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# CLIMATE CHANGE, OTHER HAZARDS AND RESILIENCE OF ROAD NETWORKS

## A PIARC COLLECTION OF CASE STUDIES

TECHNICAL COMMITTEE 1.4 *CLIMATE CHANGE AND RESILIENCE OF ROAD NETWORKS*

PIARC

# STATEMENTS

*The World Road Association (PIARC) is a nonprofit organisation established in 1909 to improve international co-operation and to foster progress in the field of roads and road transport.*

*The study that is the subject of this report was defined in the PIARC Strategic Plan 2020–2023 and approved by the Council of the World Road Association, whose members are representatives of the member national governments. The members of the Technical Committee responsible for this report were nominated by the member national governments for their special competences.*

*Any opinions, findings, conclusions and recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of their parent organisations or agencies.*

*This report is available from the internet site of the World Road Association (PIARC): http://www.piarc.org*



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## A PIARC COLLECTION OF CASE STUDIES

**TECHNICAL COMMITTEE 1.4 *CLIMATE CHANGE AND RESILIENCE OF ROAD NETWORKS***

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This collection of case studies has been prepared by the Technical Committee 1.4 Climate Change and Resilience of Road Networks of the World Road Association (PIARC).

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# EXECUTIVE SUMMARY

2022R33EN

# CLIMATE CHANGE, OTHER HAZARDS AND RESILIENCE OF ROAD NETWORKS

## A PIARC COLLECTION OF CASE STUDIES

This report contains a collection of case studies related to climate change, other hazards and resilience of road networks. It comprises an introduction, outlining the work program for Technical Committee (TC) 1.4 Climate Change and Resilience of Road Networks, and objectives of two Working Groups within the Technical Committee. These are Working Group 1, which aims to identify uniform and methodological approaches to increasing resilience of roads. It covers hazards and environmental threats within the context of road infrastructure resilience as well as assessing methodologies and approaches to increase resilience. Working Group 2 involves an update of the PIARC International Climate Change Adaptation Framework for Road Infrastructure (PIARC 2020 ; PIARC 2012).

In order to support the development of these PIARC products, a survey to collect international case studies was conducted. This report has been divided into two parts:

- Part 1 – Overview of Case Study Collection Process and Results
- Part 2 – Assembly of Case Studies

Part 1 provides an overview of the case study collection process, the methodological background, and statistical results of the survey which included 71 studies from 24 countries and 6 continents around the world. It also includes a summary of identified definitions of resilience to contribute to the development of the TC Working Group reports.

Part 2 includes a summary of key case studies collected and summarised according to a consistent template. These have been categorised according to their systematic focus, i.e. which spatial perspective of climate change adaptation and resilience of road infrastructure is addressed by them. Overall, it was found that the majority of case study templates can be assigned to the category ‘whole network’, followed by the category ‘assets/site specific’ and ‘regional’.

The full reports from Working Group 1 and 2 will refer to these case studies.

# CONTENTS

# 1. INTRODUCTION

The World Road Association (PIARC) considers the following four Strategic Themes within the Strategic Plan 2020-2023: “Road Administration“, “Mobility“, “Safety and Sustainability“ and “Resilient Infrastructure“ (World Road Association, 2020). This report, in the context of Strategic Theme 1 “Road Administration”, represents an output of Technical Committee (TC) 1.4 “Climate Change and Resilience of Road Networks”.

TC 1.4 consists of two Working Groups and an internal Case Study Task Force. Working Group 1 aims to identify uniform and methodological approaches to increasing resilience of roads. It covers hazards and environmental threats within the context of road infrastructure resilience as well as assessing methodologies and approaches to increase resilience – taking into account the economic, environmental and social aspects of resilience management. Additionally, Working Group 2 involves an update of the PIARC International Climate Change Adaptation Framework for Road Infrastructure (PIARC 2020 ; PIARC 2012). The overall goal of the Case Study Task Force is to collect international case studies and to review these in order to provide structured information in a consistent form to both Working Groups.

The collection of case studies was finalised in 2021 to provide a good basis for the work in the 2020-2023 cycle and the related reports. However, the collection of further case studies has continued and expanded in the light of the topics identified for the 2020-2023 cycle. This includes the (re)evaluation of already collected case studies from the previous cycle, entailing identification of case studies especially with regard to holistic methodologies on the topic of resilience, resilience measures and to approaches to financial aspects of resilience management. Additionally, the coordination and collection of case studies with the relevant TCs, in particular with those of Strategic Theme 4 “Resilient Infrastructure” as well as the compilation, categorization and pre-evaluation of suitable case studies, framework approaches etc. with regard to the tasks within this TCs are regarded as necessary assignments (PIARC 2020).

In this context, the Task Force collected case studies by conducting a survey involving the TC 1.4 member countries. For the purpose of reviewing case studies in detail, the Task Force provides both Working Groups direct access to a case study database. This enables the rapid identification of relevant studies and their contents to prepare the Working Group reports.

This report presents the purpose and the approach of the case study collection process. It provides a brief description of the survey and the questions used to categorize case studies. Based on the methodological background, the results of the survey are presented in detail. In that context, first an overview of all case studies received from across the world is provided. This is followed by a categorization of case studies based on a series of questions. This statistical analysis of all received case studies is visualized in various diagrams and can be found in the appendix of this report. Finally, the report summarizes the previous work and briefly addresses the next steps until the end of the 2020-2023 cycle. It should be noted that only case studies submitted by 31 March 2022 are presented in this report. If case studies were submitted beyond this date, they were still added to the case study database.

## 2. TECHNICAL COMMITTEE 1.4 WORKING GROUPS

PIARC Technical Committee (TC) 1.4 Climate Change and Resilience of Road Networks observes that road and transport owners and operators are required to manage a broad spectrum of threats in the future and these alone and in combination can have a significant impact on the availability of road networks. In order to address climate and other hazards risks to networks (including aging infrastructure, natural disasters, man-made disasters), TC 1.4 aims to update the PIARC International Climate Change Adaptation Framework for Road Infrastructure (developed in previous PIARC cycles) and seeks to identify uniform and holistic methodological approaches to climate change and other hazards resilience. TC 1.4 assesses and identifies the best practice of adaptation and resilience activities for low and middle income countries (LMICs) and plays a fundamental role in providing access to information about resilience measures and its dissemination among low and middle income (LMICs).

The work of Technical Committee TC 1.4 is carried out around the following topics:

- 1.4.1 Uniform and holistic methodological approaches to climate change and other hazards resilience
- 1.4.2 Update of the PIARC Climate Change Adaptation Framework for Road Infrastructure

**Issue 1.4.1** aims to cover "Uniform and holistic methodological approaches to climate change and other hazards". This includes the concepts of all hazards and threats and a holistic approach to resilience where wider impacts beyond assets across the whole network are considered for all-hazards as well as climate change. Within this issue, there is consideration of resilient approaches such as risk management approaches, decision-making and uncertainties/deep uncertainties, as well as economic, social and environmental aspects of resilience management. These include the identification of socio-economic impacts of hazards on roads, identification of decision areas that need enhanced socio-economic information, identification of key users of such information, and identification of economic and other evaluation measures to increase resilience. Consideration will also be given to the implementation of resilience into asset management practices. The aim of this task is to explore the effectiveness of a possible PIARC all-hazard framework for resilient road networks. It is intended that the work of this Working Group will pave the way towards establishing an all-hazard resilient Framework in the future.

**Issue 1.4.2** covers an update of the PIARC International Framework for the Adaptation of Road Infrastructure to Climate Change (detailed below).

An Internal Case Study Task Force has the role of assisting the Working Groups in identifying all relevant literature sources from countries worldwide, and to support the development of the Reports for each issue.

**International Climate Change Adaptation Framework for Road Infrastructure**

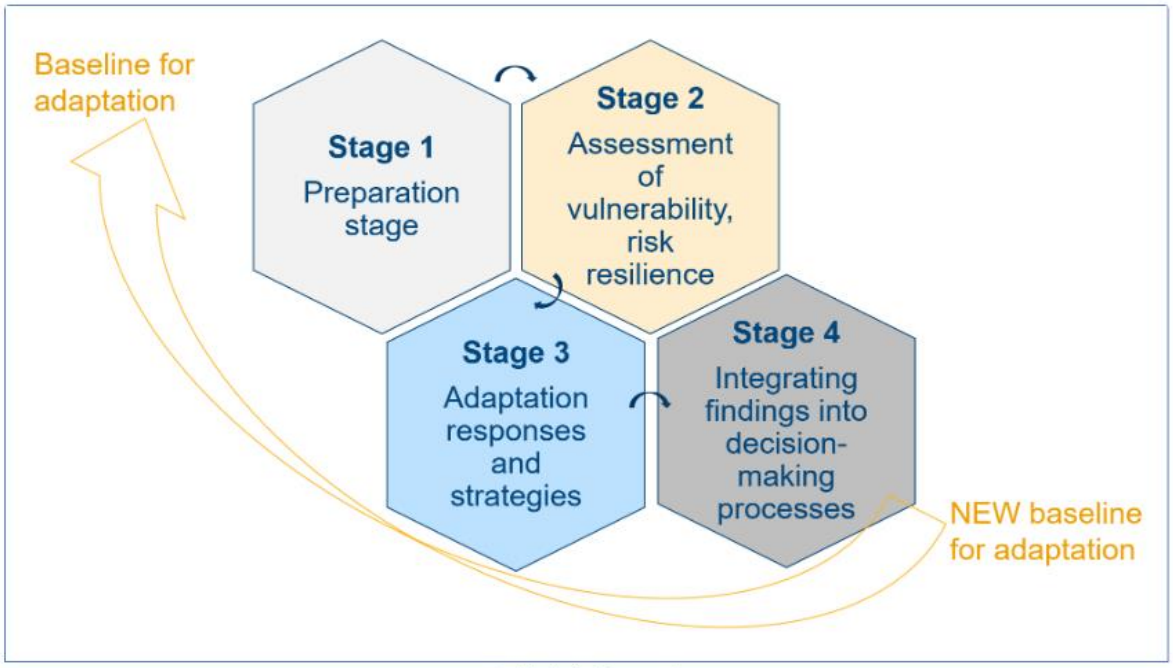
In 2015 PIARC developed an International climate change adaptation framework for road infrastructure (the Framework). The Framework aims to guide road authorities through the process of increasing the resilience of their networks and assets and is designed to be applicable at any scale such as national, regional, local or asset specific, and was designed to be of practical use

for road owners and managers in high and low-middle income countries. The Framework comprised four main elements, supported by a series of international case studies.

Following this first version of the Framework, PIARC saw a need to identify how this further captures current experience. This was the motivation for extending work on this Framework into other PIARC cycles (2016-2019) where two additional Final Reports have been developed and are available on the PIARC website. These include:

- Adaptation Methodologies And Strategies To Increase The Resilience Of Roads To Climate Change – Case Study Approach
- Refinements Of PIARC's International Climate Change Adaptation Framework For Road Infrastructure.

In this current cycle (2020-2023), Technical Committee 1.4 Climate Change and Resilience of Road Networks will provide an Update of the PIARC Climate Change Adaptation Framework. This will involve, taking on board the suggested refinements from the previous cycle, as well as the inclusion of new case studies and approaches and proposing a framework with a new structure and revised contents. New elements will also be provided within this updated version of the Framework, such as aspects of criticality, adaptive capacity and consideration of adaptation pathway approaches. It aims to be structured into separate parts, one containing processes and descriptions, the other providing an overview of possible methodologies for performing an impact assessment, vulnerability assessment, risk assessment and resilience assessments. Special attention will be given to defining the starting point or the baseline for adaptation, in order to capture all the various needs of road authorities.




*Update to the Framework.*

# PART 1: OVERVIEW OF CASE STUDY COLLECTION PROCESS AND RESULTS

## 3. PURPOSE OF THE CASE STUDY COLLECTION PROCESS

The goal of the Technical Committee 1.4 internal Case Study Task Force was to collect case studies that provide insight into climate change and resilience of road networks. In order to provide an overall picture on this subject as representative as possible, the case studies cover all continents and come from high-income countries as well as middle- and low-income countries. The collection of case studies was conducted by means of an online-survey with the purpose of providing case studies and information to the two working groups for a technical review.

The survey was also disseminated to other PIARC Technical Committees such as TC 1.5 Disaster Management, TC 4.1 Pavements, TC 4.2 Bridges, TC 4.3 Earthworks, and TC 4.4 Tunnels, including REAAA.

## 4. METHODS

In order to collect case studies relevant to both working groups, the Technical Committee 1.4 Case Study Task Force conducted a survey across TC 1.4 member countries. To promote the representation of low and middle-income countries (LMICs) and accomodate the idea of a platform for mutual knowledge exchange, care was taken to ensure that case studies from these same countries were considered adequately in the report. To maximize the number of case studies, a survey form was created on the online survey and questionnaire provider *LamaPoll* while TC 1.4 members were encouraged to participate via email. The survey form required participants to provide preliminary information such as main characteristics or topic of the case studies. Further information has been requested at a later stage after the initial review of the case studies had been completed. Overall, the survey includes 18 questions which are divided into four different sections:

- Section 1: General Information
- Section 2: Audience and Administration
- Section 3: Scope of the Case Study
- Section 4: Steps and details of the methodologies

In order to establish a common understanding of central concepts of TC 1.4 and completion of the survey, a glossary with term definitions for e.g. adaptation, resilience, sensitivity etc. was provided before proceeding with a series of questions. Section 1 included information about the title and author of the case study as well as information about the submitting person/agency, the related country and the confidentiality of the study (see Figure 1). Section 2 comprised the main audience, related administrative processes and the type of the case study (see Figure 2 for an excerpt). In section 3, participants were requested information about the objective of the case study, considered threats, whether it proposes a definition of resilience and if so, which aspect of resilience the study addresses and which changes towards the future are considered (see Figure 3 for an excerpt). The last section asked participants about the step of the reslience process the study focuses on, which type of method is used, what the scope of the impact analysis is and which type of approach is used to identify, analyse and prioritize interventions (see Figure 4). Additionally, an abstract of the case study and a website containing more detailed information of the case study was requested.

The information was collected using the online survey form and this information was stored in a case study database. The purpose of this database was to support both Working Groups in organising the case studies in a practical way and enabled information to be filed across an entire set of case studies according to different attributes. This function is useful for selecting a specific subset of case studies to facilitate the review.

