in improving the efficiency of transportation systems via the investments they make in infrastructure for highways. NRA agencies also manage traffic and enforce laws and regulations; therefore, improving highway system efficiency is critical. If congestion reduces the average speed on freeways below 45 mph, CO_2 emissions increase (Davis & Boundy, 2010; West, McGill, & Sluder, 1999). In part, this is because vehicles achieve lower fuel economy at slower speeds. Increasing vehicle speeds to the range of 45 to 60 mph typically reduces GHG emissions per mile. Smoothing out stop-and-go traffic so that vehicles can travel at a relatively constant speed will also reduce CO_2 emissions. However, increasing traffic speeds beyond 60 mph will generally increase CO_2 emissions per mile. For every 5 miles per hour above 60 mph, fuel consumption increases by about 8 percent (DOE, 2010c).

Researchers at the University of California at Riverside have used detailed traffic flow data to estimate that each of the following three strategies could reduce CO_2 emissions on Los Angeles freeways by 7 to 12 percent, and in combination by as much as 30 percent (Barth & Boriboonsomsin, 2009; AASHTO, 2009).

- Congestion mitigation: ramp metering, incident management including real-time traveller information, and congestion pricing
- Speed management: speed limit enforcement, intelligent speed adaptation
  Traffic smoothing: variable speed limits, dynamic intelligent speed adaptation, and congestion pricing

Further, since reducing traffic congestion saves time, which is a larger component of travel costs than fuel costs, vehicle travel is sure to increase somewhat when traffic congestion is reduced (Greene and Plotkin, 2011). The overall GHG reduction from reduced congestion is therefore likely to be considerably less than 1.6 percent, and probably closer to 0.5 to 1 percent of highway vehicle emissions (Cambridge Systematics, Inc., 2009).

The SULTAN Tool (SUstainabLe TrANsport)
The Illustrative Scenarios Tool has been developed as a high-level calculator (not an in-depth model) as part of the EC's on-going 'EU Transport GHG: Routes to 2050' study to help provide indicative estimates of the possible impacts of policy on transport in the EU (primarily energy use and GHG emissions, also costs, energy security, NOx and PM emissions) (Hill and Morris, 2012).

The purpose of the tool is to allow the quick scoping of a wide range of transport policy options to get a feel for what scale of action might be required. It will also be used as part of the analysis for the final written technical outputs of the project. The aim of the tool is to help transport and climate change stakeholders to develop Policy Scenarios, based on the assumptions on how policy will impact the future transport system, and then to allow them to quickly and easily view the GHG emissions that would result from the system under the Policy Scenario developed.

The following selected parameters can be calculated using the SULTAN tool per individual and multiscale scenarios:

- Total combined lifecycle (calculated based on input from modes such as road vehicles, rail, fright, maritime shipping, rod/rail, etc).
- Cumulative GHG emissions (input from modes as above)
- Total final energy
- Average energy carbon intensity
- Total emissions by mode and many more

4.4.2 *Implications for DeTECToR tools and guidance*

Based on the Swedish Road Administration experience the following conclusions regarding reduction of GHG emissions are:

- Saving money and reduced GHG emissions often goes hand in hand – proposed requirements are not expected to increase costs at least not to 2020.
- The vision on climate neutrality in 2050 need development in cement and steel sector (for ex. CCS-technology). Development should be followed in cooperation with the industry.
- Proposed requirements on reduction of GHG emissions are reasonable and acceptable in most cases, but development and clarification is needed in some cases.
- Transport Administrations should work with consultants, contractors and suppliers to reduce conflicts with regulations
- Contractors and material suppliers advocate incentives to complement the requirements to promote innovation and encourage the industry to go beyond the requirement
- For maintenance, an initial work is required to identify GHG emission sources and reduction potentials.

This type of information can be incorporated in the procurement tool and guidance.

Some basic principles applicable to reducing emissions from infrastructure include the following (Johansson *et al.*, n.d.):

- The requirements should be long term so that the consultants and contractors get sufficient time to develop cost efficient strategies to develop solutions to deal with them. This includes rather more ambitious requirements later than less ambitious requirements with no lead time.
- The requirement on reduction of GHG emissions for a certain year about 5 years from now should be supplemented with an indicative, longer term target 10 years from now. This will give the consultants and contractors long-term rules to develop solutions for the future.
- Technically neutral requirements on reductions of GHG emissions that describe what should be achieved instead of how it should be achieved. In this way the consultants and contractors can chose the most cost efficient solution.
- Monitoring should be mandatory for every contract that is subject to the requirements. Monitoring of separate contractors for all contracts that they have can also be done. By comparing results of different contractors and benchmark them a form of competition between them can be established.

- The requirements should be complemented with research and development activities together with the consultants and contractors. Focus should be put to reducing the cost of promising solutions with large potential to reduce GHG emissions.
- Barriers for using cost efficient solutions should be identified as well as solutions to unlock these.
- Encouraging Green procurement for all purchases (materials, service, maintenance, construction, vehicles, etc) leading to reduction of CO_2 emissions. According to EU Directive 2009/33/EC or the Clean Vehicles Directive requires that energy consumption and environmental impacts are included in all public authority purchasing decisions for road transport vehicles (European Commission, 2011). The aim of these EU GPP criteria is to go beyond that of the directive and set minimum and award criteria that further aid the purchasing decision and reduce environmental impacts.

4.5 Including consideration of climate change in road operations

Embedding climate change in road operations is a broad subject, covering multiple topics such as those listed in Table 6.

Table 6. Aspects of NRA operations

Mitigation	Adaptation
Setting organisational policy and targets	
Developing an action plan	
Prioritisation - Identifying sources of high emissions	Prioritisation - Identifying vulnerable, critical assets and assessing risk
Gathering evidence and producing a business case for action	
Employing specific actions to reducing operational carbon	Improving the ability of specific infrastructure to withstand a larger/different range of weather variation at prioritised locations
Employing specific actions to reducing embodied carbon	Improving response and recovery
Supporting the use of low carbon vehicles	Use of weather warning and forecasting systems to trigger NRA action or warn users
Changing culture/mind sets	
Communication with users and 3rd parties (e.g. neighbouring landowners, water companies etc.)	
Incorporating in asset management processes/plans, economic appraisal and project planning	
Inclusion in standards and design specifications	
Influencing supply chain, e.g. via procurement	
Measuring and monitoring progress	
Review and revise	

There are very few research projects which cover all these aspects of NRA operations, but there are a number of overarching frameworks or guidance documents which describe many of these elements; for example, the PIARC International Framework for climate change adaptation for roads. This document was developed to provide guidance for road authorities of all types to help them plan action on climate change adaptation. It takes them through steps to identify, assess and prioritise risk to road assets and operations, develop and select adaptation responses and integrate the findings into decision-making processes.

The majority of research projects focus on one particular aspect of NRA operations; for example, development of indicators or methodologies for assessing risk. Many of the reviewed projects address the influence of climate change and extreme weather events on the transport infrastructure in general, but only touch on the operational aspects slightly. Developed tools and guidelines mainly concentrate on the identification of potential risks and methods for determination of adaptation and mitigation action. The methodology for applying these approaches into the road operation was not the main objective of the research.

In the following chapter, the project related to consideration of climate changes in road operation are listed under the relevant topic areas and the important results related are described.

4.5.1 *State-of-the-art*

Relevant research projects on different aspects of embedment into NRA operations are described below.

Overall approach

RESILENS (Realising European ReSILiencE for Critical INfraStructure)
RESILENS develops a European Resilience Management Guideline (ERMG) to support the practical application of resilience to all CI sectors will be developed. Accompanying the ERMG will be a Resilience Management Matrix and Audit Toolkit which will enable a resilience score to be attached to an individual CI organisation (e.g. CI provider or road operators) and at different spatial scales (urban, regional, national and transboundary).

Overall, RESILENS aims to increase and optimise the uptake of resilience measures by CI providers and guardians, first responders and others (e.g. road operators).

SmartResilence
SmartResilence is a still ongoing project that aims to provide an innovative and holistic methodology in order to create a system of resilience management to address the complexities of large integrated systems and the uncertainty of future threats.

The aim is to impact planning and organisational institutions which are in conjunction with critical infrastructure (such as operating units) in order to enhance resilience through increased awareness, preparedness and appropriate behaviour during disasters.

Measuring and monitoring progress

To be able to improve some aspect of performance, there needs to be an accurate and consistent method of measuring it. There are a number of different research projects developing indicators or tools related to climate change mitigation and adaptation:

IRWIN (Improved local winter index to assess maintenance needs and adaptation costs in climate change scenarios)
The objective of IRWIN was to develop an improved winter road index using historical observations from the Road Weather Information System (RWIS) networks in Sweden and Finland. Index can be used as an assessment aid in present-day as well as future climate scenarios.

The index developed in this study has shown to be a useful tool for future maintenance operations. It can give valuable information to stakeholders as to where and when measures need to be taken. It is highly recommended that Road Owners start operational archival and quality control of all road weather observations in their countries.

SUNRA (Sustainability – National Road Administrations)
SUNRA covers 26 different aspects of sustainability performance including climate change adaptation and mitigation. (**Climate change adaptation:** questions relating to processes and policy, flooding, drought, wind speed and growing season, habitat and species. **Climate change mitigation:** questions relating to processes and policy, traffic emissions, operational energy, materials, transport of materials and waste and construction plant.)

It helps NRAs to define sustainability considerations at a strategic level in order to make it available for operation

CEREAL (CO_2 Emission REduction IN roAd Lifecycles)
The CEREAL project aimed at enhancing Europe wide carbon foot printing of road construction and pavement maintenance and for operating units. The project was based on experience with CO_2 tools for road construction and maintenance projects. It provided European NRAs with a tool, called the Carbon Road Map, which is easy to use for calculation of CO_2 impact.

LICCER (LIfe Cycle Considerations in EIA of Road Infrastructure)
Environmental impacts from the road transport sector are often associated with the vehicles on the road as well as the construction, operation and maintenance of the road infrastructure. The LICCER project gives an overview of the road infrastructure planning process and the roles of environmental assessments and life cycle within them. Project takes impacts from traffic on the road are taken into account.

MIRAVEC (Modelling Infrastructure Influence on RoAd Vehicle Energy Consumption)
Most of the changes applied have small effects on the average CO_2 output per vehicle per km and therefore significant changes in the fuel consumption will be most easily achieved on sections with high traffic levels and road infrastructure. The project provides guidelines which can be used when talking about road operation costs in connection with fuel consumption costs.

Culture

KULTURisk (Knowledge-based Approach to Develop a Culture of Risk Prevention)
The KULTURisk project is developing a culture of risk prevention by evaluating the benefits of different risk prevention initiatives. The project shows that prevention measures are more effective from a social and economic point of view than post-disaster recovery. A culture of risk prevention is promoted by emphasizing the importance of increasing risk awareness / preparedness and shaping risk perception of the public in order to influence human perception and understanding in relation to road operation.