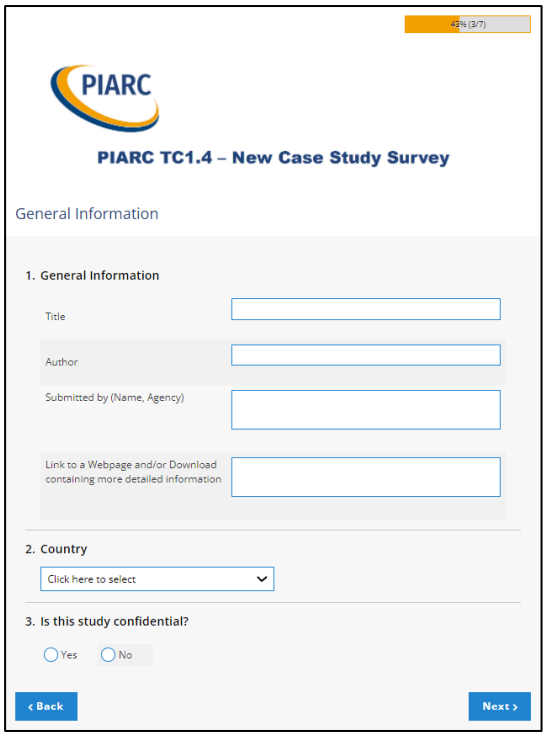



*Figure 1: Questions of Section 1*

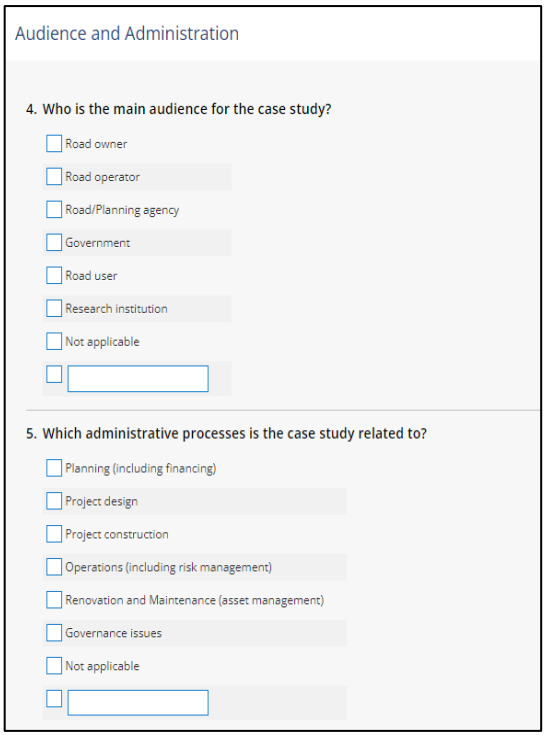



*Figure 2: Questions of Section 2 (excerpt)*

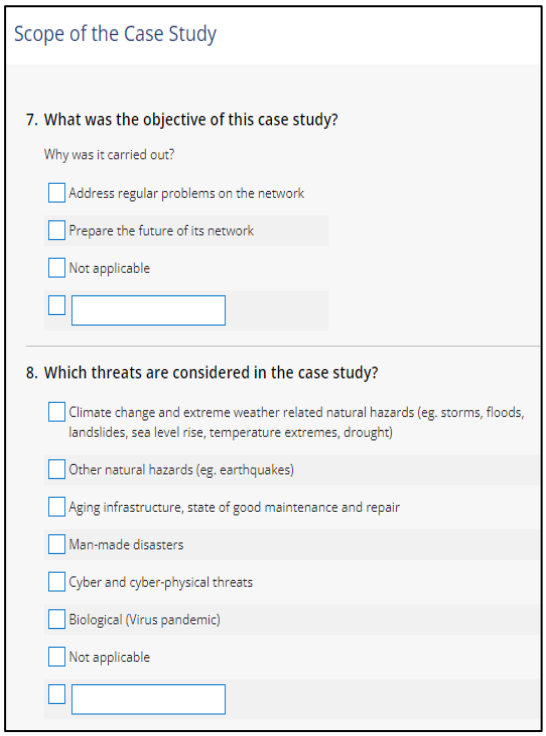



*Figure 3: Questions of Section 3 (excerpt)*

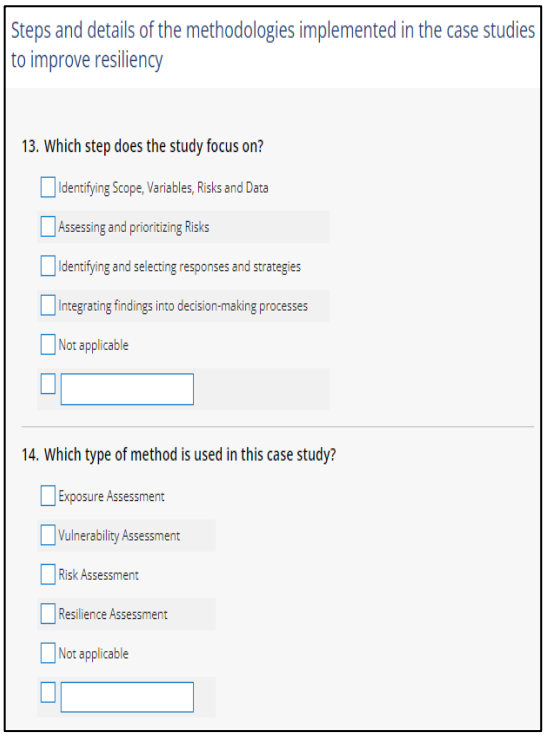



*Figure 4: Questions of Section 4 (excerpt)*

## 5. RESULTS OF THE CASE STUDY SURVEY

Until 31 March 2022 the Case Study Task Force received a total of 71 case studies from 24 countries and six continents. This totalled to 40 from 11 different countries, the majority of received case studies are from Europe. While four of these case studies have a continent-wide context, the most European case studies are from France (9), followed by Germany (7), Norway (6), Italy (4), Portugal (4), Denmark (1), Georgia (1), Greece (1), the Netherlands (1), Slovenia (1) and Spain (1). Fourteen case studies have been contributed by North American countries: eight from the United States of America and three from each Canada (Quebec) and Mexico. This is followed by 10 case studies from Australia/Oceania, seven being from Australia and three being from New Zealand. The remaining case studies were received from India, Indonesia, the Philippines and South Korea in Asia (each 1), from the African countries Mozambique and Morocco (each 1) and one case study from Chile in South America (see Table 1 and Figure 5).

*Table 1: Number and origin of Case Studies*

| Continent | Number of case studies |
|---|---|
| Europe | 40 |
| North America | 14 |
| Australia/Oceania | 10 |
| Asia | 4 |
| Africa | 2 |
| South America | 1 |

| Country | Number of case studies |
|---|---|
| France | 9 |
| United States | 8 |
| Australia | 7 |
| Germany | 7 |
| Norway | 6 |
| Portugal | 4 |
| Italy | 4 |
| not specified | 4 |
| New Zealand | 3 |
| Canada (Quebec) | 3 |
| Mexico | 3 |
| Chile, Denmark, Georgia Greek, India, Indonesia, Morocco, Mozambique, Netherlands, Philippines, Slovenia, South Korea, Spain | one each |

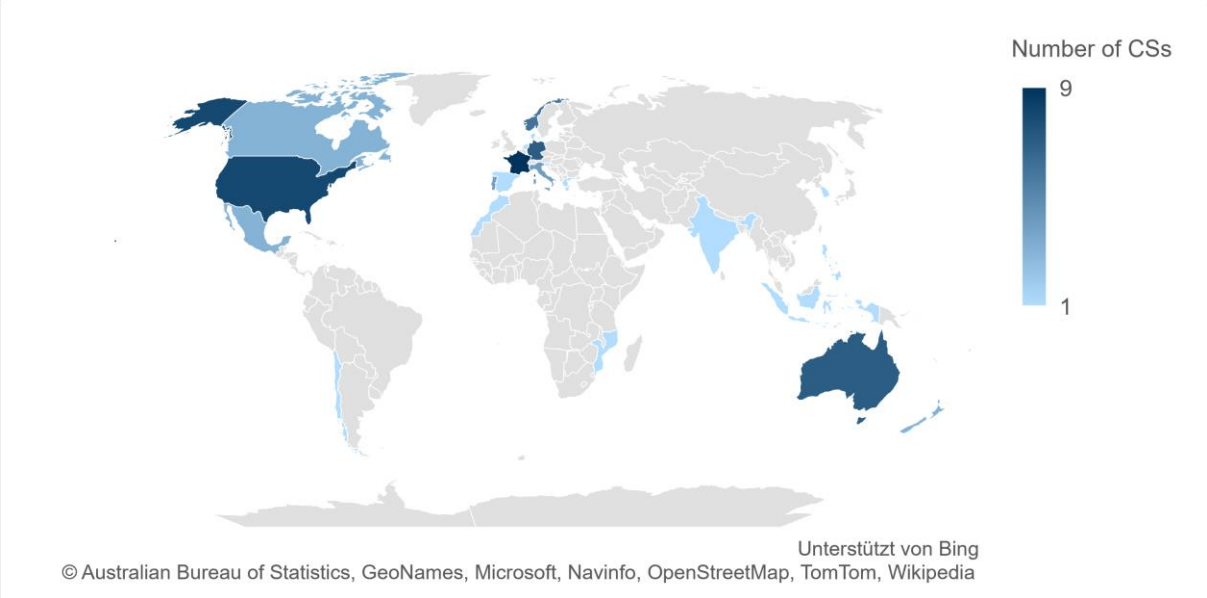



*Figure 5: Number of received case studies per country represented in the survey*

Please note: Some questions could not be answered for all case studies. In this case, the answer option "not applicable" was selected. The answer options «Other » were specified in free text boxes. The contents are shown below the figures.

It should be noted that these numbers represent neither the continental proportion nor the total numbers of case studies available globally. Therefore, the results have to be treated carefully,

bearing in mind that they are based on the case studies collected by this survey. Approximately 16 per cent of case studies included confidential information and are therefore only accessible to a limited extent. However, the majority of case studies are publicly available and are written in, or translated into, English. Only few case studies are in other languages, such as Spanish.

It was determined through the case study analysis that the main audiences for the case studies are road owners (60%), road operators (54%), road/planning agencies (53%) or governments (51%). About a quarter of the case studies address research institutions and 9 per cent have road users as a target group. Further potential audiences include road administrations, communities or consultancies in the field of climate change risks and transport infrastructures (Figure 6). Most of the case studies are related to the administrative processes of operations including risk management (61%), planning including finances (60%), renovation and maintenance (46%) as well as project design (46%). About 23 per cent are related to project construction or governance issues (Figure 7).

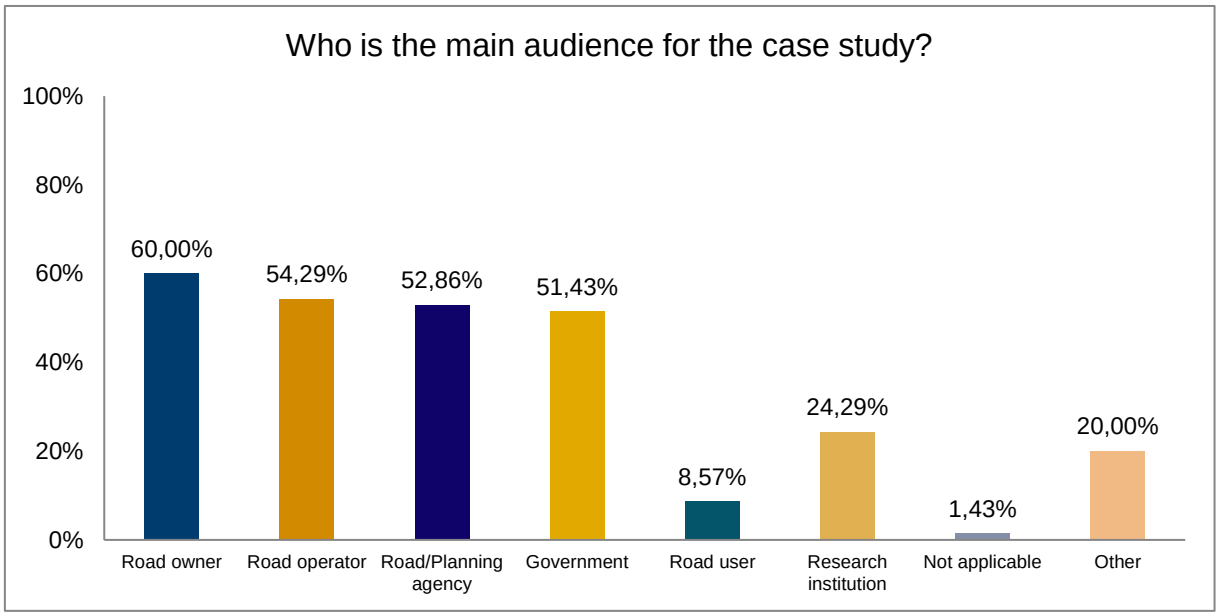



*Figure 6: Percentage distribution of case studies related to main audience*

Other : Community; consultancies in the field of climate change risks; transport infrastructures; general public; industry; Infraestruturas de portugal, sa (ip, sa) is the public company that manages road and rail infrastructures, in accordance with a joint, integrated and complementary strategy. the sole shareholder of ip, sa is the portuguese state. ip, sa is subject to the supervision of the ministries of infrastructure and housing and finance. ip, sa - national road administration; Lisbon metropolitan area; municipality, owners and operators of transport infrastructure (road, rail, waterway); users of transport infrastructure (manufacturing, transport and logistics companies, etc.); port managers; port operators; railway operators; World bank