Understanding impacts and assessing risk

CliPDaR (Design guideline for a transnational database of downscaled climate projection data for road impact models)
Within CliPDaR, ensemble strategies were used which draw from the climate assessments and projections of several models. It also gives guidelines for NRAs how to deal with

relatively cold winters/hot summers (or return periods of extremes) regarding to road operation.

RAIN-EX (Risk-Based Approach for the Protection of Land Transport Infrastructure against Extreme Rainfall)
RAIN-EX developed a practical methodology for the identification and assessment of critical (transport) infrastructures with regard to flooding event that incorporates risk management. As a result, a handbook on risk management of land transport infrastructure against extreme flooding events was produced. The guide was aimed to enable owners and operators to assess their existing infrastructure regarding protection goals with respect to criticality of the structures.

CIPRNET (Critical Infrastructures Preparedness and Resilience Research Network)
Critical Infrastructures are becoming sensitive to cyber threats and catastrophic meteorological events and requires more research, which is lagging behind in its practical application. CIPRNet planned to create new capabilities for critical Infrastructure operators and emergency managers by building the required capabilities and developing a virtual community to support national, cross-border and regional emergency management in their preparation and response to disaster emergencies affecting Critical Infrastructure.

STREST (Harmonized approach to stress tests for critical infrastructures against natural hazards)
STREST developed innovative hazard models to include in stress tests of non-nuclear critical infrastructures to tackle the problem of extreme events, with focus on large earthquakes, floods and domino effects. The project developed fragility functions for components of petrochemical plants, dams, harbours, gas/oil distribution networks and common industrial buildings with respect to earthquakes, floods and tsunamis, and demonstrated how these components can be integrated at the system level that can also be related to an operational point of view.

The outcome of a critical infrastructure stress test is a grade, convening where the risk is with respect to pre-determined risk acceptance criteria.

Technical Committee C.3 (Managing Operational Risks in Road Operations) of the World Road Association PIARC carried out a comprehensive study on risk management for the road authorities in 2012 [9], using representatives from several countries in the world. In addition to discussing the general methodology for risk management, numerous case studies were presented which deal with the risks associated with natural influences. Climate change will intensify these natural influences in the future.

In 2016 Technical Committee 1.5 Risk Management of PIARC published a very comprehensive report Methodologies and Tools for Risk Assessment and Management Applied to Road Operations (World Road Association, 2016). The report deals with methodologies and tools for risk assessment and management applied to road operations including managing risks in relation to climate change.

<u>Adaptation actions</u>

RAIN (Risk Analysis of Infrastructure Networks in Response to Extreme Weather)
The project considers adaptation strategies with a focus on measures that can be adopted to improve the resilience of the existing infrastructure network (focus on: roads, railways, electrical power supply, and telecommunications infrastructure). It also provides an

assessment of the predictability of severe weather with current state-of-the-art forecasting systems (e.g. windstorms, heavy precipitation, coastal floods, river floods, heavy snowfall, blizzards, freezing rain, wildfires, hail, thunderstorm gusts and tornadoes.). Road operators are reliant on precise, local weather forecasts in order to be able to react appropriately.

USE-iT / FOX (Users, Safety, security and Energy In Transport Infrastructure; Forever Open infrastructure across all transport modes)
FOX project identifies common needs and innovative techniques in the areas of construction, maintenance, inspection, and recycling & reuse of transport infrastructure. USE-iT concentrates on producing a research roadmap which helps to address the cross-modal challenge of reducing carbon and energy consumption in a more strategic manner, by sharing good practice and promoting collaborative research. Also challenges identified in the project include: Generating renewable energy / harvesting energy from transport infrastructure, reducing the embodied carbon in transport infrastructure and embedding consideration of carbon and energy in governance and transport planning and operation.

Influencing the supply chain

LCE4ROADS (Life Cycle Engineering approach to develop a novel EU-harmonized sustainability certification system for cost-effective, safer and greener road infrastructures)
The LCE4ROADS project arose from the necessity for a new, green, holistic and EU-harmonised certification system integrating a Life Cycle Engineering (LCE) approach: environmental indicators along with the economic, technical and social aspects, for the assessment of future and existing road infrastructures, as well as their construction materials such as asphalt mixtures and cement-based materials.

As a result, a guide for the implementation of the certification system and to develop the most suitable implementation strategies including smart and green public procurement was created. This can also be seen as an orientation for operating units.

4.5.2 *Implications for DeTECToR tools and guidance*

The following findings related to DeTECToR were identified during this review:

- CIPRNet and STREST projects have identified critical assets, which should be taken into account when planning mitigation or adaptation actions related to meteorological events. The list of critical assets as an important input for CBA tool. Additionally, STREST has developed risk acceptance criteria for extreme weather events related to critical infrastructure. These acceptance criteria are a part of optimisation algorithms inside of CBA.
- CliPDaR and RAIN-EX projects have developed guidelines how to deal with period of extreme (cold and hot weather, have rain and flooding). Critical assets and related mitigation and adaptation actions could be considered in CBA tool.
- Few projects have conducted pilot studies to prove the developed methodology. The approach of selected studies could be considered for planning of case studies in DeTECToR.

4.6 *Including consideration of climate change in economic appraisal*

4.6.1 *Introduction*

In recent years in Europe, future maintenance needs have commonly been compared using long terms costs of the maintenance and the costs of disruption to road users. However, it is now accepted that the funding impacts of maintenance are much wider than the direct costs and the costs of disruption to road users. Therefore, economic appraisals that omit climate change do not provide a true reflection of future costs. In addition, the deterioration rates and likelihoods of failure used will not be robust, so the decisions taken based on them may not be optimal for users or be the most cost-effective solution for NRAs. With the likely increase in the frequency and intensity of extreme events and their impact on the vulnerability and resilience of the network increasing, it is becoming more vital that climate change is included in the decision-making process and this includes understanding the cost implications.

It is also necessary to understand the costs related to adapting transport infrastructure to climate impacts in order to be able to compare different options and take informed decisions on where best to utilise limited resources to make the network resilient. NRAs need to be able to make informed trade-offs with budgets against future maintenance costs and the wider impacts on the community, and this is only possible with robust economic appraisal methods.

Economic appraisal methods

As documented in RSSB (2016), the main techniques used in economic appraisal are:

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

Cost-benefit analysis (CBA)
CBA is used extensively in transport and other sectors to inform investment decisions. It quantifies the positive and negative consequences of a project in monetary terms over a set appraisal period. The CBA produces the Benefit Cost Ratio (BCR) which is used to compare different options (Mediation Adaptation Platform, 2013a). The larger the BCR, the stronger the business case for investment. CBA is most effective when robust sources of data are available. The strengths and weaknesses of CBA are summarised in Table 7.

Table 7. Strengths and weaknesses of CBA

Strengths	Weaknesses
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

Cost-effectiveness analysis (CEA)
CEA compares the costs of an analysis to effectiveness; this measure does not have to be monetised. CEA 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, 2013b). However, its application to adaptation studies is more challenging due to it being the response of many different impacts. The strengths and weaknesses of CEA are summarised in Table 8.

Table 8. Strengths and weaknesses of CEA

Strengths	Weaknesses
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

Multi-criteria analysis (MCA)

MCA involves the assessment of options against a number of criteria, followed by their ranking and prioritisation. 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 (Mediation Adaptation Platform, 2013c). The strengths and weaknesses of MCA are summarised in Table 9.

Table 9. Strengths and weaknesses of MCA

Strengths	Weaknesses
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

Evaluation of economic appraisal use and examples

It is common for an NRA to carry out some form of economic appraisal when planning either a new construction scheme or the maintenance of an existing infrastructure asset. Most have tools and standard methodologies to help them do this; for example, WebTAG 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.

In order to conduct all the required economic analyses, a wide range of economic decision support tools have been implemented or customised for road operators. These widely address the direct costs of works only and often make no reference to either wider costs to society or incorporating climate change.

Two examples of economic decision-support tools are provided below.

The *Highways Maintenance Appraisal Toolkit (HMAT)*, released by the DfT, UK, is a spreadsheet based tool that was developed for analysing different maintenance budgets or effects of performance targets for networks ranging from local networks up to national networks. The tool included the impacts of different road conditions on vehicles, as well as including an assessment of the carbon impact from different maintenance treatments. However, it did not have a direct assessment of the impact of climate change or of the different maintenance that might be required to adapt to a changing climate.

*HDM-4 (*Highway development and management) is a software package with a road investment model designed to aid road authorities by making comparative cost estimates and economic analyses of different investment options, developed by the World Bank. The software includes the use of economic analysis, MCA, asset valuation, budget scenario analysis and sensitivity analysis. Cañavera Herrera (2016) analysed HDM-4 and found that while the model could be flexible enough for managing flooding events, the model struggled to incorporate climate change considerations. This is because the environmental characteristics used in the road deterioration models only use annual averages with no consideration of extreme events or sensitivity analysis for climatic variability.

Mackie and Worsley (2013) conducted a review of cost-benefit analyses in transport projects for seven countries: England, the Netherlands, Sweden, Germany, USA, Australia and New Zealand. They found that there has been a tendency for economic appraisal frameworks to move towards monetisation in respect of climate change. Many similarities were reported between countries such as the use of BCRs and the presentation of non-monetised impacts. However, there were some differences such as the treatment of risk and uncertainty which is not uniform internationally. For example, England uses the quantified risk approach, which is similar to that used in the USA, Australia and New Zealand, while the Netherlands use the discount rate uplift (Mackie and Worsley, 2013). Monetisation of the impacts of climate change has increased over the last decade, largely influenced by the 2006 Stern Report (Stern, 2006).

4.6.2 *Difficulties including climate change in economic appraisal*

While the need to include climate change in economic appraisal is being increasingly recognised, it presents a number of key challenges:

- Uncertainty and risk
- Discount rates and appraisal period
- Monetisation of wider impacts to society

Uncertainty and risk

Incorporating uncertainty and risk in economic appraisal of transport projects are major challenges in relation to the inclusion of climate change impacts. Uncertainty is caused by the following factors (IIASA *et al.*, 2014):

- Lack of information/knowledge on the phenomena/systems to be analysed
- Conflicting data sources and knowledge that may contradict each other
- Subjectivity of opinions and differing interpretation of available pieces of information and data by the analyst.

The many uncertainties in the appraisal of transport projects make the development of a methodology challenging; for example, future travel demand or asset deterioration is rarely known with certainty. However, climate change adds another layer of complexity to this as there are uncertainties in climate models due to incomplete knowledge of the climate system and measurement errors (IIASA et al., 2014) and the difficulty forecasting future global greenhouse gas emissions. It is also unknown how different types of aging infrastructure will respond to the impacts of climate change and to what degree of risk mitigation any adaptation action will provide. Furthermore, the complex socio-economic contributions of transport systems present difficulties in assessing the full consequences of disruption to transport (RSSB, 2016). For example, the impact on accessibility to employment, education, services etc. and the long term reputational damage to local businesses and tourism which rely on dependable transport links to clients and suppliers. Decision-making under uncertainty is therefore a key issue when considering climate change.

Two approaches can be used to address this are:

- Real options appraisal (ROA)
- Adaptive management

Real options appraisal (ROA)
ROA is similar to CBA, but can incorporate additional flexibility by enabling a staged approach with the measurement of risk and uncertainty into the appraisal of options (HM Treasury and DEFRA, 2009; Mediation Adaptation Platform, 2013b). ROA is advocated in the Supplementary Green Book guidance by HM Treasury and DEFRA (2009) for accounting the effects of climate change and was used by the Environment Agency (2012) to investigate climate change adaptation options for London would provide an appropriate level of flood protection up to 2100. More details on this project are provided in section xxx. The strengths and weaknesses of ROA are summarised in Table 10.

Table 10. Strengths and weaknesses of ROA

Strengths	**Weaknesses**
Produces quantitative outputs with a direct analysis of economic benefits and costs	Complex methodology requiring expert knowledge/capability
Ability to consider added flexibility and uncertainty	Resource intensive with the need for plentiful streams of data
High applicability to externalities compared to CBA.	

Adaptive Management
Adaptive management, or iterative risk management, is a long-established approach that uses monitoring, research, evaluation and iterative development to improve future management strategies (Mediation Adaptation Platform, 2013d). The focus of the approach is on the management of uncertainty with plenty of space/time for learning and iteration. Applications have generally included identifying risk and impact thresholds, and assessing options that can respond to the threshold levels. This approach has been recommended for adaptation studies such as in the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) (IPCC, 2012). The strengths and weaknesses of adaptive management are summarised in Table 10.

Table 10 – Strengths and weaknesses of adaptive management

Strengths	Weaknesses
Iterative approach that encourages learning to adjust decisions over time	Thresholds can be difficult to identify
Uses scenarios in relation to uncertainty	Challenging when multiple risks act together or with indirect links to climate change

Sensitivity analysis and Monte Carlo Simulation are two methods that are used to explore uncertainty and risk within economic appraisals:

- Sensitivity analysis – Used to explore the impacts of uncertainty on the outcome of economic appraisals. It is the most commonly used method for addressing uncertainty and is applicable to climate change because of the various scenarios used for future projections. Sensitivity analysis can be embedded within ROA and is included separately for CBA, CEA and MCA approaches. Sensitivity analysis is employed by determining how much a variable, such as the discount rate, would have to increase or decrease to make a particular project an attractive investment (HM Treasury, 2003).

  In the case of CBA, sensitivity analysis would produce a range of BCRs which would highlight the sensitivity of a specific parameter to the final output. If an input parameter with a high confidence had a low level of sensitivity that would increase the overall confidence in the outputs. However, if the reverse was true, a parameter with a low confidence that produces a high degree of sensitivity in the results would reduce the confidence in any outputs. This type of sensitivity analyses was key in some of the criticisms of the Stern Report (Lilley, 2012).

- Monte Carlo Simulation – Used to model variations in multiple parameters in combination according to defined thresholds to produce a stochastic distribution of values. The simulation can be run many times to explore different combinations. Monte Carlo simulations incorporate uncertainty by defining probability distributions for any parameter in a model that is addressing uncertainty. This technique was detailed in HM Treasury (2003) and is applicable for climate change studies because of the many variables subject to widespread uncertainty.

Guidance for uncertainty and risk

HM Treasury and DEFRA (2009) provided guidance in the Supplementary Green Book Guidance on incorporating the impacts of climate change in the development, appraisal and evaluation of projects, policies or programmes. The measurement of risk was recommended using web-based tools such as the UKCIP Adaptation Wizard and the UKCIP Business Areas Climate Impacts Assessment Tool (BACLIAT). These were recommended for use to determine the vulnerability and/or adaptive capacity of a project, policy or programme to climate change (UKCIP, 2014; UKCIP, 2015).

Three key approaches to addressing uncertainty over future climate change were identified:

- Incorporation of flexibility – to address changes in impacts of climate change due to uncertainty of climate change scenarios

- Increase resilience – Design of activity to be effective for a wider range of climate conditions
- Identify low-regrets and win-win adaptation measures – Implementing activities that produce large benefits at relatively low costs, and those that not only address future climate change, but provided additional benefits

ROA can provide a framework for incorporating the uncertainty of climate change and the value of flexibility into decision making.

Discount rates and appraisal period
The Treasury Green Book describes discounting as a technique used to compare costs and benefits that occur in different time periods (HM Treasury, 2003). A CBA will typically discount future costs; an appropriate discount rate when considering climate change and adaptation has been heavily debated. HM Treasury recommended a discount rate of 3.5% for the first 30 years of a project's life, dropping to 1% after 300 years and this is further supported by the European Commission who recommends a rate of 3.5% or 5.5%. Stern (2006) suggested a lower discount rate should be used for projects with long-term impacts. Criticisms of the Stern Report, such as Lilley (2012), have disagreed with the use of the low discount rate because of the large weight given to events in the future which are assumed to be unavoidable consequences of the actions taken by current generations.

The selection of the discount rate and the 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, 2016). Most climate change-related projects have been conservative in selecting their analysis period at no further than 50 years beyond present. This reflects the uncertainty in the long-term impact of future climate change. RSSB (2016) recommends an analysis period with a minimum of 60 years due to the low frequency of extreme weather events. They noted that economic appraisals should take account of the residual life and risk of adaptation up to the end of their analysis period.

Monetisation of wider impacts to society
Climate change can have two types of impact on road infrastructure. Rises in average temperature, changes in precipitation patterns etc. can increase maintenance costs and reduce the life of assets. There are also changes to the severity and frequency of extreme events such as flooding and landslides. These types of events are likely to result in significant repair and clear-up costs for the road operator, however research into landslide events (Winter et al., 2005; 2009; 2013a) suggests that the major impacts of events like this (if there are no serious injuries and fatalities) are economic and social. The inability to use part of the road network, results in socio-economic costs due to increased journey time (in more remote communities this can be significant) and lack of access to service to goods and services, employment, health and education facilities etc. There can also be long-term indirect impacts on lack businesses and tourism. The effect of a road closure can spread far beyond the immediate geographical area, as the disruption cascades to other parts of the network.

Attempts to try and monetise the external costs and wider impacts on communities, businesses and countries as a whole has been challenging. A case study by Chatterton *et al.* (2010) for the Environment Agency aimed to compile a comprehensive monetary estimate of the cost of the summer 2007 floods in England with a focus on the effect on services such as energy, water and transport. Winter *et al.* (2012) also examined the indirect consequential economic impacts of landslide events in Scotland by using questionnaire surveys. Both studies are described further in Section 4.6.3.

Most transport economic appraisal methods do not take into account wider costs, partly due to the complexity, but also as transport operators are most concerned about the costs to their organisations. However, this means the full-value of many adaptation measures are not recognised or the true risk of not taking action understood.

4.6.3 *Research and guidance*

There have been a number of research projects, guidance documents and tools which attempt to address some of the challenges of the economics of climate change such as ECONADAPT, ROADAPT, WEATHER and ClimateCost and tools such as the Resilient Analytics Infrastructure Planning Support System IPSS™ tool. There are also projects outside the road industry which address similar issues.

Guidance and recommendations

A number of research projects have produced guidance for decision makers for dealing with the economics of climate change adaptation.

The ROADAPT (Roads of today, adapted for tomorrow) project 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.

Three levels of impact are identified; reduced mobility service (reduced speed, restrictions on HGVs etc.), degraded level of service (lane closures) and no transport services (full closure). The timeframe for an event is described and it suggests modelling high impact events at critical points in the network to assess the impact. A different method is provided for each network level and an example illustrating its implementation. Costs from the project HEATCO (Harmonised European Approaches for Transport Costing and Project Assessment) are used.

The WEATHER (Weather Extremes: Impacts on Transport System and Hazards for European Regions) project considered the impact of weather extremes across the EU through climate change on all transport modes with a particular focus on addressing the difficulty/uncertainty of quantifying these impacts to support decision making. The costs and benefits of suitable adaptation management strategies for transport systems in respect to climate change were considered (WEATHER, n.d.).

The WEATHER project promotes an integrated and holistic approach, and recommended the development of a set of best practices and tools for emergency preparedness. The study had the following recommendations in their final report (Doll *et al.*, 2012):

- Improvement of damage cost estimates by a regular monitoring of failures in the European transport systems
- Explore co-benefits of adaptation strategies
- Perform company specific risk assessment plans and establish local risk assessment plans

The ClimateCost project (The Full Costs of Climate Change) supported adaptation planning through the building of the knowledge base on the economics of adaptation to climate change for market and non-market sectors (including infrastructure), and the conversion of this information into practical information for decision makers. The study considered the uncertainty within climate models by focusing on three types of emissions scenarios and how these affect the benefits and costs of adaptation options. It was concluded that a framework for decision making is required for building in uncertainty to adaptation strategies (Watkiss, 2011).

The ECONADAPT (The Economics of Climate Change Adaptations) project aimed to support adaptation planning by building a solid and robust knowledge base for the economics of climate change adaptation. As part of ECONADAPT, case studies utilised economic appraisal methods such as CBA and ROA; for example, a case study was conducted of the appraisal of coastal and river flooding, and its impact on a new urban development in Bilbao, Spain. The economic assessment integrated uncertainty by combining ROA, stochastic modelling and the estimation of risk. The main advantages of these methodologies were to consider and integrate multiple sources of uncertainty into the assessment such as future emissions, regional climate and hydrological modelling. It was also highlighted that the appraisal and evaluation of possible adaptation options requires a comprehensive and multi-disciplinary exercise with a range of expertise (Scussolini *et al.*, 2016).

Economic tools which include climate change impacts
There are also a limited number of tools which have been developed which take into account climate change impacts.

There are many examples of guidance and advice provided by European projects but few examples of where this has been translated into the development of usable tools with respect to climate change that can be used by decision makers.

Resilient Analytics developed Infrastructure Planning Support System (IPSS^{TM}), 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.). IPSS^{TM} 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
- Proactive, adaptation approach

Analyses include construction and maintenance costs, and specific project data can be added such as relevant cost information, degradation rates and adaptation options.

Resilient Analytics detailed their quantitative approach on different types of road infrastructure using a case study for the state of California (Resilient Analytics, 2014). The study involved an assessment of the vulnerability of the road network and specific costs of adaptation options, which were found to provide substantial benefits. The findings can help to inform a policy strategy when combined with existing plans to identify critical assets and ultimately, reduce the risk and cost of climate change to road network construction and maintenance (Resilient Analytics, 2014). However, the tool operates at a network level and does not have sufficient detail to inform adaptation planning for specific locations or the capacity to compare different adaptation options.

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. Future climate change risks are incorporated using UKCP09 data layers. The tool recognises the impacts of the risks on the economy, community and businesses and is aligned to WebTAG economic assessments with the production of BCRs (Ward, 2015). While the tool is currently being rolled out in the South West of England, it could be transferable to all NRAs and beneficial in being able to plan resilience adaptation and manage highway infrastructure more effectively.