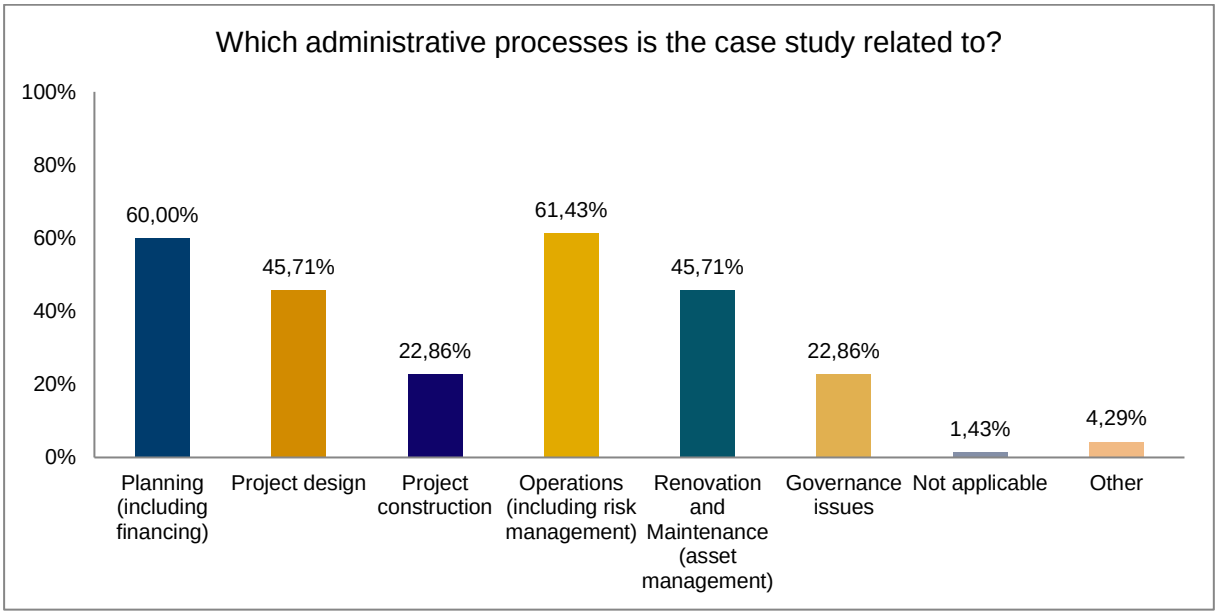



*Figure 7: Percentage distribution of case studies related to administrative processes*

Other : Planning; design & financing; Policy statement; Standards

Six different types of case studies were submitted via the survey. It was identified that the majority of case studies include topics concerning research and development (37%), strategy and policy guidance (35%), pilot studies (32%) and the implementation in daily practices (30%). 20 per cent of the submitted case studies are technical guidelines or white papers, while only 7 per cent are standards or regulations (Figure 8). Almost all of the case studies (86%) have the objective to prepare the future of its network, while 44 per cent also address the regular problems of the network. Another common objective is developing concepts for a resilience management using for example damage assessment or scenario-based stress tests (Figure 9).

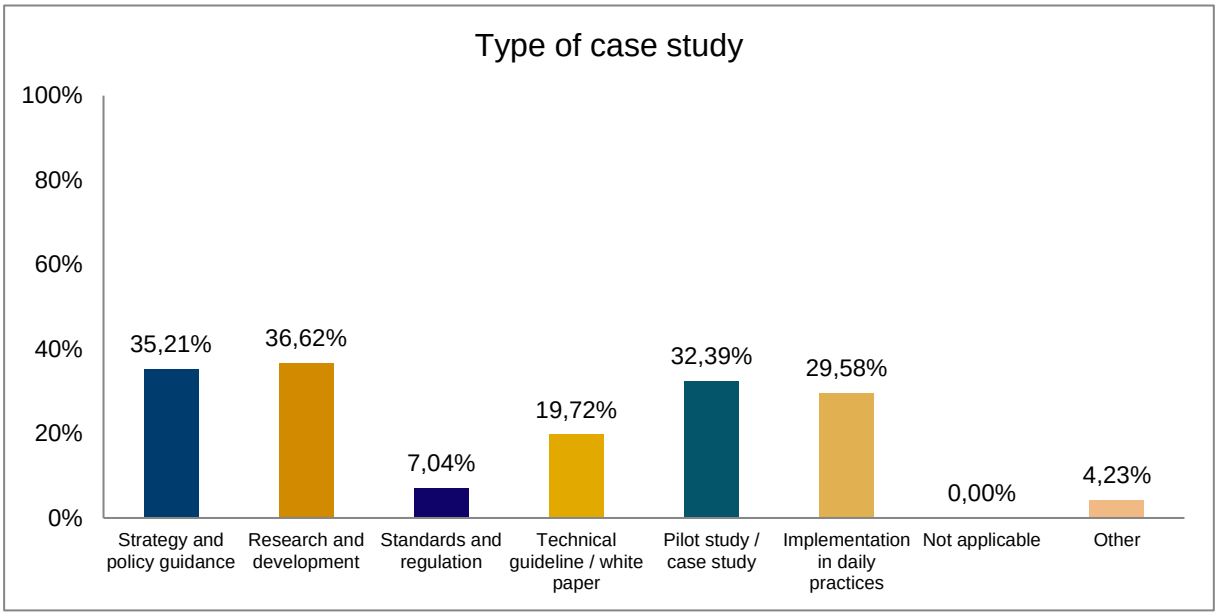



*Figure 8: Percentage distribution of case studies related to case study type*

Other : Project rating system guidance; Risk prioritisation database.

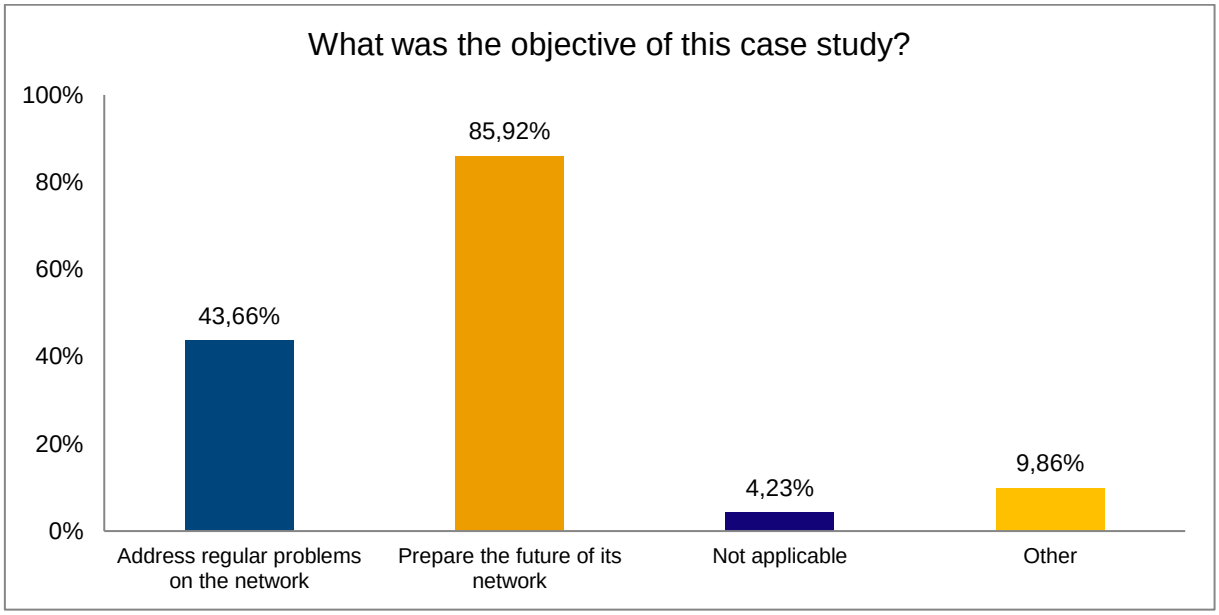



*Figure 9: Percentage distribution of case studies related to the objective*

Other : Damage assessment after a flood; developed with the support of 100 resilient cities – pioneered by the rockefeller foundation (100rc); development of a concept for resilience management; framework for assessing sustainability and resilience in new infrastructure; railway; rsearch/increase knowledge; scenario-based stress test for an important transport corridor (road, rail, waterway)

The hazards considered include mostly climate change and extreme weather related natural hazards (90%) or other natural hazards (27%). Another main topic is aging infrastructure, maintenance and repair (38%) or man-made disasters (14%). Cyber or cyber-physical threats were considered in 8 per cent of the case studies and 7 per cent deal with biological hazards such as the virus pandemic covid-19 (Figure 10). Several changes towards the future are considered in the case studies, dominated mostly by climate change issues (86%). Other future changes that have been examined are socio-economic (23%) and environmental developments (21%) as well as the aging (21%) or future changes of infrastructure (Figure 13).

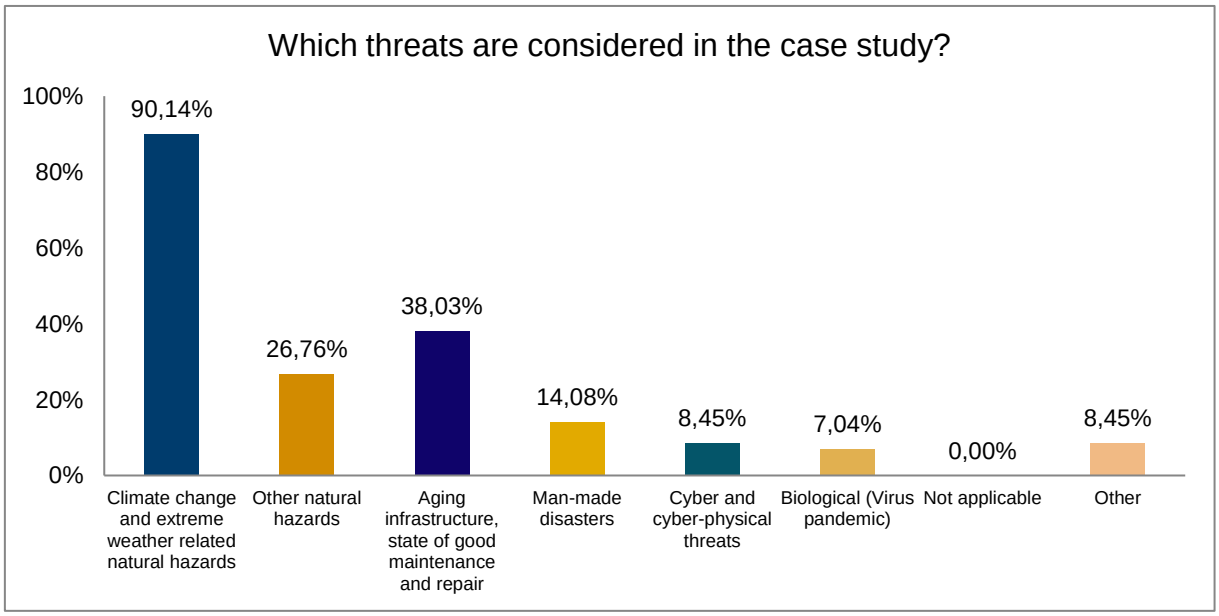



*Figure 10: Percentage distribution of case studies related to considered threats*

Other: Climate change and water management; gravitational mass movement; high water; low water; extreme event; In theory, all of the above could be addressed; the framework focused on urban transportation issues; link closure caused by a traffic incident; not specific mentioned; There is a detailed analysis of the impacts of COVID-19

In general, the case studies mainly focus on assessing and prioritizing risks (68%) and on identifying scope, variables, risks and data (68%). Additionally, various studies focused on the identification and selection of responses and strategies (62%). With 37 per cent, slightly more than a third of the case studies concentrate on integrating the findings into decision-making processes (Figure 14). Various methods were used in the different case studies, including risk (62%), vulnerability (55%) and exposure assessment (51%). In addition, methods for assessing resilience (35%), scenario-based stress tests, traffic simulations and cost assessments were used (Figure 15).

The overall scope of the impact analyses focus on damages to the road (63%), road or system losses for the users (55%), losses for society in general (37%) and safety (32%). Besides, issues of environmental nature (17%), social equity and environmental justice (6%) or damages to infrastructure and loss of function were considered in the impact analyses (Figure 16). Different approaches to identify, analyze and prioritize interventions were applied. Most of the case studies focus on qualitative approaches (35%), multi-criteria assessments (32%) or cost-benefit analyses (16%). Financial aspects were also further considered in life-cycle costing (6%) and cost effectiveness assessments (3%) (Figure 17). Almost two thirds of the submitted case studies propose a definition of resilience, while most of them address the aspect of response (83%). Aspects of preparedness and recovery are the second most frequently addressed with 78 per cent each. The prevention phase is covered in 70 per cent of the case studies (Figure 11 and 12).

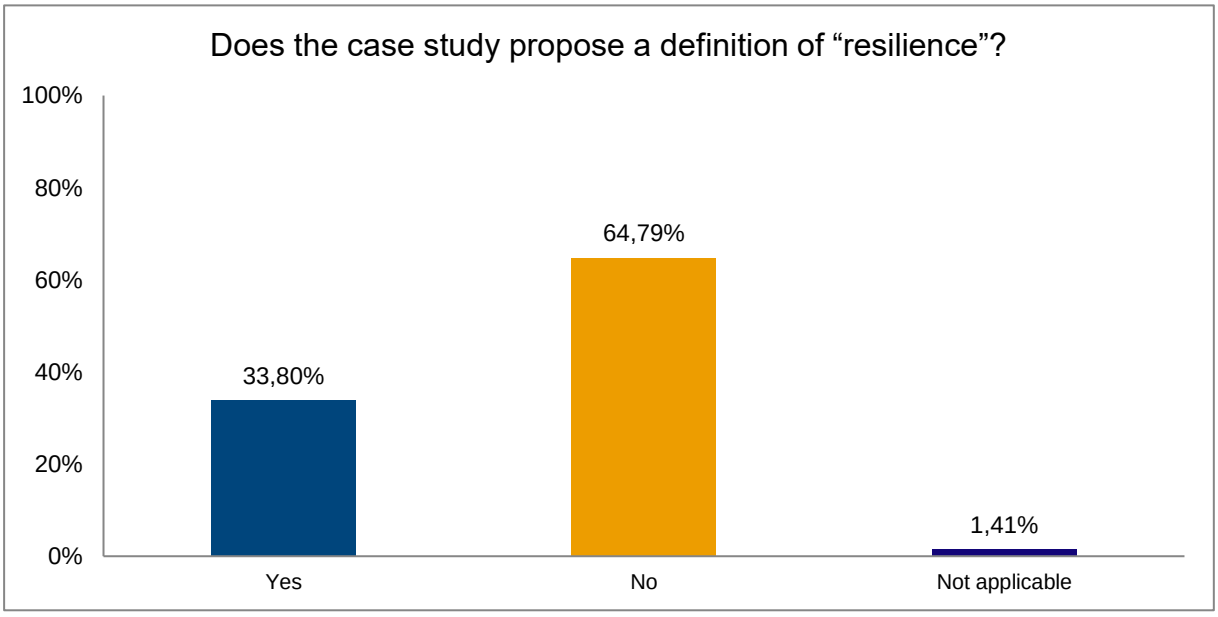



*Figure 11: Percentage distribution of case studies related to the proposal of a resilience definition*

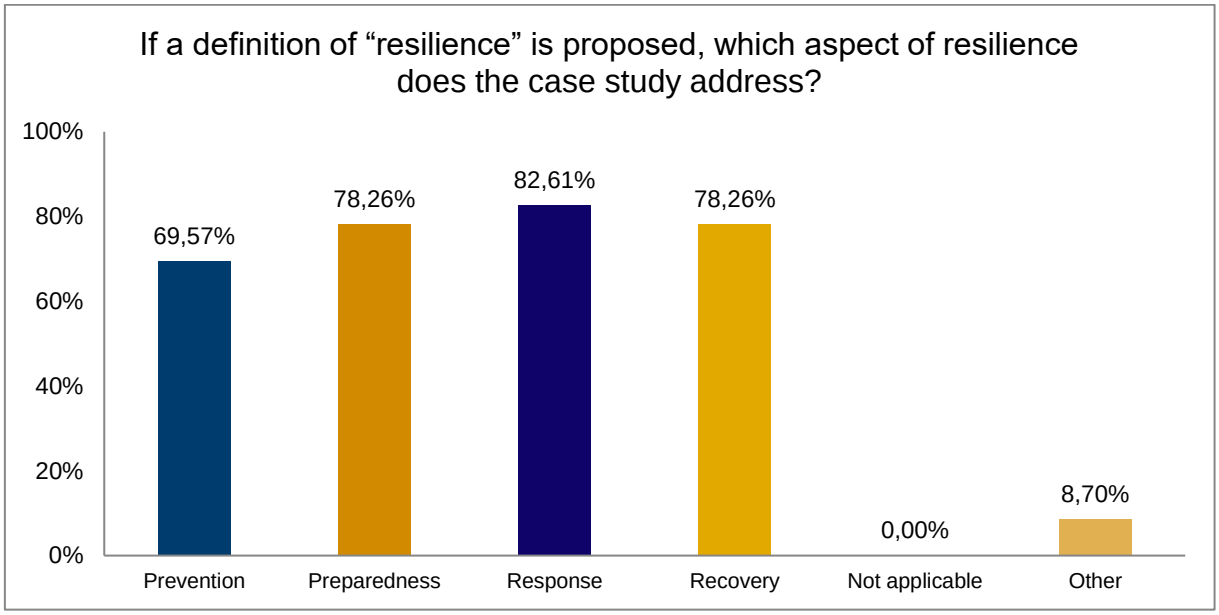



*Figure 12: Percentage distribution of case studies related to the addressed aspect of resilience*

Other : Adaption; Method testing

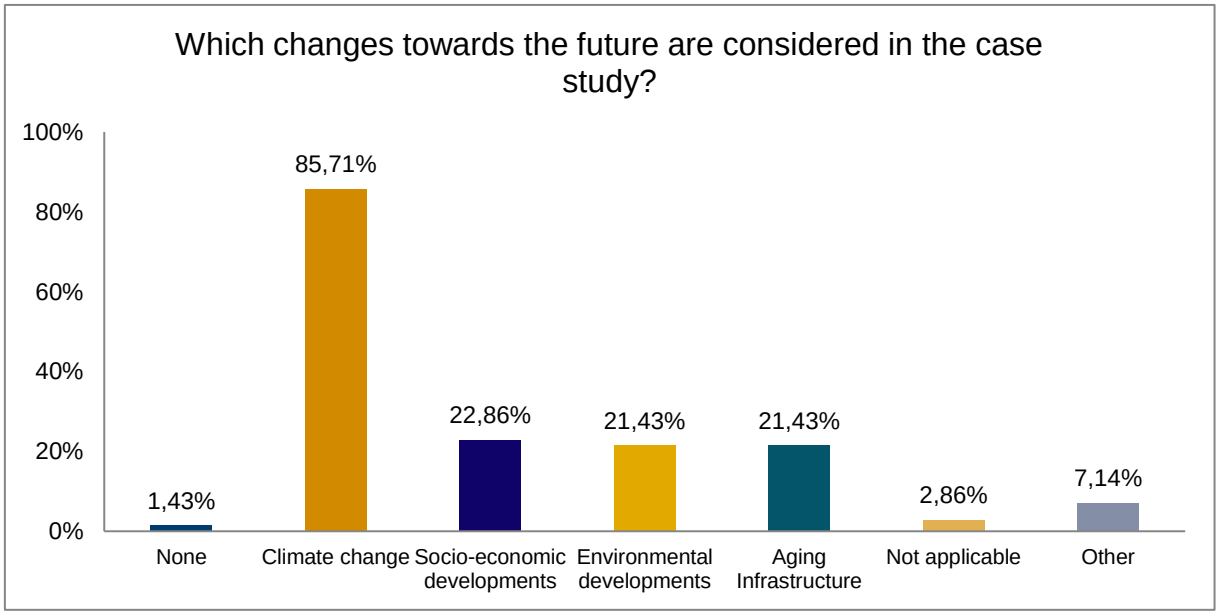



*Figure 13: Percentage distribution of case studies related to considered future changes*

Other : General trends in all the mentioned issues are considered; not other specific mentioned; projections and forecasts of future conditions (e.g., climate projections) or directly considered in the concept for resilience management so far; the framework may in theory address any of the aforementioned changes; traffic and transport infrastructure in the year 2010 and 2030

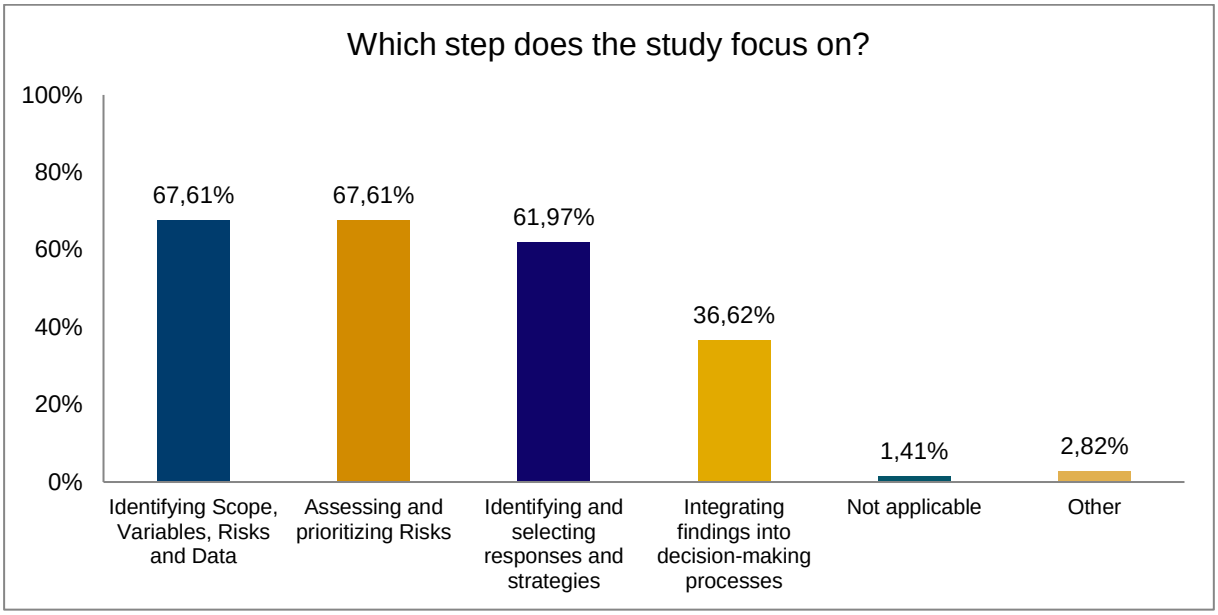



*Figure 14: Percentage distribution of case studies related to step in focus*

Other : Does most of these steps; at the project level; policy statement

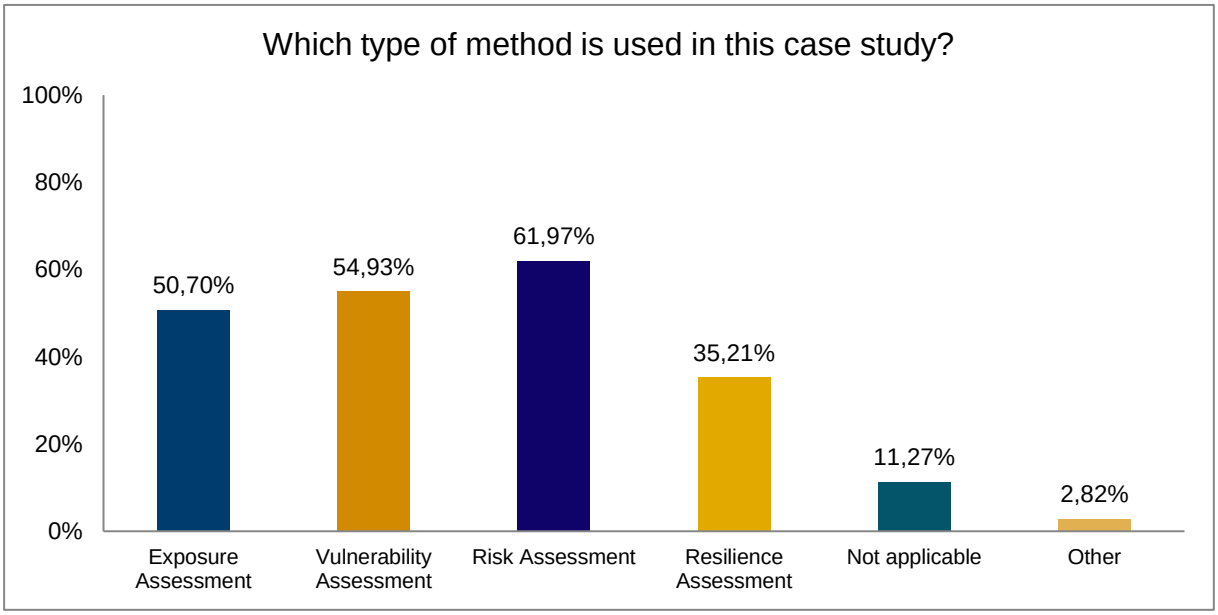



*Figure 15: Percentage distribution of case studies related to used type of method*

Other : Organisational resilience approach; scenario-based stress test; traffic simulation; cost assessment

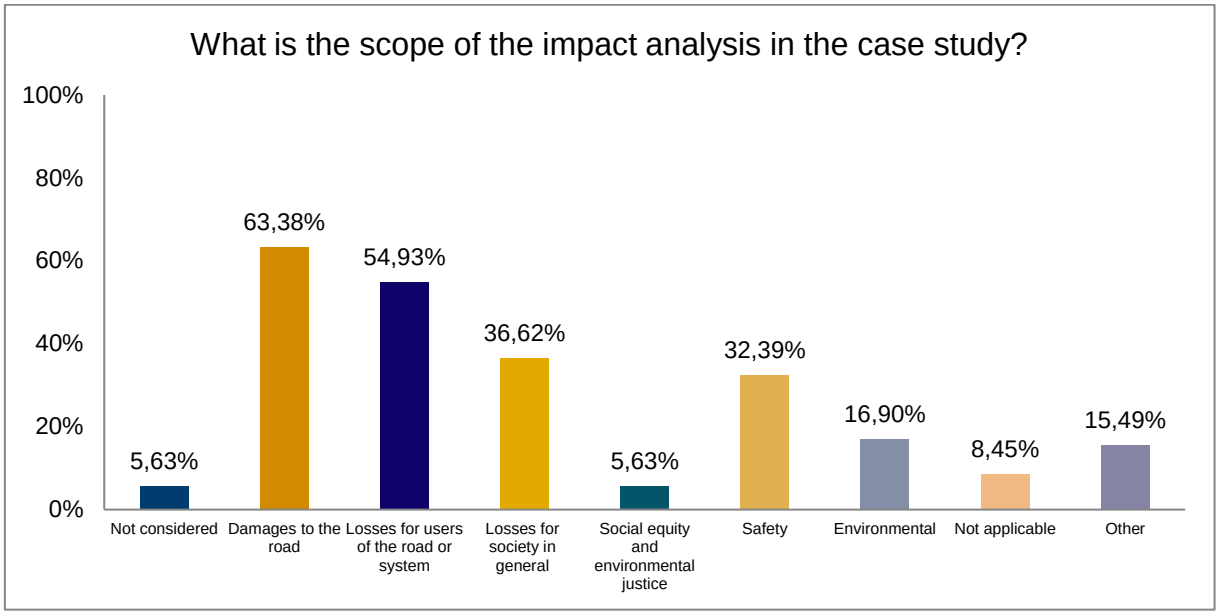



*Figure 16: Percentage distribution of case studies related to scope of impact analysis*

Other : Damages to the port infrastructures (including e.g natural areas); functions; economic impacts and more generally, damages to the port environments; damages to the railway; impacts on the maintenance and operation of the network; potential damages to road infrastructure; railway; resilience is considered by sector e.g. cities and the built environment; road maintenance and operation

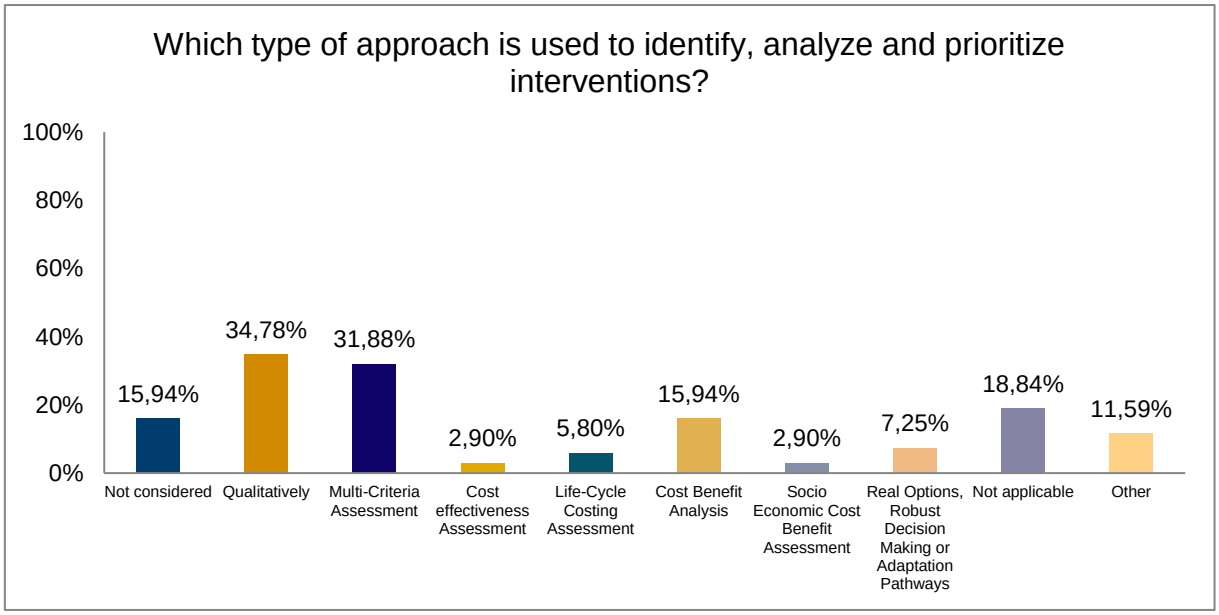



*Figure 17: Percentage distribution of case studies related to type of approach for identification, analysis and prioritization of interventions*

Other : Analytic hierarchy process; collecting all necessary expert opinion to formulate a broadly accepted set of service and resilience targets; functional resonance analysis method; identification of the need for climate projections and indicators to adapt standards; Indicator-based assessment approach; combination of indicators using matrices for the assessment of impacts and consequences on the object and network level; nature-based features used to adapt projects to be more resilient; road map of actions to follow this strategy

## 6. DEFINITIONS OF RESILIENCE

Through the case study collection process, it was identified that there are a number of definitions of resilience which have been developed . The various definitions from the different studies can be found in Table 2.