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).

After determining the location and parameters of blue spots, regular inspections are necessary to analyse the needs for maintenance, repair and other interventions. The tool is also capable of including climate scenarios to model the future occurrence of blue spots. The recommendations are then assessed through a CBA to prioritise investments. Cañavera Herrera (2016) found that the tool relies on large amounts of specific data and is largely transferable for use by NRAs provided that elevation and flood data is available. While the tool focuses on the vulnerability and risk of specific sections of the road network, the analysis does not address social or environmental impacts from the flooding.

Case studies

Application of methodologies to case studies in the road and other sectors.

Road

As part of the study by Chatterton *et al.* (2010) for the Environment Agency, they assessed the impact of the 2007 summer floods on road traffic through damage to road infrastructure and user delay costs in travel time due to road closures. Analyses were based on the Department for Transport's (DfT) cost-benefit analysis (COBA) appraisals. Various sources of data were used to estimate the monetary cost on road traffic such as data from insurance companies, Highways England and Local Government Authorities (LGAs). Costs were estimated at £191 million with about half attributed to damage to the road network and the other half to traffic delays.

Uncertainty within the data was acknowledged, notably in the estimate of traffic delay and redirections. Highways England attempted to determine the disruption cost using data on the type and magnitude of traffic flows, and the extra distance travelled by users due to blockages at key areas of the road network. While a mean of direct traffic disruption was estimated, the range of estimates was more appropriate because of the high uncertainty in the data. Chatterton *et al.* (2010) evaluated the uncertainty by classifying the degree of confidence in the robustness of data methods using a scale of one to four as outlined in the Multi-coloured manual by Penning-Rowsell *et al.* (2005). The data sources for the transport costs was ranked as between two and four, reflecting variations in the modelled assumptions but also taking note of the uncertainty in the data for disruption costs.

Altvater *et al.* (2012) evaluated adaptation options to climate change for four different sectors including road transport. The impact of climate change through higher temperatures and more intense precipitation is likely to result in the increased propensity of roads to rutting. The benefits and costs of implementing two adaptation options were considered using a CBA: a heat resistant asphalt adaptation strategy and improved drainage systems.

Based on the avoidance of road traffic delays for closures to repair damage to the surface, the results found that the road adaptation strategies produced benefits for both adaptation options:

- Heat resistant asphalt – benefits of 2 to 2.6 billion Euros per year
- Higher capacity of drainage systems – benefits of 50 to 240 million Euros per year

It was recognised that uncertainty in both the costs and benefits of the adaptation options could have a large impact on the results. Furthermore, the benefits did not include the avoided cost of maintenance and repair, and the avoided cost from road accidents. This study demonstrates the need for sensitivity analysis or Monte-Carlo Simulation, and the important of robust data to produce reliable estimates of the costs and benefits of adaptation options in relation to climate change.

Atkins (2013) used a CBA to investigate the impact of adaptation for roads in England to the likelihood of hotter and drier summers. It was agreed that the impact of hotter and drier summers would likely lead to a reduction in the service life of asphalt surfacing. The costs of additional maintenance and user delays were compared against the implementation of a series of adaptation actions such as more rut-resistant resurfacing treatments.

Net Present Value (NPV) and BCR were used to present the results of the CBA over the 60-year appraisal period for two scenarios – a central scenario and a worst case scenario. The results showed a relatively low return on the investment for the various adaptations. This could be improved with further research on adaptation options and their costs, as well as wider analysis of climate change impacts on roads. Highways England is aiming to address the paucity of data through more extensive monitoring data to improve the assessment of the impacts of climate change on pavements in England.

Dietz (2016) produced a CBA of climate change adaptation options for the Chignecto Transportation Corridor in Nova Scotia. A high-level analysis was conducted to assess the economic consequences of climate risks. Adaptation options were developed through consultation with stakeholders to address future flood scenarios. The NPV and BCR of adaptation options showed that engineered dykes produced the best return on investment for protection of infrastructure including the road network. The study was successful in bringing together stakeholders to discuss future climate change adaptation options on a holistic level. A need was identified to publicise the use of dykes to increase public acceptance.

Other relevant projects

AECOM (2012) conducted a series of climate adaptation CBA case studies in Australia; for example, one of the case studies focused on the impact of temperature on Melbourne's metropolitan rail network. An economic framework was developed to determine the costs and benefits for adaptation options. The framework methodology contained six steps.

1. Scope the study – The project parameters are set and the study boundary is established.

2. Quantify impacts of historical weather events – Weather thresholds are identified, as well as the relationship between a particular weather event and an impact.

3. Quantify changes in future weather events – The number of projected yearly events triggering thresholds are identified for different climate change scenarios.

4. Model impacts without adaptation – The assumptions and economic parameters governing the model are established and the model is designed.

5. Model impacts with adaptation – Adaptation options are identified and the costs and benefits for the prioritised options are developed.

6. Analyse portfolios of adaptation and communicate with findings – The modelling results are analysed to prioritise adaptation options and determine the preferred timing for implementation.

The utilisation of the framework for the case study of the impact of temperature on Melbourne's metropolitan rail network represented an in-depth analysis of alternative option whereby the following was carried out:

- Economic costs were monetised using a CBA
- Sensitivity analyses were used with probability distributions to model the impacts of climate change
- Stakeholder engagement encouraged in selection of adaptation options

The use of the framework was successful in using CBA for adaptation options to climate change and highlighted the worth of expanding on the scope of the analysis to include a comprehensive evaluation of costs and benefits including those that may be challenging to monetise.

The use of multiple economic appraisal techniques can be beneficial and this was demonstrated by the Environment Agency (2012) who investigated climate change adaptation options that would provide an appropriate level of flood protection for London up to 2100. The following economic appraisal techniques were used in this study (HM Treasury and DEFRA, 2009):

- CBA – Used to estimate monetary costs and benefits of the adaptation options
- MCA – Used to include social and environmental outcomes within the decision making process through the CBA
- ROA – Used to provide an economic framework to take account of the uncertainty of climate change and to factor in flexibility into the decision making process

The project demonstrated that, while resource intensive, the combination of different economic appraisal techniques produced a holistic approach to economic appraisal with consideration of climate change. This was attributed to the involvement of both monetary data and social and environmental impacts through a CBA and MCA respectively, as well as factoring in flexibility and uncertainty through the ROA.

Winter *et al.* (2012) attempted to determine the economic impacts of selected landslide events in Scotland. The following impacts were addressed:

- Direct economic impacts – Including costs of clean-up and repair/replacement of lost or damaged infrastructure
- Direct consequential economic impacts – Related to the disruption to infrastructure and loss of utility
- Indirect consequential economic impacts – Effects on businesses

As part of the direct consequential economic impacts, QUADRO was used to model a series of case studies to assess the costs imposed on road users (delay to road users, fuel carbon emissions and accident costs) while closures or diversions are in place. For example, analysis of a landslide event on the A83 Rest and be Thankful found there were benefits of maintaining a temporary diversion and that re-opening the road as soon as possible was necessary. This was because of substantial user delay costs, using QUADRO analyses, which were in the region on £80k per day for a full closure.

The indirect consequential economic impacts were analysed using questionnaire surveys in relation to two landslide events. Survey respondents were mostly in the tourist, retail and transport sectors and based on indicative results, it was found that businesses were particularly dependent upon road transport, especially for incoming goods and visitors. The low response of the survey highlights the difficulties in assessing the wider costs to society with limited robust dataset available for analysis.

Palmer (2013) found that determining the impact of landslides in Scotland has been challenging because of a paucity of reliable data. The risk of landslide disruption in Scotland is likely to be exacerbated by climate change and therefore, there is a growing need to develop a robust database of landslide events to develop accurate economic analyses of events to inform mitigation and adaptation. This is beginning to be addressed by Transport Scotland's Integrated Road Information System (IRIS) which has been fully operational since August 2014. This records the incidence of landslides on portions of Scotland's Trunk Road Network. As the coverage is still at a limited extent, landslide incidents are still likely to be higher than currently reported (ClimateXChange, 2016).

A rail study carried out by TRL used a CBA to investigate the adaptation of rail geotechnical assets to deal with drought conditions in East Anglia (Reeves et al., 2013). A methodology was applied to three case studies to determine whether work to stabilise vulnerable earthworks to withstand climate effects was more cost-effective than carrying out remedial work whenever required.

Correlations between the soil moisture deficit (SMD), a proxy for drought, and track maintenance requirements were identified. These relationships were then applied to future SMD values by using predicted climate scenarios, to estimate the amount of maintenance of consequent delays likely in the future. The costs for the stabilisation of earthworks were then compared against the costs of delay and maintenance.

The annual risk for each 30 year period was calculated in the 60 year analysis period. This was applied to the cost calculations to produce a BCR. Sensitivity analysis was conducted for delay and maintenance costs generated from the 10th, 50th and 90th percentile climate variables from UKCP09 and number of trains.

An Excel-based cost model was used to calculate the NPV for stabilisation actions and for not carrying out work. Calculation of the Incremental Economic Indicator, a measure of the cost effectiveness of the remediation calculated as the ratio of whole-life cost savings to increased initial outlay, identified that the high cost of stabilisation would not be recovered within the analysis period. It was concluded that further research was required to develop the model and relationships, as well as determining if the methodology could be transferable to other locations.

4.6.4 *Summary and recommendations*

Economic appraisal methods including the consideration of uncertainty were discussed in section 4.6. It was concluded that 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.

Research has found many issues with the accessibility of relevant and specific data, which has limited some studies; for example, Altvater *et al.* (2012) and Atkins (2013) both recognised the need for robust datasets for economic appraisals. In the case of landslides in Scotland presented by Winter *et al.* (2012) and Palmer (2013), the paucity of landslides data is beginning to be addressed with improved monitoring; however, the scale and extent of data can still be improved and as historical records are still poor, continual challenges will exist with the data. European projects such as ECONADAPT have focused on the collation of data, both quantitative and qualitative, in databases, to improve the ease of accessibility for certain types of information.

Addressing uncertainty has been the focus of many studies where adaptation to climate change has been the focus including a case study for ECONADAPT to provide more sound estimates in economic appraisals. Few studies have attempted to address the wider costs to society with most attempts being qualitative and resource-heavy.

Where sound datasets do exist, the use of a framework/methodology has been effective in providing a uniform process for conducting economic appraisals with respect to climate change; for example, AECOM (2012) outlined a clear process for comparing costs and benefits for adaptation options using climate change scenarios. Combining economic appraisal techniques can also be effective, as demonstrated by Environment Agency (2012), to be able to monetise as many costs as possible, including social and environmental impacts and incorporating uncertainty.

A summary of research projects from Section 4.6 is summarised in Table 11.