*Table 2: Definitions of resilience within the case studies*

| Definition | Case Study Title |
|---|---|
| ‘‘The ability to prepare for changing conditions and withstand, respond to, and recover rapidly from disruptions” (FHWA, 2015). The terms resilience and resiliency are used interchangeably by researchers and practitioners. For consistency throughout this article, the authors have adopted the term resilience to be in line with FHWA’s terminology. | Comparative evaluation of measures for urban highway network resilience due to traffic incidents |
| "The capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation.“ | Case Study: Implementation of Climate Adaptation measures on pilot road in Mozambique |
| "The method is a simplified resilience assessment, where emphasis is put of three parameters: robustness, redundancy, and recovery. These parameters are scored based on their local, regional, or national importance and the scores are combined in a total score for the project – which is then a basis for comparison between project solutions.“ | The 3R method - a simplified resilience approach for assessing road projects in Norway |
| "The ability to anticipate and resist the effects of a disruptive event, minimise adverse impacts, respond effectively post-event, maintain or recover functionality, and adapt in a way that allows for learning and thriving.“ | National Disaster Resilience Strategy |
| "A system is resilient when it can adapt to internal and external challenges by changing its method of operations while continuing to function. While elements of the original system are present there is a fundamental shift in core activities that reflects adapting to the new environment.' (Ciara Rooney - Source: ww.activegarage.com/resilience-engineering-1-robust-resilient)“ | Water management for road authorities in the face of climate change |
| "The study discusses different definitions of resilience, however the methodological concept is based on the definition provided by Hollnagel (2011) : 'The intrinsic ability of a system to adjust its functioning prior to, during or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions'“ | RESilience management guidelines and Operationalization appLied to Urban Transport Environment |
| "Resilience is the ability of a system to be prepared for actual or potential damaging incidents, to factor them in, to avoid them, to overcome them and to recover from them as quickly as possible. Damaging incidents are unusual occurrences or processes of change caused by humans, technology or nature, having extreme or disastrous consequences.“ (Deublein et al., 2020) | Development of a concept for resilience management for federal highways in Germany |
| "The definition is based on the IPCC’s definition and adapted to transport infrastructures: The capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure. Resilience is a positive attribute when it maintains capacity for adaptation, learning and/or transformation.“ | Resilience of SANEF road network to climate change |
| "The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of | Planning for adaptation to climate change – |

| | |
|---|---|
| functioning, the capacity for self-organization, and the capacity to adapt to stress and change.“ (IPCC, 2007) | Guidelines for Municipalities |
| "The resilience of critical infrastructure depends on the capacity of owners and operators to effectively manage the risks to their operations. This includes having in place mature risk management procedures, based on best practice, to effectively prepare for, prevent, respond to and recover from foreseeable risks and developing capabilities that empower and enable organisations to manage unforeseen risks.“ | Critical Infrastructure Resilience Strategy: Policy Statement |
| "Resilience – the capacity of an infrastructure system or organisation to cope with, and quickly recover from, an adverse climate change impact. Resilience can be enhanced through changes in management, procedure and awareness, as well as physical measures.“ (TRL, 2008 – Transport Research Laboratory, 2008, Climate Change Resilience Indicators, report for South east England Regional Assembly, CPR117, September) | Australian Green Infrastructure Council Guideline for Climate Change Adaptation |
| "Resilience is defined by the Victorian Government as the capacity of individuals, communities, institutions, business and systems to survive, adapt and thrive no matter what kind of chronic stresses and acute shocks they experience. The critical infrastructure framework takes an ‘all hazards, all emergencies’ approach to building resilience, which reflects the potential for both natural and human-induced events that can disrupt or damage critical infrastructure.“ | Victoria’s Critical Infrastructure All Sectors Resilience Report 2020 |
| "100RC defines urban resilience as the capacity of individuals, institutions, businesses and systems within a city to adapt, survive and thrive no matter what kind of chronic stresses and acute shocks they experience.“ | Resilient Melbourne Strategy |
| "City resilience is the capacity of individuals, communities, businesses and systems within a city to survive, adapt and thrive no matter what kinds of chronic stresses and acute shocks they experience.“ | Resilient Sydney: A strategy for city resilience 2018 |
| "Resilience or resiliency is the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions.“ | Vulnerability Assessment and Adaptation Framework, 3rd edition (2020) |

# 7. IMPLEMENTATION OF SURVEY RESULTS INTO TECHNICAL COMMITTEE 1.4 ACTIVITIES

The results of this survey have provided a useful input into the preparation of the reports of the two Working Groups of Technical Committee (TC) 1.4. Besides the collection and classification of relevant case studies, the work of the Task Force was focused on making the results easily accessible via the TC 1.4. The case study database contains all the above-mentioned aspects for each submitted case study and thus offers the possibility for the Working Groups to filter the case studies in order to get a quick overview of the relevant case studies. Through this, it serves both Working Groups as a source of information for the review of case studies and the preparation of the Working Group reports. In addition, the database contains references where further information and documentation on the case studies can be found.

The compilation of the Case Study Database required the provision of case studies by TC 1.4 members and other colleagues in their respective countries. Throughout the current PIARC cycle the Task Force received great support which was necessary to compile the Case Study Database. All the information collected by the Task Force could serve as a basis for the work in future PIARC cycles. It should be noted that a relatively low response rate from LMICs may affect the applicability of the findings from the case studies to those countries. The response rate of these countries could be improved through different strategies initiated by PIARC. This could include leveraging resources to holistically target LMICs from PIARC as umbrella organization that go beyond the efforts of individual Technical Committees.

# PART 2: ASSEMBLY OF CASE STUDIES

Part 2 of the report of Technical Committee 1.4 represents an assembly of case study templates on climate change adaptation and resilience of road infrastructure that were included in the individual reports of Working Group 1 and Working Group 2.

All case studies have been collected by conducting a survey distributed across members of Technical Committee 1.4. For this part of the report, they were categorized according to their systematic focus, i.e. which spatial perspective of climate change adaptation and resilience of road infrastructure is addressed by them. It was found that most case study templates can be assigned to the category 'whole network', followed by the category 'assets/site specific' and 'regional'.

## 8. CASE STUDY TEMPLATES

The largest number of templates comes from Europe (22), followed by North America (8) and then Australia/Oceania (4) and Asia (1).

The Case Study templates were categorized according to their focus on the whole network, regions or specific assets and sites. This results in the following distribution for the categories: whole network (20), regional (7) and assets/site specific (8).

### 8.1. WHOLE NETWORK

- Climate impact analysis of the federal transport system in the context of floods
- Climate impact analysis of the federal transport system in the context of storms
- Climate impact analysis of the federal transport system in the context of mass movements
- Methodological framework for adapting road infrastructure to climate change in Mexico
- Geospatial analysis of climate change in road infrastructure in Mexico
- Implementing the International Climate Change Adaptation Framework for Road Infrastructure in Mexico
- xgeo.no – Expert tool for preparedness, monitoring and forecasting
- National landslide and avalanche warning system
- System for assessment and responding to geohazards
- National Resilience Programme Business Case
- Analysis of the risks incurred by extreme climate events on infrastructures, systems and transport services
- Potential impacts of climate change on transportation infrastructures and systems, on their design, maintenance and operation standards and the need for detailed climate projections
- Envision - Sustainable Infrastucture Framework
- ForeSEE Project - Assesment of existing climate databases
- Toward a Resilient Highway Network in the Netherlands
- Criticality assessment in road projects in Mexico
- CEN WORKSHOP AGREEMENT - CWA 17819
- Mainstreaming Disaster Risk Management to Sustain Local Roads Infrastructure
- Methodology for Calculating a Vulnerability Score Used in Network Vulnerability Assessments
- New Zealand Mandatory Climate-related Financial Disclosures

## 006 Climate impact analysis of the federal transport system in the context of floods

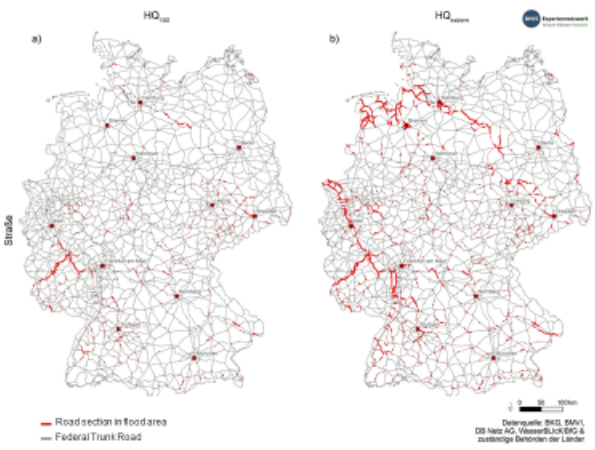
**Purpose**
Analysis and assessment of flood event impacts on road, railway and waterway infrastructure caused by river floods, coastal water levels and heavy precipitation for the transport network of Germany based on the studies of the BMVI-Network of Experts

**Output**
- Key statements on the future projection of precipitation conditions, runoff of major rivers as well as sea level
- Key statements, statistics and maps on the impact of these changing conditions on Germany's transport system

**Benefits**

Assess the need for adaptation of federal transport system to climate change impacts

Support in the planning of new construction and maintenance measures




Sections of the federal trunk road network that lie in the area of potential flood areas of a medium (left) or extreme river flood and storm surge scenario (right) (highlighted in red).



*Further information:*

*https://www.bmvi-expertennetzwerk.de/DE/Publikationen/TFSPTBerichte/SPT103.html?nn=1371986*

*(German language)*

## 007 Climate impact analysis of the federal transport system in the context of storms

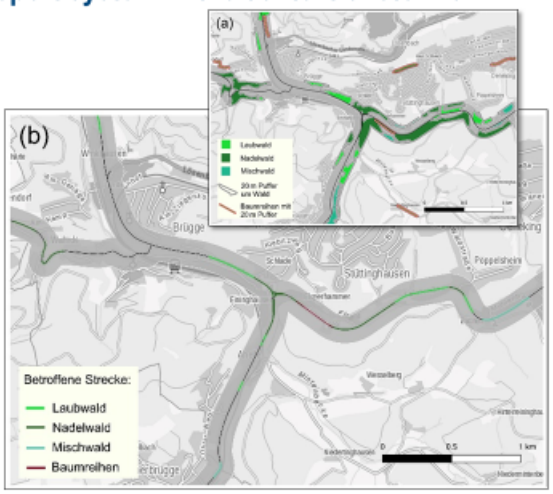
**Purpose**
This report summarizes the studies of the BMVI-Network of Experts concerning storm hazards and provides some indications of the type and scale of foreseeable risks of storms to the federal transport system

**Output**
- Key statements on the future projection on extreme winds and storms over land/sea and on potential storm surges
- The exposure of transport infrastructure to storms is mainly determined by the availability of vegetation
- Exposure analysis for wind throw was carried out

**Benefits**

Assess the need for adaptation of federal transport system to climate change impacts

Support in the planning of new construction and maintenance measures




Location of forested areas within a 100 m observation area around the federal main road network (a) and the derived exposure against wind throw at a distance of 20 m (b)



*Further information:*

*https://www.bmvi-expertennetzwerk.de/DE/Publikationen/TFSPTBerichte/SPT104.html?nn=1371986*

*(German language)*

## 008 Climate impact analysis of the federal transport system in the context of gravitational mass movements

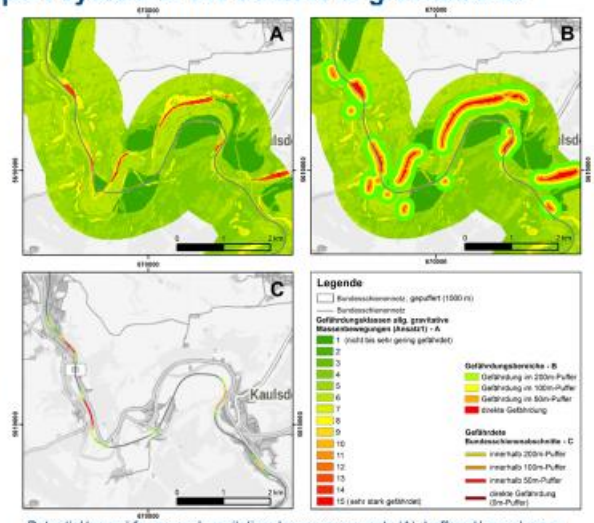
**Purpose**
This report summarizes the studies of the BMVI-Network of Experts concerning hazards due to gravitational mass movements

**Output**
- Key statements on the future projection on triggering climatic parameters for gravitational mass movements such as permanent or heavy precipitation and freeze-thaw changes
- Key statements and statistics on the impact of gravitational mass movements on Germany's transport system in the context of changing climatic conditions

**Benefits**

Assess the need for adaptation of federal transport system to climate change impacts

Support in the planning of new construction and maintenance measures




Potential hazard for general gravitational mass movements (A), buffered hazard areas of the hazard classes ≥10 (B) and the resulting affected line sections (C), expert knowledge-based approach, section of the federal rail network



*Further information:*

*https://www.bmvi-expertennetzwerk.de/DE/Publikationen/TFSPTBerichte/SPT105.html?nn=1371986*

*(German language)*

# 033 Methodological framework for adapting road infrastructure to climate change in Mexico

**Purpose:** The Framework has been developed to assist road engineers who operate and maintain the national road infrastructure, and has an engineering approach to face the challenge that has represented the climate change.