Table 11. A summary of research and guidance projects and their approaches to economic appraisal

Research Project	**Economic appraisal methods used**	**Specific points**	**Focus of project**
Resilient Analytics Infrastructure Planning Support System (IPSS™) tool	CBA-focussed tool	• Compares costs of adaptation options using climate models and initial upfront costs vs. "business as usual" with costs incurred from increased maintenance due to increased climate stress. • Addresses uncertainty Evaluates social vulnerability and environmental impacts	State/County level e.g. state of California
Blue spot concept	CBA-focused tool	• Vulnerability assessment through GIS • Use of climate scenarios • CBA used to prioritise investments Does not address wider social or environmental impacts	Specific blue spot locations
ROADAPT Research Project	Socio-economic assessment	• Monetisation of travel time costs e.g. energy consumption, value of time spent for passengers/goods transported • Consideration of other externalities such as GHG emissions and noise Selection of events with a high level of uncertainty in terms of consequence	Focus on different levels such as network, territorial and economic
WEATHER Research Project	MCA approach	• MCA used instead of CBA due to concerns over monetary data Did not address uncertainty	Focus on different areas of transport
ECONADAPT (The Economics of Climate Change Adaptations) Research Project	CBA, ROA used for two case studies	• Vulnerability assessment and climate change scenarios used Central focus on dealing with uncertainty using various approaches such as Monte	Specific adaptation measures e.g. appraisal of flooding for a new urban

		Carlo Simulation, stochastic modelling and estimation of risk	development
ClimateCost (The Full Costs of Climate Change)	CBA	• Quantified in monetary values the economic impacts of climate change Focus on uncertainty in climate models	Country level
Chatterton *et al.* (2010) "The costs of the summer 2007 floods in England"	CBA	• Costs from study focused on the wider impacts with the following addressed; impacts to households, businesses, emergency services, utilities, communications (such as transport), public health and agriculture • For road user impacts, DfT's cost-benefit analysis (COBA) was used Uncertainty of data sources ranked on a scale of 1 to 4	Impact of event on wider community
Altvater *et al.* (2012) "Adaptation measures in the EU: Policies, costs and economic assessment"	CBA	• The benefits and costs of adaptation options using up-front costs were compared to business as usual and the increases in maintenance due to climate change. • Focus on road traffic user delays caused by maintenance Uncertainty in data recognised but not clear how addressed	Global-level study for Europe across four different sectors
Atkins (2013) "Economics of climate change adaptation and risks – Final report"	CBA	• Two climate scenarios used • Maintenance and user costs assessed when comparing adaptation options to no adaptation. • Wider costs such as impacts on water quality and reduction in assets' net value was considered qualitatively • Appraisal period of 60 years 2010 values used with a discount rate of 3.5% for 30 years and 3% thereafter in line	Sector level – road

		with DfT's WebTAG guidance	
Dietz (2016) "Cost-benefit analysis of climate change adaptation options for the Chignecto transportation corridor"	CBA with stakeholder consultation	• Flood scenarios considered • Adaptation options developed with stakeholder consultation • Costs for current age of infrastructure appeared to not include maintenance or replacement • Appraisal period of 50 years • Discount rate of 4% used to reflect changing value of the US $ NPV and BCR outputs used to rank adaptation options	Network level e.g. Chignecto transportation corridor
AECOM (2012) "Economic framework for analysis of climate change adaptation options – Framework specification"	CBA with economic framework	• Development of weather thresholds and multiple climate scenarios • Impacts modelled with and without adaptation using NPV outputs • Stakeholder engagement used to derive adaptation options • Economic costs include damage to infrastructure and loss of consumer welfare by willingness to pay • Uncertainty assessed using sensitivity analyses with probability distributions • Appraisal period of at least 60 years. For two of the case studies it was 90 years Discount rate of 6-7% used for standard Infrastructure projects but sensitivity tested with lower such as 3%	Project/asset level with three case studies
Environment Agency (2012) "Thames Estuary 2100: Managing flood risk through London and the Thames Estuary"	CBA, MCA and ROA	• Different climate scenarios used • Monetary costing of costs and benefits in CBA including wider impacts across economic, environmental and social impacts addressing the wider • Consideration of social and	Project/asset level

		environmental outcomes in MCA • Factoring in flexibility and uncertainty in ROA with strategy to be revisited every 5 to 10 years to take account of updated models Appraisal period of 90 years	
Winter *et al.* (2012) "Assessment of the economic impacts of landslides and other climate-driven events: Final Report"	Direct economic analysis, direct and indirect consequential economic impacts analysis	• Direct economic analysis for the cost of clean-up and to repair damaged infrastructure • Direct consequential economic impacts analysis used QUADRO tool to model costs on road users through closures/diversions Indirect consequential economic impacts assessing wider impacts using qualitative methods such as questionnaire surveys.	Impact of event on wider community

4.6.5 *Implications for DeTECToR tools and guidance*

Recommendations on using the research/tools/good practice identified:

- Combination of economic appraisal tools – While resource-intensive, the most successful approaches to economic appraisal have used multiple appraisal methods e.g. Environment Agency (2012) used CBA, MCA and ROA to address the complexity of climate change such as uncertainty.
- Development of a framework/methodology – Examples e.g. AECOM (2012) set out a clear methodology for assessing the economic appraisal of a transport project. This approach has high transferability and transparency. It would be of benefit to have a set process with an element of flexibility incorporated in to allow for specific assets,
- Need for plentiful streams of data – To be able to assess assets, more specific data of longer timescales is required. While this may not be possible historically, the installation of more specific asset monitoring and/or weather impact datasets at a high resolution will help to further inform economic appraisals. Future climate change projections will continue to be challenging; therefore improvements in the development of more robust asset datasets could help to highlight vulnerability of specific assets to climate change more effectively.
- Addressing uncertainty – To reflect the uncertain nature of climate change, uncertainty analysis through the use of ROA/adaptive management and/or some form of sensitivity analysis is crucial to identify the sensitivity of the data used and to improve the accuracy of estimates.
- Inclusion of wider costs to society – While providing challenges in determining the wider costs, these costs are often undervalued in terms of their importance.

4.7 Incorporation of climate change considerations in procurement

4.7.1 *Introduction*

This section describes the embedment of climate change in procurement. The inclusion of climate change and other environmental, social and longer term economic impacts in procurement can be referred to as sustainable procurement or green procurement. Sustainable/green procurement includes the use of low carbon emission materials, processes and products etc. to reduce carbon emissions and actions to adapt to climate change such use of sustainable urban drainage systems. Sustainable procurement takes social, economic and environmental aspects of construction projects into consideration (Figure 27). Sustainable procurement can be employed for road design, construction and maintenance. This means that sustainable requirements/targets need to be established and enforced on the network level for all construction and maintenance contracts. Traffic operations are also a very important component of the GHG emission control and awareness; thus, reduction targets should be included in operation contracts as well. Specifying the use of renewable energy (e.g. using solar panels as source of power for electronic signs) is also part of sustainable procurement.

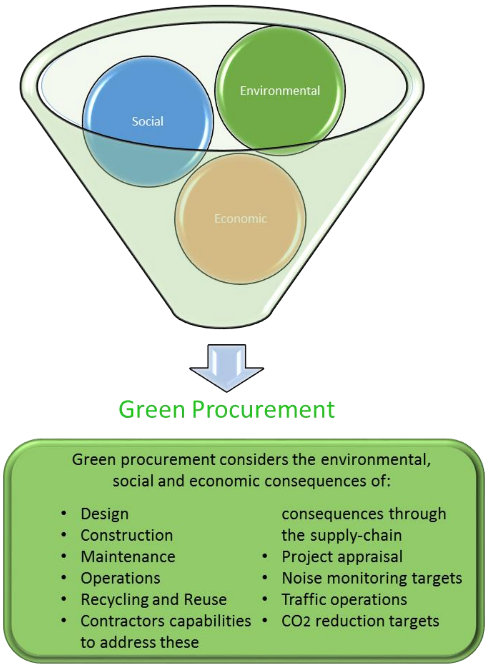

Figure 27. Green Procurement

4.7.2 *State-of-the-art*

There have been a number of European projects that relate to the inclusion of climate change in procurement. These mainly focus on climate change mitigation, for example developing tools for carbon emission calculations such as CEREAL or LICCER which are described in detail in chapter 4.4. However, the majority of sustainable procurement good practice can be found from identifying initiatives used by NRAs or others rather than research.

Procurement specifications

Examples of research projects and initiatives which relate to the inclusion of climate change in procurement specifications are the US Greenroads project broadly described in section 2.3.4 and the following:

Ecolabel - An initiative which discusses standardisation of EU sustainable projects and assigns the labels if they meet certain criteria (European Commission, 2017). The project identifies materials and services that contribute to sustainability through demonstrated environmental impacts in their life cycle. The project is based on assessment of the road itself and its components (materials/products). It will use the current standards in the road construction industry and will eco-label the ones that meet green procurement requirements. EU harmonised eco-labelling methodology integrating a life cycle engineering (LCE) approach that covers environmental indicators along with economic, technical and social aspects for the assessment of current and future road infrastructure (including construction materials, asphalt mixtures, etc.)

LCE4ROADS – This project developed a certification methodology for road products and infrastructures. The LCE4ROADS software tool was developed, integrating the certification methodologies developed for road infrastructures on the basis of process modelling and simulation application, aiming the evaluation of the global performance of road stages. It also developed a guide for the implementation of the certification system and guidelines on how to develop the most suitable implementation strategies including smart and green public procurement.

KPIs (Greenroads) – design for larger capacity culverts, more resistant road surface-ultra high performance fibre reinforced concrete (UHPFRC), porous asphalt, drainage system and reservoirs for storm control and water management SUDS, self-healing concrete, geothermal and solar energy harvesting for resilience to extreme weather etc. more environmentally friendly de-icing chemicals.

Tender Evaluation

The most commonly used method of including climate change in tender evaluation is through the assignment of a specific (normally small e.g. 5%) percent to carbon reduction in the tender scoring. However, there are a number of other more novel procurement methods such as the ProRail CO_2 ladder previously described and the Greenroads sustainable rating system developed by CH2M HILL and the University of Washington in 2009 (Greenroads, 2012). This requires that each project includes:

- Environmental Review Process
- Lifecycle Cost Analysis
- Lifecycle Inventory
- Quality Control Plan
- Noise Mitigation Plan
- Waste Management Plan
- Pollution Prevention Plan
- Low Impact Development
- Pavement Management System
- Site Maintenance Plan and Educational Outreach.

The majority of required criteria are derivatives of codes or laws; and so do not present an additional burden to the project team. In addition, there are six voluntary credit categories which tenders can include in their proposal:

- Environment and Water (8 criteria)
- Access and Equity (9 criteria)
- Construction Activities (8 criteria)
- Materials and Resources (6 criteria)
- Pavement Technologies (6 criteria)
- Custom Credits (2 criteria).