**Output:**

- The vision of the Framework is to be able to consolidate this tool as a manual for adaptation to climate change in any road organization in the country, since it is based on international experience, but supported by local instruments.

**Benefits:**

The main advantage of using the Framework is its process, which allows for the establishment of an integrated planned phase, which ensures its implementation and the obtaining of reliable results, as well as a systematic analysis for the identification, assessment and prioritization of risks associated with climate change.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*Further information:*

https://imt.mx/archivos/Publicaciones/PublicacionTecnica/pt557.pdf

*(Spanish language)*

## 034 Geospatial analysis of climate change in road infrastructure in Mexico: impacts, vulnerability, future climate and risks

**Purpose:** Identifying risk sites on the network by the help of GIS - methodology and the examples.

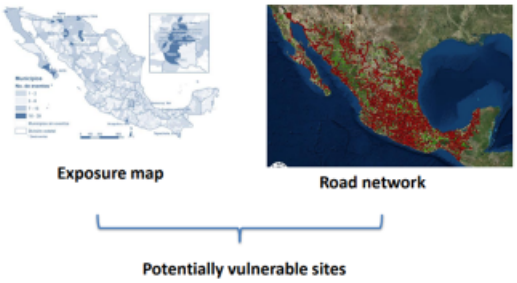
**Output:**

- The case study is supported by maps of risk and climate change made in Mexico, and that when maps overlay with the road network, the sections of the road network. exposed to different climatic threats can be identified.
- Useful tool to identify which assets, sites or elements are at risk/threatened/vulnerable.

**Benefits:**

The use of tools such as GIS that allow geospatial analysis of climate change, may increase the coverage of the vulnerability analysis of the Mexican highway network.

Good basis for prioritizing adaptation action when road networks are very large.

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PIARC

*Further information:*

https://imt.mx/archivos/Publicaciones/PublicacionTecnica/pt523.pdf

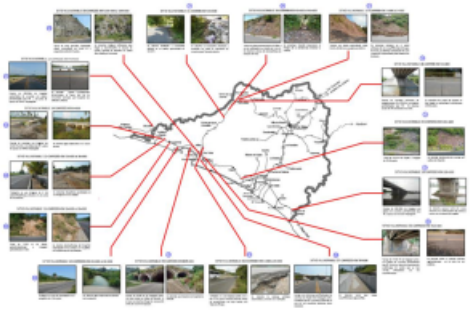
*(Spanish language)*

# 039 Implementing the International Climate Change Adaptation Framework for Road Infrastructure in Mexico

**Purpose:** Implement the PIARC Adaptation Framework and identify opportunities for improvement.

**Output:**

- The CS illustrates how to apply the Framework in all its stages and steps, making use of information from Mexico.
- The CS adapted various evaluation matrices for the case of Mexico, since the Framework needs to be adapted to the context of each country.



**Benefits:**

Evaluate the applicability of the Framework, the information needs for using it in the different countries and the opportunities for improvement.

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*Further information:*

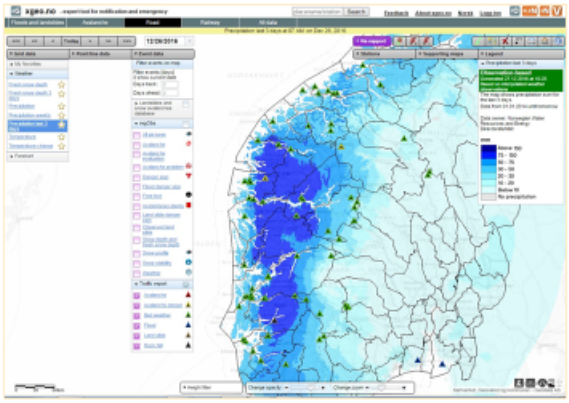
*https://routesroadsmag.piarc.org/en/Routes-Roads-Magazine-Numero-378-Roads-Tunnels/5353,Routes-Roads-Mag-378-Update-International-Climate-Change-Adaptation-Framework-Road-Infrastructure-The-case-of-Mexico#c1a16ba0y34*

*(English language)*

## 150 xgeo.no – Expert tool for preparedness, monitoring and forecasting

- Weather data
- Road data
- Data on earlier events

- Threshold values
- Emergency levels → responsibility and action



Recognizing situations requiring a higher emergency level.

Topics to include?
Making use of available data, data-sharing, combining weather, terrain conditions and previous weather-related events.

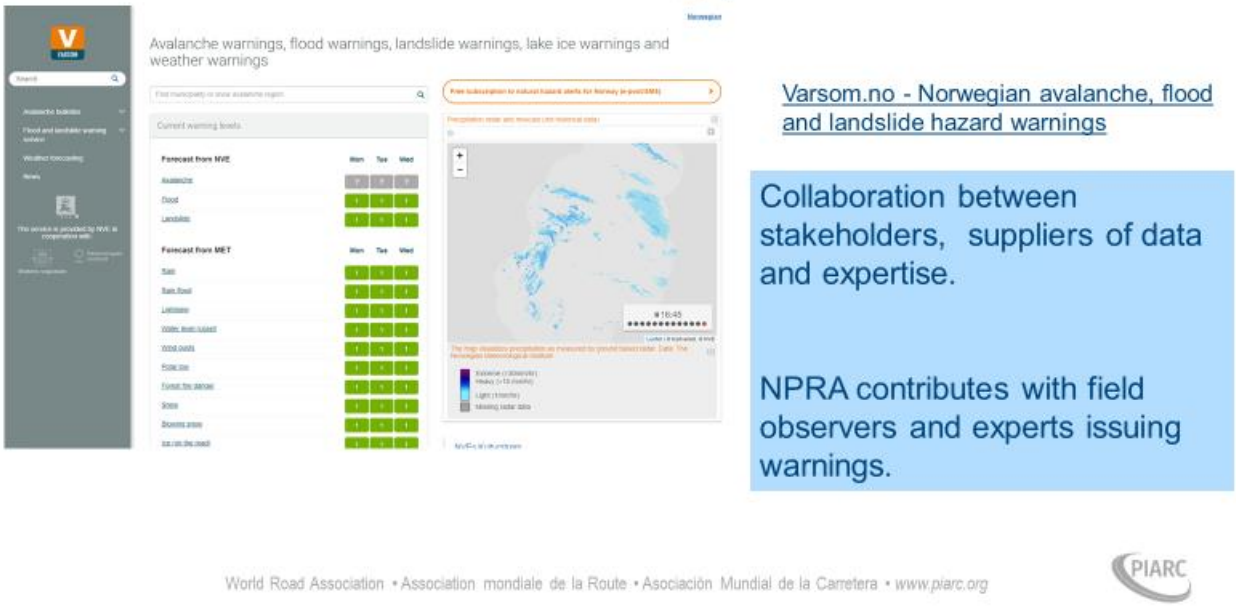


*Further information:*

*www.xgeo.no*

*(English language)*

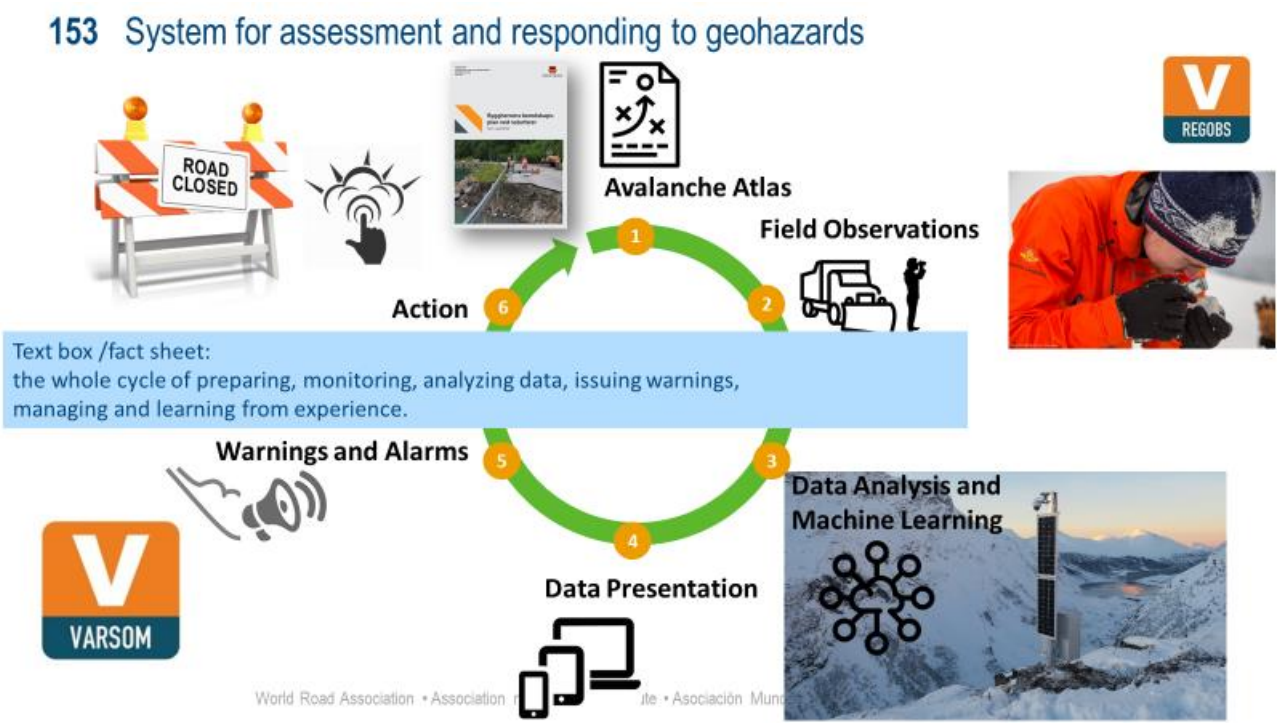
## 152 National landslide and avalanche warning system




*Further information:*

*https://www.varsom.no/en*

*(English language)*




*Further information:*

*https://www.vegvesen.no/fag/teknologi/geofag/skred/beredskap* https://www.varsom.no/en

*(Norwegian language)*

## 157 National Resilience Programme Business Case

The purpose of this project was to provide an evidence base of the nationally important risks posed to the New Zealand land transport system from natural hazards; and identify initiatives to address the systemic resilience risks, issues, deficiencies and opportunities

The main outputs from the work were the project report, and spreadsheet and geospatial files of the databases of risks and assessments.

*An example of how to undertake a pragmatic risk assessment of a significant length of network, using the consistent data sets available at such a scale.*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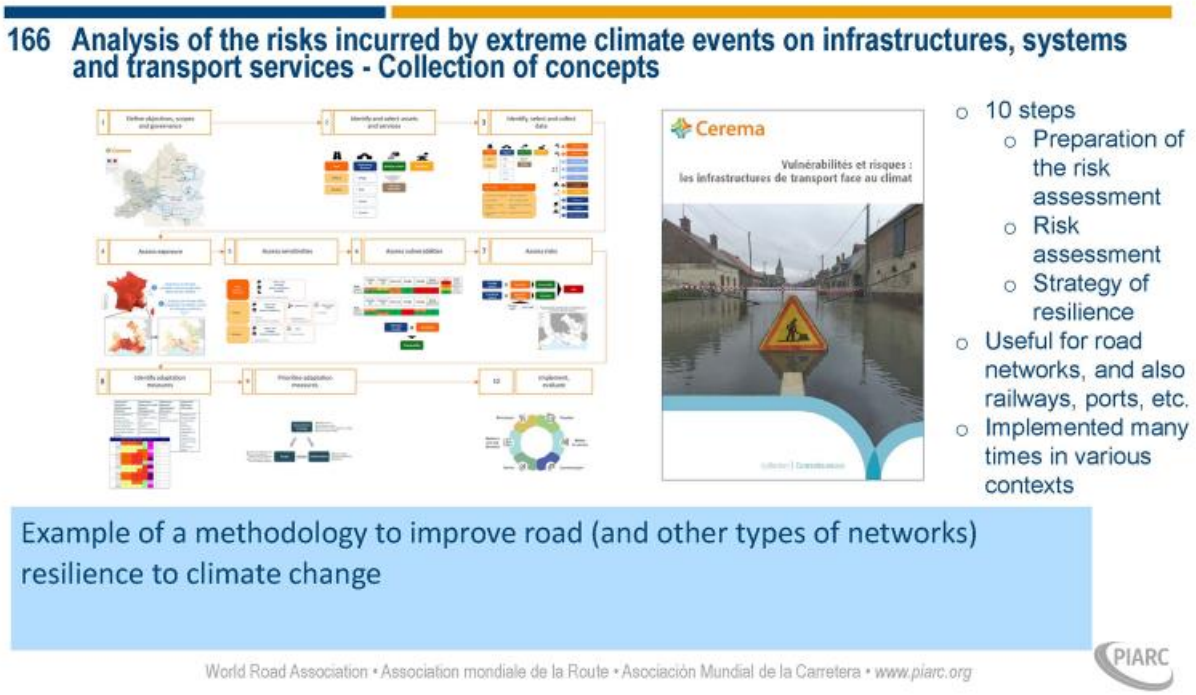
*Further information:*

*Homepage:* https://www.nzta.govt.nz/roads-and-rail/highways-information-portal/technical-disciplines/resilience/national-resilience-programme-business-case/

*Executive summary:* https://www.nzta.govt.nz/assets/Highways-Information-Portal/Technical-disciplines/Resilience/nrpbc/National-Resilience-PBC-Executive-Summary.pdf
https://www.varsom.no/en