All criteria are intended to inspire action towards a higher standard of construction sustainability using current technology and tools. After project requirements are fulfilled, voluntary credits are selected, documented, and submitted to Greenroads for a third party review (Greenroads, 2012). Each credit is weighed by Greenroads on a scale of 1-5 depending on its potential to influence the sustainability of projects. Four awards levels exist for the Greenroads system: Bronze (32-42 voluntary credit points), Silver (43-53 voluntary credit points), Gold (54-63 voluntary credit points) and Evergreen (64 upwards voluntary credit points). The tool may be used on highways and conceptually on bridges, tunnels and other structures associated with similar works. It is web based and can be used throughout the life cycle of the project (Greenroads, 2012).

Monitoring

One of key issue with regard to sustainable procurement is monitoring the implementation of sustainability requirements. It is necessary not only to include and specify climate change requirements specifically in procurement processes but also to ensure that they are implemented once the project is underway. Examples of this include sustainability action trackers, regular sustainability progress meetings with the supplier and regular submission of KPI data such as carbon emissions generated within a specified time, e.g. 6 months.

Related to monitoring is the need for accountability for reaching the agreed targets. For example financial implications for contractors as in the Swedish example described earlier. Another method used for other types of KPIs is a points based system where different types of infractions incur a certain number of points and when a threshold is reach action is taken by the client.

Procurement policy

The UK Department for Environment, Food and Rural Affairs (DEFRA, 2012) developed a tool to set priorities for the sustainable procurement of services, equipment, materials and other products. An example of this tool is provided in Table 12.

Table 12. Sustainable Procurement Priority Tool (DEFRA, 2012)

Service/Asset/Product Description	Spend level	Environmental Risk Score (1-5) 5=very high risk	Socio-Economic Risk Score (1-5) - 5= very high risk explain the last three social criteria	Risk Score 1: level of existing risk management activity (1-3)	Risk Score 2: scope to do more (1-3)	Risk Score 3: level of reputational risk (1-3)	Overall Risk Score (Automatic)	Improvement scope (1- 10) 10=very big scope	Influence (1-10) 10=potentially very big influence	Overall priority Score (Automatic)
Maintenance of road										
Maintenance of traffic										
Low Emission Infrastructure and Vehicles										
Drainage										
Bridges										
Pavements										
Geotechnics										
Tunnels										
Road Furnishings										
Static Signs										

A total for the Risk, Scope and Influence of each proposed action are calculated, and plots for risk versus spend and influence versus scope for each asset/product/service can be visually represented in the outputs. This enables identification on the areas where the most impact for the least amount of investment can be obtained. Example plots are presented in Figures 25 and 26.

Figure 25 displays a graph locating all of the chosen services/assets/product groups in relation to the influence and scope scores for each, and is designed to help an organisation determine market engagement strategy. The graph is divided into quadrants, splitting the groups into upper and lower halves by both influence and scope. The quadrants are labelled “Challenge”, “Pioneer”, “Encourage” and “R&D” (Research & Development).

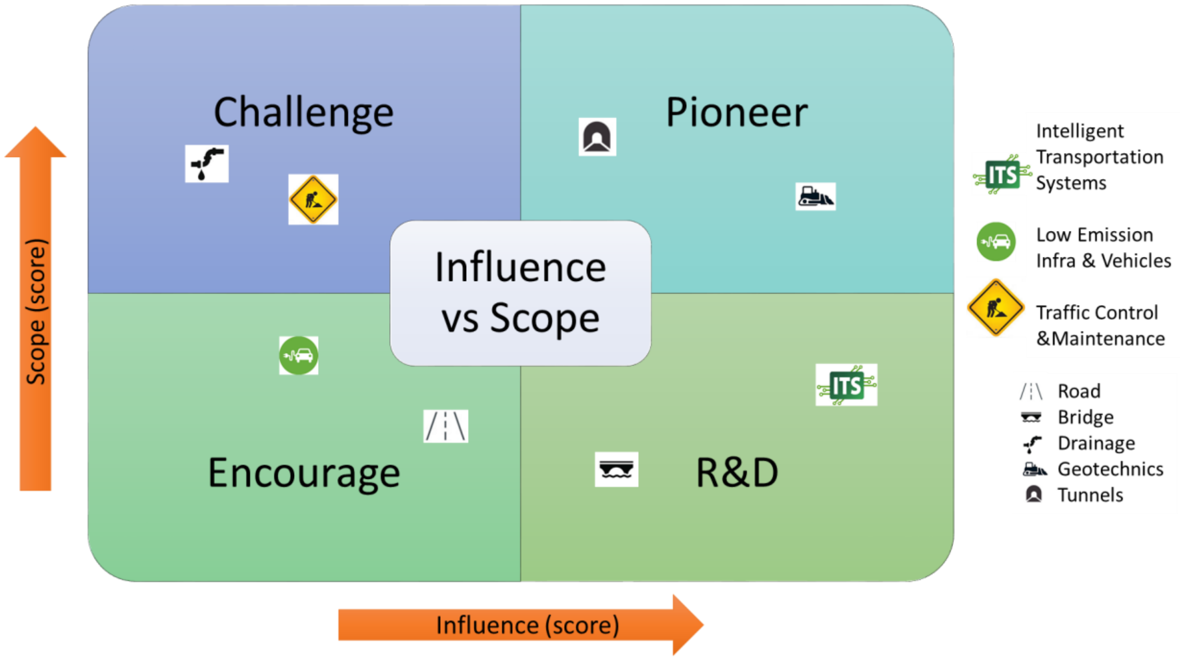

Figure 25. Proposed Influence vs Scope Prioritisation Tool (DEFRA, 2012)

Figure 26 displays a graph locating all of chosen assets/services/product groups in relation to the spend amount and risk score for each, and is designed to help an organisation prioritise procurement action. The graph is divided into quadrants, splitting the product groups into upper and lower halves by both spend and risk. The quadrants are labelled “Secure”, “Critical”, “Acquisition” and “Cost driven”.

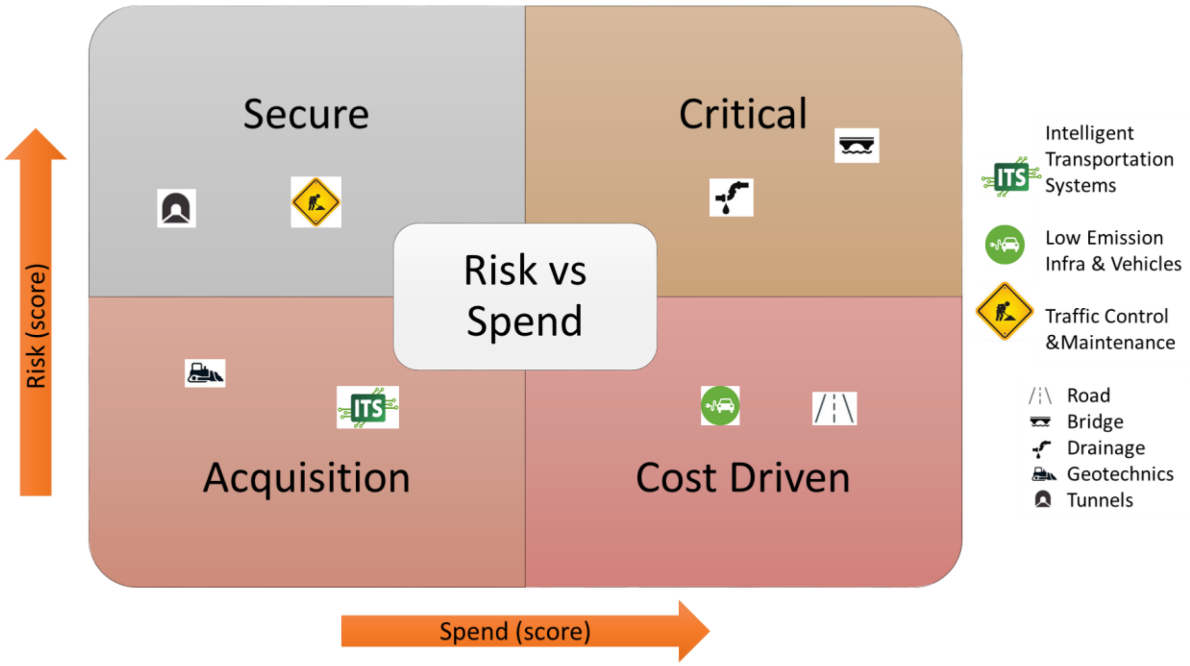

Figure 26. Proposed Risk vs Spend Prioritisation Tool (DEFRA, 2012)

4.7.3 *Implications for DeTECToR tools and guidance*

DeTECToR procurement tool and guidance will include recommendations and examples related on to the inclusion of climate change mitigation and adaptation in procurement processes. The identified projects and initiatives will help to inform these. Conceptual examples can be adopted and modified accordingly from the DEFRA Sustainable Procurement Prioritisation Tool, as well as guidelines developed by the EC and countries such as the UK, Norway and Switzerland on sustainable public procurement. In addition innovative examples such as those used by ProRail and the Swedish NRA will be included. It is clear that there are more examples of the inclusion of mitigation in procurement, than adaptation, so additional consideration will need to be given to this area.

5 Putting climate change research into practice

This section details case studies from all topics in Section 4 where NRAs have put into practice research and good practice.

5.1 Good practice in risk assessment and economic appraisal

Risk assessment is an important and integral part of Asset Management Plan. Concerning to ISO 55000 or PAS 55, the Risk Management is a crucial and non-negligible element of modern Asset Management.

The overall approach for risk assessment consists of few steps: identification of potential hazards, root-cause searching, planning of risk related actions in Asset Management Plan, execution and verification. As the review of latest research shows, the NRAs have already partly implemented mentioned steps.

Projects such as AllTrain or RIMAROCC have developed comprehensive risk catalogues related to critical transport infrastructure assets. The methodology proposed in RIMAROCC has been verified in a follow-up project, ROADAPT, which proposed the QuickScan method as a tool for risk appraisal road networks. This method is based on interactive workshops and uses questionnaires to assess the risks. The proposed QuickScan method has been verified in the projects, however the question remains, if this method can handle complex and large road networks.

Another example for practical approach for risk assessment is from the RIVA project, which focuses on German motorways. This project based on general risk management approach of RIMAROCC. The aim of the project was to develop a methodology for risk assessment in complex road networks. The project grouped the climate and infrastructure parameters into a hierarchical structured indicator model (Figure 28). The project defined the ‘damage pattern category’ as the cause of potential problems in road infrastructure. The research mentioned, that in many cases the set or sequence of climate hazards lead to particular problems in the road infrastructure. They also proposed an approach for evaluation of potential exposure to hazards (sphere of cause), for the potential of effects (sphere of effect) and for the overall risk potential as a function of cause and effect.