*(English language)*



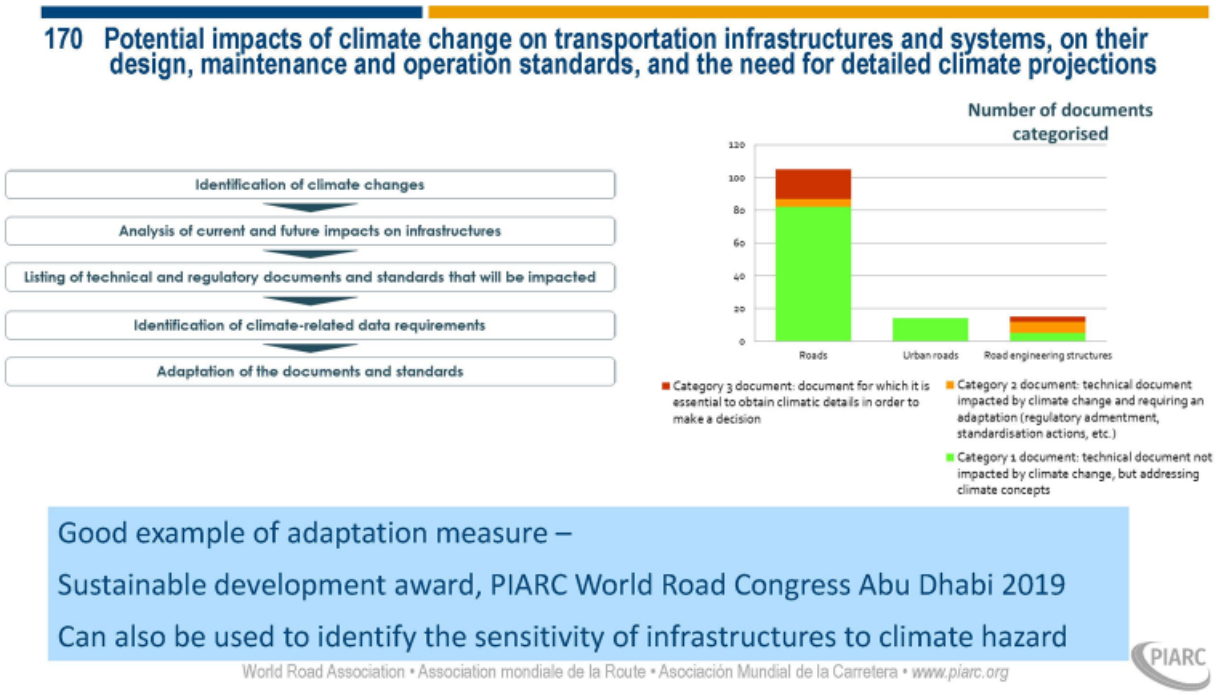

*Further information:*

https://www.cerema.fr/fr/actualites/assessing-risks-incurred-extreme-climate-events-transport

*(English language)*

*https://www.cerema.fr/fr/centre-ressources/boutique/vulnerabilites-risques-infrastructures-transport-face-au*

*(French language)*




*Further information:*

https://www.cerema.fr/fr/actualites/adapting-technical-documents-and-standards-take-account

*(English language)*

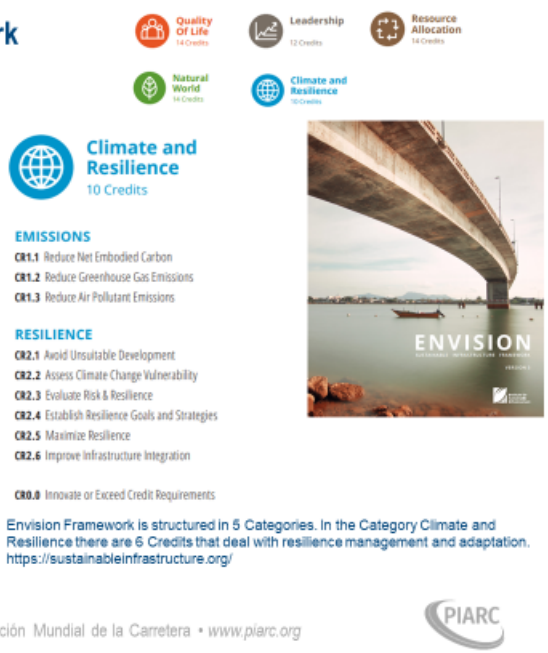
## 182 Envision - Sustainable Infrastucture Framework

**Purpose**

Envision is a framework that provides the guidance needed to plan, design and delivery sustainable and resilient infrastructure. Envision provides industry-wide sustainability metrics for all types and sizes of infrastructure to help users assess and measure the extent to which their project contributes to conditions of sustainability across the full range of social, economic, and environmental indicators. Envision helps users optimize project resilience for both short-term and long-term impacts. The Framework helps owner and project team to design and delivery a sustainable infrastructure certified by ISI (Institute for Sustainable Infrastructure.

**Benefits**

Following the Credits of the sud-Category Resilience, understanding the types of risks and probability of risks allows the project team to deliver an informed project design that anticipates and withstands these risks, minimizing its overall vulnerability. Maximizing resilience ensures a longer useful life and primes the project to more fully meet the future needs of the community.




Envision Framework is structured in 5 Categories. In the Category Climate and Resilience there are 6 Credits that deal with resilience management and adaptation. https://sustainableinfrastructure.org/

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*Further information:*

*https://sustainableinfrastructure.org*

*(English language)*

## 189 ForeSEE Project
## Assesment of existing climate databases

**Purpose**
This document describes an extensive review of climatic databases, prioritizing European ones that could be used to analyze the effects of extreme weather events on transport infrastructures. The databases presented provide high frequency information as well as an adequate spatial resolution. Three different types of databases will be included in the analysis:
- Instrumental: Pluviometric and meteorological station information, which constitutes the best representation of perceived weather. This will be the primary source of information for any analysis.
- Satellite: Satellite information presents biases that need to be accounted for, but it provides areal coverage that serves to properly include the spatial structure of the hydrometeorological variables.
- Numerical models: Numerical models do not normally capture the small-scale dynamics of climate, but they constitute an essential tool to study climate variability in decennial time scales.



*Further information:*

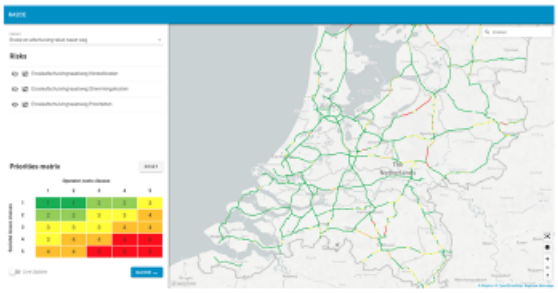
*https://foreseeproject.eu/*

*(English language)*

## 197 - Toward a Resilient Highway Network in the Netherlands

Case comprises two steps:

1. Study to gain insight in the current and future resilience of the highway network.
2. Provide an overview of measures, conducting cost benefit assessments and developing an adaptation strategy with the goal to have a resilient road network in 2050



How can the CS be used in the best possible way?

*It's an example for all stages. It includes assessment of climate change, exposure, vulnerability, criticality and resilience*

*It includes identification of measures, assessment of measures in a multi criteria assessment, conducting a cost benefit assessment of promising measures, linking to governance structure of Rijkswaterstaat (maintenance, rehabilitation, design and construction) and writing of an adaptation strategy.*

*Maybe the framework lacks a chapter on evaluation of level of risk/resilience → decision making process whether adaptation action is needed!*



*Further information:*

*https://geostenen.grid.rws.nl/portal/apps/Cascade/index.html?appid=d6ca4e4ddf5743d7b201a70cd4f1c422*

*(Dutch language)*

## 232 Criticality assessment in road projects in Mexico

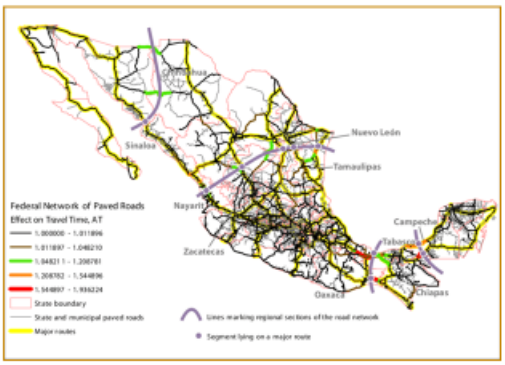
**Purpose:** The project called "Establishment of criteria that allow determining the criticality of public investment projects for network infrastructure" establish criteria to determine the criticality of public investment projects for highways in Mexico.

**Output:**

- The project seeks to increase the resilience in roads investment projects (new and existing). The process is established in two stages, the first one performs a criticality assessment to identify relevant projects of the road network, and the second stages consists of a disaster risk assessment.

**Benefits:**

Road organizations have limited resources, so they need to prioritize road assets that need to be evaluated against any hazard/threat.
Therefore, during the planning stage (prior to a vulnerability, risk, disaster risk or resilience assessment) the scope of the study must be established, determining the assets of the road network that will be analyzed.

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*Further information:*

## CEN WORKSHOP AGREEMENT - CWA 17819
## Guidelines for the assessment of resilience of transport infrastructure to potentially disruptive events

**Purpose**
This document is a result of the studies and activities performed under FORESEE project, funded under European Union's Horizon 2020 Research and Innovation Framework under grant agreement No 769373.
This document is focused on the resilience of transport systems to specified events. It can be used by any organization that is interested in measuring resilience regardless of size or extent of infrastructure. As transport can occur on infrastructure of multiple types, the measures of service and resilience are also suitable for infrastructure enabling multi-modal transport.

Considering the context of potentially disruptive events, this document is to be used to determine:
— how to measure the service provided by, and the resilience of, transport infrastructure;
— how to set service and resilience targets of transport infrastructure.
This document includes:
— the concepts of how service and resilience can be measured;
— the concepts of how service and resilience targets can be set;
— the steps to determine how to measure service and resilience;
— the steps to set service and resilience targets.

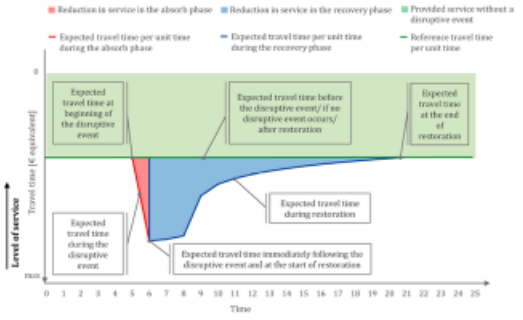


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**Figure 1 — Illustration of transport infrastructure resilience using the "travel time" measure of service**

*Further information:*

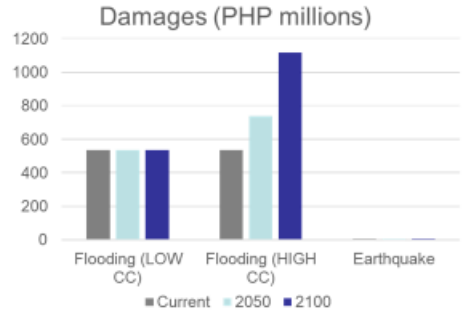
*https://foreseeproject.eu/*

*(English language)*

# 161 - Mainstreaming Disaster Risk Management to Sustain Local Roads Infrastructure

Case comprises two steps:

1. Study to gain insight in the current and future resilience of the highway network.
2. Development of an adaptation strategy, while providing a methodology to conduct a DMDU approach (Decision Making under Deep Uncertainty) on a basic level while acknowledging all uncertainties in climate change and socio economic developments




How can the CS be used in the best possible way?

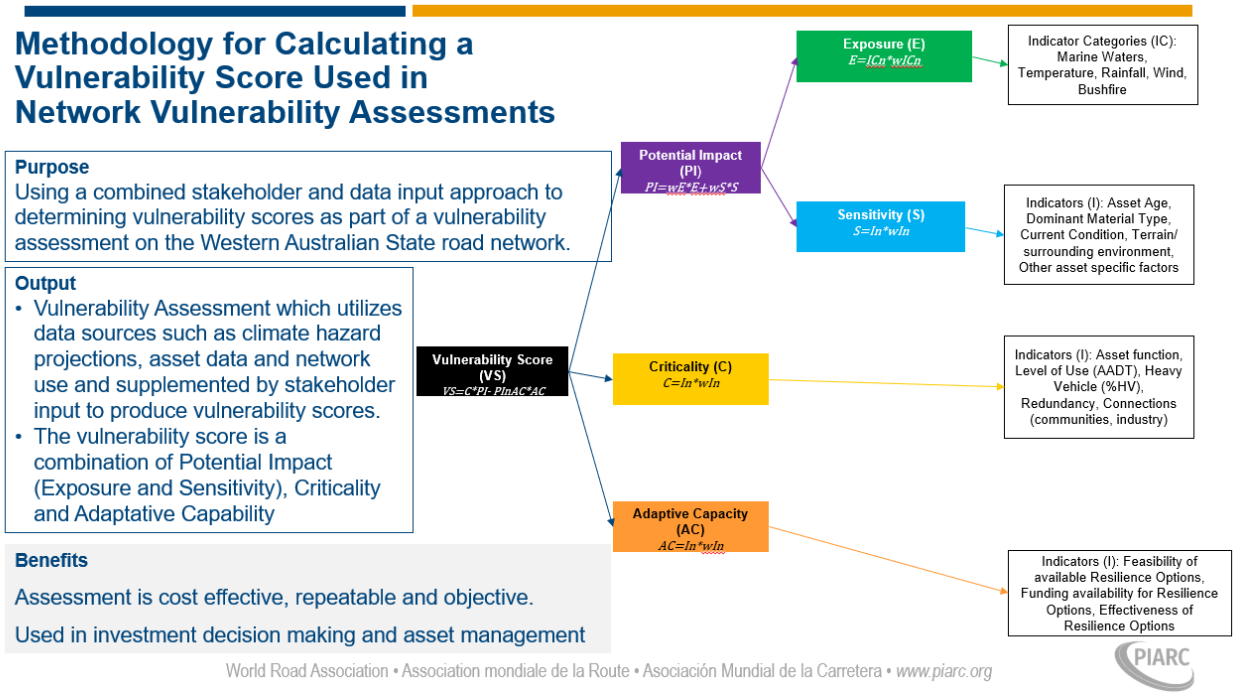
*Step 1 of the case study can be used as an example of conducting a resilience assessment in a data poor environment while still considering all relevant factors for such an assessment*

*Step 2 provides a state of the art example of application of DMDU on road networks, adapted to the capacities of the provincial road authorities that were the target audience. The developed DMDU approach considers all basic elements of DMDU and adaptation planning but has brought this down to the essential steps and the level of expertise at the road authority. This could be included in the framework as an example, but could also be included as a methodology description.*

*Further information:*

*https://documents1.worldbank.org/curated/en/386291571312802654/pdf/Mainstreaming-Disaster-Risk-Management-to-Sustain-Local-Roads-Infrastructure-Risk-Assessment.pdf*
*https://documents1.worldbank.org/curated/en/904061571298136932/pdf/Main-Report.pdf*
*https://documents1.worldbank.org/curated/en/325421571301691313/pdf/Summary-Report.pdf*

*(English language)*




*Further information:*

# Case study: New Zealand Mandatory Climate-related Financial Disclosures

The NZ Government passed legislation making climate-related disclosures mandatory for some organisations. The requirement will apply to large publicly listed companies, insurers, banks, non-bank deposit takers and investment managers.