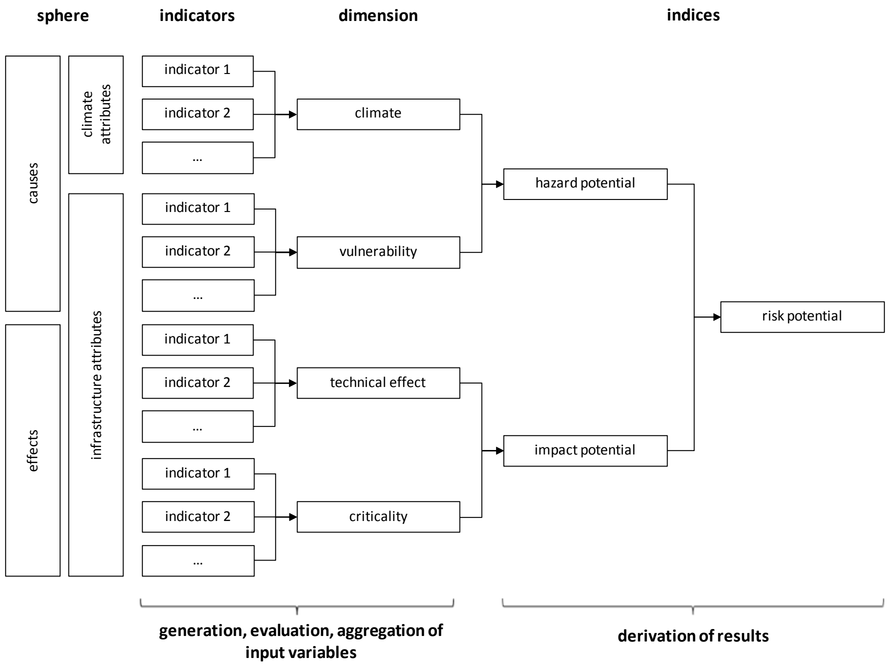

Figure 28. Overview of the hierarchically-structured indicator-model (source

The RIVA project has conducted a pilot study and shows the capability of the research to put it into practice. For the exemplary use of the RIVA methodology, nine test routes of different construction methods, age, traffic volume and climate region were selected in Germany. The results of the case studies show the impact of heat-related risks on road infrastructure in the future (Figure 29).

The potential for heat-related damages will be increasing between the analysis periods of 1971-2000 and 2071-2100. For the roadways, there was a greater increase of the risk-potential than for bridges. The results also show that one of the important factors for defining the vulnerability of the observed risk-potential is its constructional condition. The modular structure of the pilot user tool allows for integration of further/changed damage pattern categories and for expansion/change of parameter-sets.

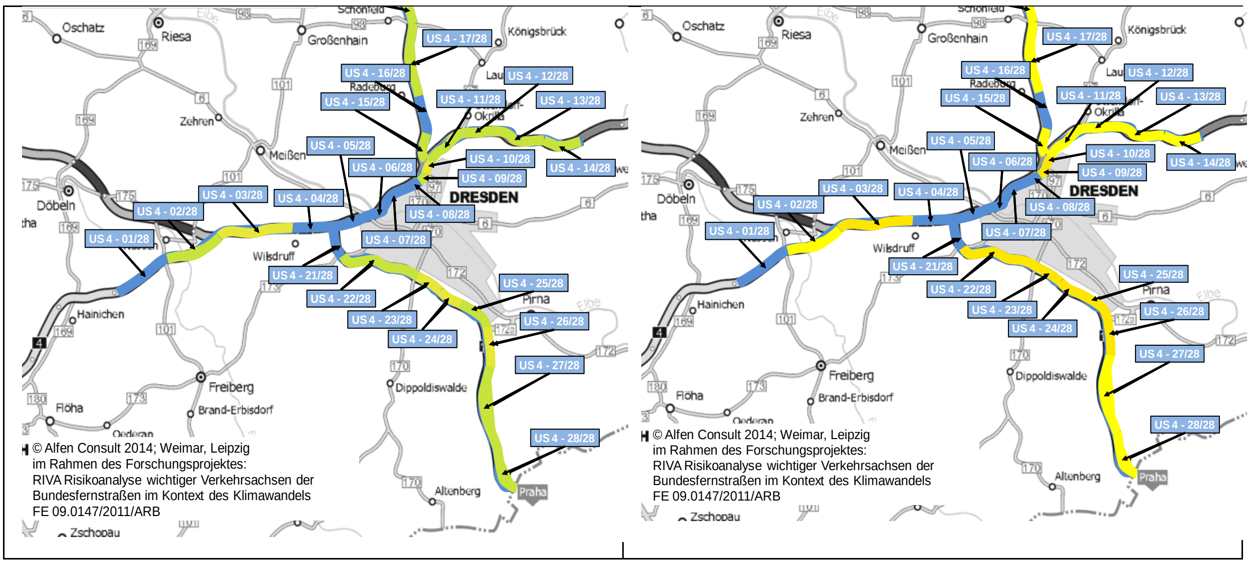

Figure 29. Development of the total hazard potential for heat-related damages and restrictions on the asphalt road surface – left period 2010-2040, right period 2071-2100 (source RIVA consortium)

The RIVA approach seems to be well aligned for the cost-benefit tool which will be developed as part of the DeTECToR project. The methodology will be discussed with NRA representatives during the workshop to see if the experiences from Germany overlap with expectation from other countries.

There are also a number of research projects which deal with adaptation and mitigation action. The ECONADAPT project has developed a method for assessing adaptive capacity of road infrastructure by considering costs and benefits of adaptation. The ECONADAPT data repository contains 54 adaptation actions and 249 adaptation sources, grouped by policy area. The project proposed a multi criteria cost-benefit analysis on road project level.

The SUNRA project covers 26 different aspects of sustainability performance including climate change adaptation and mitigation action. SUNRA proposed methods to make cost effective choices and interventions with respect to sustainable development and improve the long term road infrastructure maintenance. The SUNRA project has been put practice by Swedish Road Administration.

Both projects, ECONADAPT and SUNRA, provide approaches for the selection of optimal mitigation and adaptation action in long maintenance perspective. DeTECToR's cost-benefit tool will take both invented methods into consideration in order to select optimal mitigation and adaptation measures for the Maintenance Plan. The optimisation criteria will be discussed with NRA representatives during the workshop. The aim of this discussion will be to detect those criteria, which are important for NRAs when planning the maintenance of existing infrastructure taking into consideration the climate changes.

5.2 Good practice in embedding in procurement and operations

Embedding climate change in procurement and operation can be classed as two-dimensional (see table below). The first dimension focuses on "**green/sustainable procurement**" with the aim to reduce climate change and to fulfil the governmental sustainable strategy. The other dimension focus on "**climate change adapted procurement**" with the aim to reduce the consequences of the unstoppable climate change on the infrastructure assets.

Table 13. Embedding climate change in procurement and operation

Green/sustainable procurement / operation	Climate change adapted procurement / operation
• in order to reduce climate change • the two dimension a) determination / planning / design of section with the aim to reduce fuel consumption (tunnel vs. serpentine) b) use of green/sustainable materials	• in order to reduce the consequences of climate change for road infrastructure and users through reducing hazard potential and/or reducing vulnerability of the assets relating to climate change

Green/sustainable procurement and operation includes the use of low carbon emission materials and products, but also low carbon emission manufacturing and construction processes in construction, maintenance and operation of road networks. It also includes the consideration of the whole lifecycle carbon associated with different route options, for example a tunnel or serpentine. A serpentine could lead to high land sealing and high fuel consumption when in use, whereas the construction of a tunnel could generate a large amount of emissions during the construction phase, but lead to less emissions when in use.

Different research projects dealt with this topic, such as CEREAL or LICCER, and also some NRAs have already implemented analysis or calculation tools (see chapter 4.7). For example, Sweden uses a tool to calculate the extent of carbon emissions over the whole-life cycle of a road. Another way to embed climate change in procurement and operation is the implementation of green/sustainable evaluation criteria in the tender/procurement process such as a green-fleet-mix-index or the certification of green/sustainable produced asphalt.

Including climate change adaptation in procurement could mean specifying different materials or designs to make the infrastructure more resilience, requiring suppliers to carry out flood risk assessments or monitor vulnerable earthworks or put in place warning systems. Although some NRAs such as Germany (Die Bundesregierung, 2008) and the UK (see Figure 29) have adaptation strategies or frameworks there are limited examples of adaptation being embedded in procurement processes. There are a few examples of actions related to climate change adaptation being included in operations mostly related to flooding, for example making changes to drainage standards to account for climate change, carrying out flood risk assessments, requiring suppliers to record incidents of flooding and developing a data management system to make vulnerable drainage assets and flood hotspots.

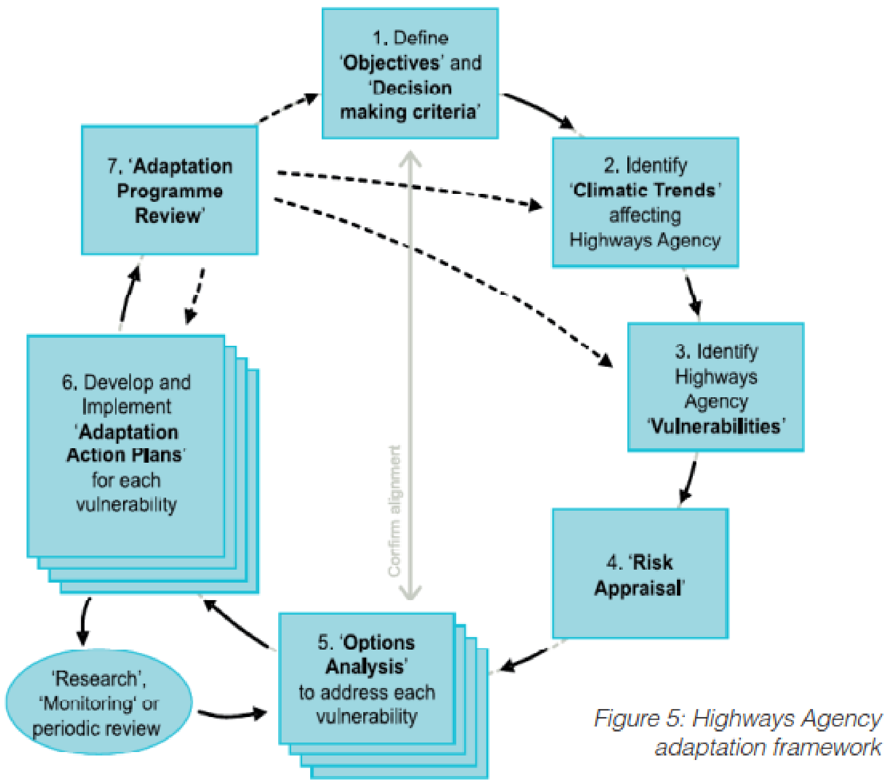

Figure 29. Example of steps to adapt to climate change (Highways Agency, 2009)

6 Conclusions and next tasks

6.1 Risk assessment and economic appraisal

Various approaches towards risk assessment and economic appraisal have been studied extensively during the literature review process, thus key outcomes are the following:

- Projects AllTrain and RIMAROCC developed a comprehensive risk catalogues related to (critical) transport infrastructure assets
- ROADAPT proposed the QuickScan method as a tool for risk appraisal road networks
- RIVA developed a methodology for risk assessment in complex road networks (based on ROADAPT). The project grouped climate and infrastructure parameters into hierarchical structured indicator model. The research mentioned, that in many cases a set or sequence of climate hazards lead to particular problems in the road infrastructure
- ECONADAPT developed method for assessing adaptive capacity of road infrastructure by considering costs and benefits of adaptation
- SUNRA proposed methods to make cost effective choices and interventions with respect to sustainable development and improve the long term road infrastructure maintenance

Based on the desk study performed, the RIVA approach provides a good basis approach for the DeTECToR project. The consortium is going to present this approach at the Workshop and use it as a start for the first interactive session.

The ECONADAPT and SUNRA projects provide approaches for the selection of optimal mitigation and adaptation action in long maintenance perspective that can be used in the development of the DeTECToR tools. The DeTECToR's cost-benefit tool will take both invented methods into consideration in order to select optimal mitigation and adaptation measures for the Maintenance Plan.

It is also clear from the literature review that quantifying the impact of weather hazards on road networks is challenging. There are multiple factors involved and data is not always available, especially for wider costs. It is important to identify which types of costs should be/can be included. Other points are that:

- Different roles within NRAs require different types of information.
- Journey time and delay is the key indicator of impact used by most research projects. There is less inclusion of other impacts especially environmental and social impacts such as the cost of carbon, impact on noise etc. which can be difficult to monetarise.
- Scenarios and sensitivity analysis can be used to provide ranges of costs – multiple sources of uncertainties mean there is no one answer.

6.2 Operations and procurement

The survey results provided information on the existing level of the embedment of climate change into procurement and operations of the NRAs. Most NRAs include some form of climate change mitigation, although this is not necessarily fully embedded in major decision-making. There is less evidence of climate change adaptation being included in procurement, although some NRAs are modifying their technical standards. Many NRAs use historic meteorological data and short term weather forecasts, but there is no systematic approach on how to use climate change data into long term planning and asset management. Clearly flooding is the key concern for NRAs across Europe and drainage, geotechnics, pavements, bridges and tunnels are the assets most affected. Thus the NRA's priorities regarding mitigation strategies to reduce negative impacts of such events as increased precipitation resulting in storms and flooding on these key assets seem to be recognised. However, there is a general lack of tools to implement these mitigation strategies and research in climate change into practical solutions. The link between climate change and associated data collected either in real time (from roadway weather sensors, satellite, etc.) and asset management is still a very new concept to most NRAs.

In contrast, carbon reduction awareness is reflected in procurement approaches used by the Swedish NRAs (Klimatykalkyl), Dutch rail (CO_2 Performance Ladder) or UK (carbon reduction targets). Life cycle engineering concepts (LICCER) and the use of measurable and key performance indicators as listed by GreenRoads and LCE4Roads projects help to achieve more sustainable construction and maintenance projects in the road sector.

Eco-labelling of materials, products, services used and purchased by the NRAs can improve to environment conservation in a significant way as described in the Ecolabel project/initiative. Monitoring and enforcement of these KPIs after the project has been awarded can be an issue; thus, it is recommended that monitoring is conducted through-out the project and after the end of the project by environmental or sustainable procurement department with the NRA.

Implementation of green procurement in the transport sector is also dependent upon an individual country approach and culture towards sustainable and environmental awareness development. Countries with scarcity of natural resources such as the Netherlands and Scandinavian countries seem to be more green-aware and in support of recycling and sustainable procurement in general.

Additional benefits for the NRAs regarding prioritisation of services/products/actions and assets subject to sustainable procurement can be demonstrated through the use of decision support tools such as the UK's Sustainable Procurement Prioritisation Tool approach which if desired, can be adopted and modified by the DeTECToR project.

6.2.1 *Stakeholder workshop*

The next step in the project is to present the initial findings contained in this interim report at the stakeholder workshop on 4th April 2017. This workshop will be used to ascertain the requirements of the NRAs for guidance and tools relating to economic appraisal and procurement.

The purpose of the Workshop is to capture the expectations of the future users (NRAs) in both areas: typed of weather/climate hazards and quantification of their impact on road assets and expectations concerning the functionality of the tool. The draft agenda is given below.

09:30	*Registration and refreshments*
10:00	**Welcome** – PEB Project Manager, Reinhard David, ASFINAG
10:05	**Introduction to DeTECToR** – Sarah Reeves, TRL

10:25 **Initial project findings** – Ewa Zofka, IBDiM

10:45 **Questions on DeTECToR**

10:55 *Break*

11:10 **Interactive Session 1: What do NRAs need to know in order to develop effective climate change adaptation and mitigation strategies?**

12:30 *Lunch*

13:15 **NRA climate change actions**

I. Reducing carbon through procurement – Håkan Johansson, Trafikverket
II. Adapting to climate change – Graham Edmond, Transport Scotland

13:45 **DeTECToR tools and guidance** – Marek Skakuj, HI

14:00 **Interactive Session 2: What should the DeTECToR tools do and look like?**

16:00 *Break*

16:15 **Piloting the tools and guidance** – Matthias Schloegl, AIT

16:25 **Plenary discussion on suitable pilot studies**

16:45 **Summary** – Sarah Reeves, TRL

17:00 *Close*

For the two interactive sessions participants will be divided into two groups. Group 1 will discuss the relevance and requirements of the risk assessment and cost benefit tool and guidance. Group 2 will focus on the tool and guidance for embedding climate change mitigation and adaptation in operations and procurement.

6.2.2 *Defining the tool and guidance requirements*

Based on workshop results, survey results and the literature review, a specification for both the CBA and procurement support tools will be created. As the next critical item/milestone, the specifications for the tool will be provided to PEB for their feedback and acceptance to be able to start the implementation phase.

In parallel to the activities listed above, the implementation of tools and preparation for pilot studies will be performed. As pilot study locations will be determined during or right after the workshop, the description of the pilot studies and setup will be conducted by the consortium in coordination with PEB.

Following the workshop the consortium will produce:

D2.3 Data requirement and availability lists

D3.1 Functional Specification

These documents will outline the functions of the tools and format of the guidance, and will need to be signed off by the PEB before the development of the tools and guidance.

6.2.3 *Confirmation of pilot study details*

Following the workshop the consortium will also confirm the pilot studies, so that we can work with these NRAs throughout the development of the tools and guidance. The provisional pilot studies are in Table 14. These will be confirmed after the workshop and with the agreement of the PEB.

Table 14. Provisional pilot studies

Country	NRA	Tool and guidance to be piloted	Case study details
UK	Transport Scotland	Risk assessment and cost benefit analysis	A78 from Largs to Skelmorlie focusing on coastal flooding
Austria	ASFINAG	Risk assessment and cost benefit analysis	Vorarlberg
Germany	BASt	Risk assessment and cost benefit analysis	To be confirmed
UK	Transport Scotland (and maybe HE, TfL)	Embedding in operations and procurement	Across organisation
Sweden	Trafikverket	Embedding in operations and procurement	Across organisation
Poland	GDDKiA	Embedding in operations and procurement	Across organisation

7 Acknowledgement

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Annex A: Project Summary Sheets

See separate zip file.

Annex B: Stakeholders Survey Questionnaire

Part A: Asset Management

Q1: 1. Which assets cause your agency the most concern in relation to climate change impacts (select all applicable)?

- bridges
- pavements
- ITS: electronic traffic signs and signals
- road furnishing: equipment, electrical
- drainage
- static signs
- pavement lane markings
- tunnels
- geotechnics (earthworks, such as embankments)
- Other:…………

Q2: Please select the weather hazards which cause you the most concern for each asset type (only one choice per asset) please slide the bar below to the right to reveal more choices):

	temperature	precipitation	storm	fog	flooding	fluvial flooding	pluvial flooding	landslides	sea level rise	ground water changes
bridges										
pavements										
ITS electr. traffic signs and signals										
Road furnishing, equipment, electrical										
drainage										
static signs										
pavement lane markings										
tunnels										
geotechnics (earthworks, such as embankments)										

Q2a: Please list any other assets and hazards which cause you concern:…………………….

Q3: Please select what kind of data do you have available for your assets:

- location
- asset characteristics
- condition
- incidents of failure
- none
- Other:………..

Q4: What is the design period for your assets?

	<5 years	5-10 years	11-20 years	21-50 years	51-100 years	>100 years
bridges (superstructure)						
bridges (substructure)						
pavement structure						
pavement surface						
ITS						
road furnishing						
drainage						
pavement lane markings						
tunnels						
geotechnics (earthworks, embankments)						
other						

Q5: What is the planning horizon for your asset maintenance?

		<2 years	2-5 years	6-10 years	11-20 years	> 20 years
bridges (superstructure)						
bridges (substructure)						
pavement structure						
pavement surface						
ITS						
road furnishing						
drainage						
pavement lane markings						
tunnels						
geotechnics (earthworks, such as embankments)						
other						

Q6: Which types of meteorological data do you use and or have available?

- historical weather information
- real time data – e.g. Collected from road weather information stations
- short-term weather forecasts/severe weather warnings obtained from weather providers
- long-term climate change projections
- seasonal predictions
- Other:……………………

How do you use this information? please explain:……………..

Q7: Do you include consideration of climate change in the:

	yes	no
design of new infrastructure		
development of technical standards		
asset management plans		
business case for construction or maintenance projects		
design of new infrastructure		
development of technical standards		
asset management plans		
business case for construction or maintenance projects		

Please describe how:…………………

Q8: Do you include climate change impacts in the economic appraisal of potential construction projects or future maintenance plans?
☐yes
☐no

Q9: Do you use any risk assessment tools/models which allow you to estimate the costs of weather impacts?
☐yes
☐no
Please provide more information (i.e. what kind of costs):…………………

Part B: Procurement

Q10: Please indicate which of the following approaches your organisation employs to reduce carbon emissions through its procurement processes:

- considering carbon emissions when deciding which projects to fund
- including requirements relating to carbon reduction in tender specifications
- specific consideration in tender evaluation e.g. a proportion of the score is related to the tenderers approach to carbon reduction)
- inclusion of KPIs related to carbon in project and maintenance contracts
- including a requirement for contactors to measure carbon emissions in contracts
- None of the above
- Other:…………………..

Please provide any additional information:………………………

Q11: Which of the following tools/techniques does your organisation use to encourage its supply chain to reduce carbon emissions?

- setting carbon reduction targets for infrastructure projects
- benchmarking KPIs related to carbon across its projects
- encouraging the use of renewable energy
- requiring contractors to use a carbon calculator
- industry awards/recognition for contractors who perform well
- economic incentives (e.g. additional payments) for carbon reduction achievements

Please provide any other information:…………………………….

Relevant to climate change adaptation

Q12: Does your organisation consider climate change risks when:

- developing the business case for funding projects
- preparing project specifications and contracts
- determining data collection or incident reporting needs
- emergency response planning
- none
- Other:

Please provide any other information:………………………..

Q13: If required, do you consent to being contacted again in relation to this work:
☐yes
☐no