The goal of mandatory climate-related disclosures is to:

- ensure that the effects of climate change are routinely considered in business, investment, lending and insurance underwriting decisions
- help climate reporting entities better demonstrate responsibility and foresight in their consideration of climate issues
- lead to more efficient allocation of capital, and help smooth the transition to a more sustainable, low emissions economy.

Mandatory climate-related disclosures will help New Zealand meet its international obligations and achieve its target of net zero carbon by 2050.

Reporting will be against a standard, structured around four thematic areas that represent core elements of how organisations operate:

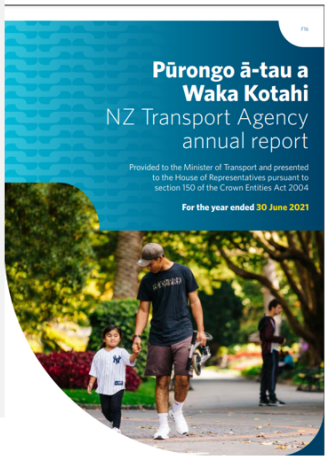
- governance
- strategy
- risk management
- metrics and targets

In 2021 for the first time, Waka Kotahi NZ Transport Agency voluntarily reported against the Climate Related Financial Disclosures standard in its annual report

This case study could be used as an example of new approaches to monitoring and reporting on climate change performance of private or public organisation.

See https://environment.govt.nz/what-government-is-doing/areas-of-work/climate-change/mandatory-climate-related-financial-disclosures/ and

https://www.nzta.govt.nz/assets/resources/annual-report-nzta/2020-21/nzta-annual-report-2021-section-g.pdf






*Further information:*

*https://environment.govt.nz/what-government-is-doing/areas-of-work/climate-change/mandatory-climate-related-financial-disclosures/*

*https://www.nzta.govt.nz/assets/resources/annual-report-nzta/2020-21/nzta-annual-report-2021-section-g.pdf*

*(English language)*

## 8.2. REGIONAL

- Wellington Regional Land Transport Resilience Programme Business Case
- Action plan for infrastructure management in the context of climate change – coastal zones
- Increasing resilience of earth structures on roads in northern Spain
- Towards a more resilient spanish road network
- Natural Hazard Plans for Operation Contracts
- Risk Assessment to Climate Change – DIR Med case study
- Resilience of SANEF road network to climate change

## *158* Wellington Regional Land Transport Resilience Programme Business Case

The Wellington Region is vulnerable to a range of natural hazards, including earthquakes, tsunami, major storms, floods and landslips.

Waka Kotahi, in collaboration with local councils and KiwiRail, identified the most-at-risk locations in the land transport system, and recommended a programme of interventions to address the risks at these locations.

The CS could be used as a text box, and inform sections 1.7, 2.3, 3.2 or 5.1.

*An example of MCA and Cost-Benefit Analysis approaches and was used as input to a wider integrated multi-sector plan. However, its primary focus and maximum credible event used for planning was not climate change related!*




*Further information:*

**Action plan for infrastructure management in the context of climate change – coastal zones [Plan d'action sur la gestion des infrastructures dans un contexte de changments climatiques (PAGI3C) – zones côtières]**

To integrate erosion and submersion into a coastal risk analysis to enhance risk and asset management in coastal areas, the Ministère des transports du Québec has adopted an Action plan for infrastructure management in the context of climate change (PAGI3C) in order to strengthen the resilience of transportation networks in coastal zones. Based on four main objectives, structuring actions are initiated for an approach from reaction to prevention.

Haute-Gaspésie, 2016

UQAR's Maritime Québec Monitoring Network

**Toward an integrated and concerted management of coastal areas**

Against the backdrop of the coastal zone as a coherent territory for reflection and action, the long-term objective is **to move toward principles of integrated management of coastal territories aimed at sustainable development and rallying coastal communities around common issues.**

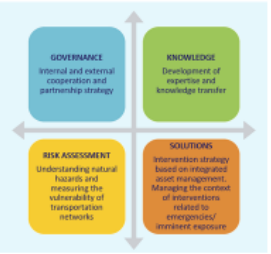
- Mobilize and include stakeholders to ensure a shared vision and the integrated management of the coastal zone
- Interdepartmental cooperation committee implemented
- Collective approach to implement solutions and carry out projects
- Social acceptability of project / stakeholders, local and regional population




**Action plan for infrastructure management in the context of climate change – coastal zones [Plan d'action sur la gestion des infrastructures dans un contexte de changments climatiques (PAGI3C) – zones côtières]**

**Structuring actions – From reaction to prevention**

- **Research partnerships**: creation of a research chair in coastal engineering
- **Characterize** the evolution and dynamics of coastal systems
- **Assess the vulnerability** of transportation networks **and risks** in coastal zones
- Develop coastal **intervention prioritization indices** (IPIC)
- Create **decision support tools** and implement **appropriate solutions** for the sustainable development of the maritime environment
- Implement an **asset management system** to ensure the sustainability of coastal protection works and a **coastal bank monitoring system**
- **Develop a regional intervention plan** based on integrated asset management principles in risk areas
- Conduct an **environmental impact study for each region** rather than for each project, including an extensive coastal community **consultation program**




The importance of knowledge (development and sharing), working with the available resources in a continuous and iterative process.

**An action plan base on 4 main objectives**:

1. Improve governance and infrastructure management practices in a context of climate change
2. Develop expertise and improve knowledge transfer
3. Understand natural hazards, measure the vulnerability of transportation networks and assess the risk
4. Implement adaptation solutions to improve the resilience of the network and develop an intervention and investment strategy



*Further information:*

## INCREASING RESILIENCE OF EARTH STRUCTURES ON ROADS IN NORTHERN SPAIN. LESSONS LEARNED IN THE PERIOD 2011-2018

This case study is an analysis of several experiences in slope and foundation drainage, and runoff water management to improve resilience in roadway infrastructures. The actions resulted from temporary rain and adverse weather conditions between 2010 and 2018, which caused singular damage to several road slopes in Northern Spain. The objective of the repair was to restore road safety and road stability. With regard to the drainage of earthworks, the action carried out on the slope of the A-8 highway includes its stabilization by Biological Engineering.

N-621 and A-67 Motorway



*Further information:*

*https://www.piarc.org/en/activities/PIARC-Directory-Technical-Reports*
*(PIARC Ref.: RR392-035)*

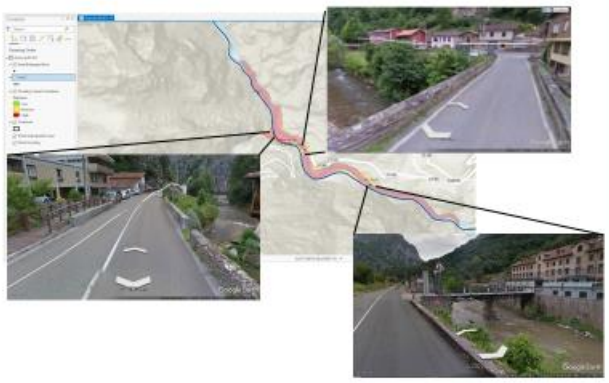
*(English, French and Spanish language)*

## TOWARDS A MORE RESILIENT SPANISH ROAD NETWORK

This case study is focused on the methodology that is being proposed in order to help increasing resiliency in the Spanish network.

The main output are the preliminary results obtained in the pilot case in Cantabria referred to the hazard and exposure assessment, following the proposed theoretical approach. This proposal aims at the inclusion of climate change and resiliency considerations in the road transport system (both infrastructure and safety and security issues) management.

N-621 Exposure assessment



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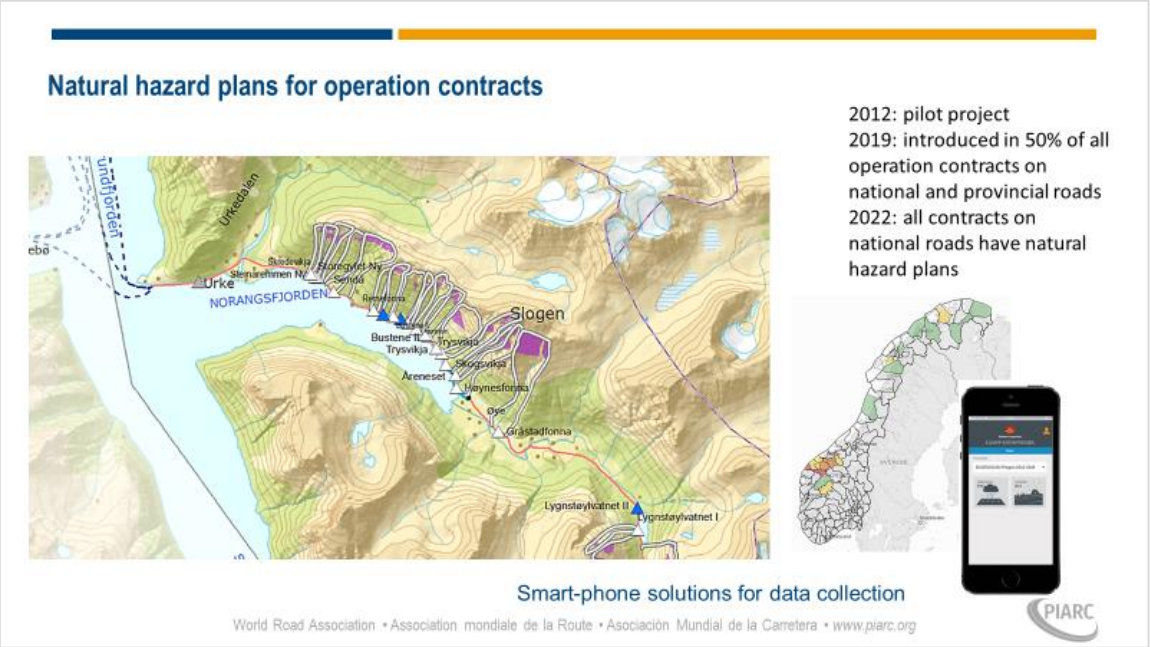
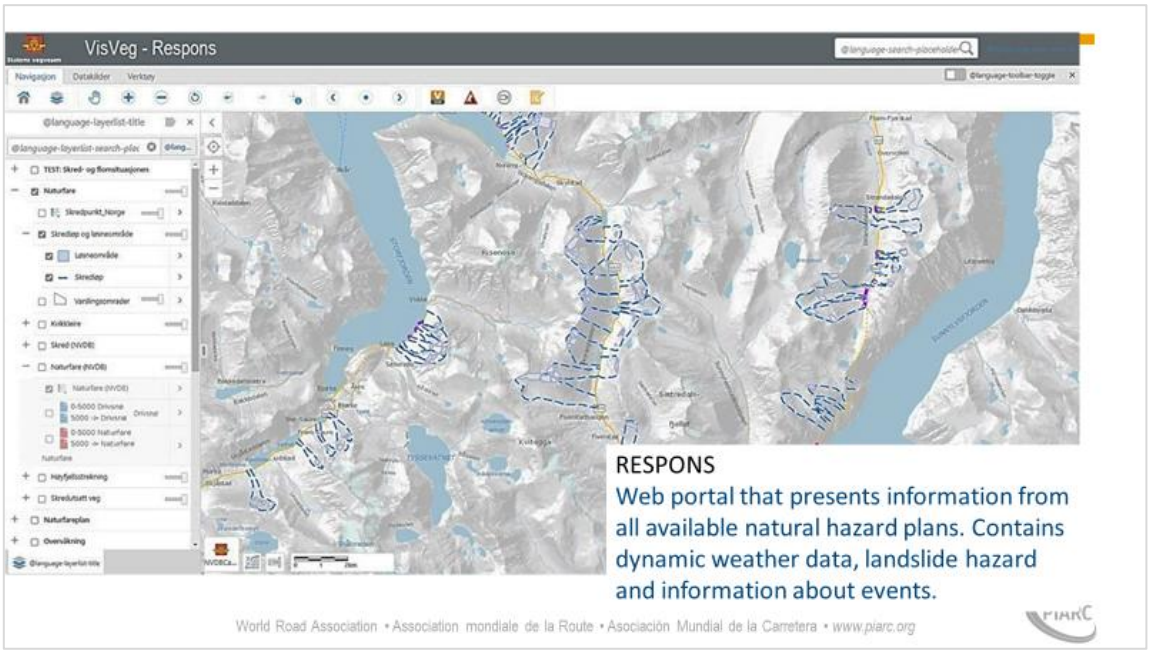
*Further information:*

*https://www.piarc.org/en/activities/PIARC-Directory-Technical-Reports*
*(PIARC Ref.: RR393-017)*

*(English, French and Spanish language)*




*Further information:*

*https://www.vegvesen.no/fag/teknologi/geofag/skred/beredskap*

*(Norwegian language)*

## 171 Risk assessment to climate change - DIR Med case study

| Beneficiary | Objectives |
|---|---|
| | Assess exposure and current and future vulnerabilities in a context of climate change |

- **Assessment of current and future exposure**
  - Identification of climate projection data: sources, models, scenarios, horizons, scopes
  - Assessment of future climate exposure: temperatures, precipitations, flooding, etc.
- **Sensitivity and vulnerability assessment**
  - Assets categorisation and identification of functionnalities
  - Assessment of the current sensitivity
  - Assessment of the future sensitivity
  - And vulnerability assessment

For :
- All infrastructures of this network

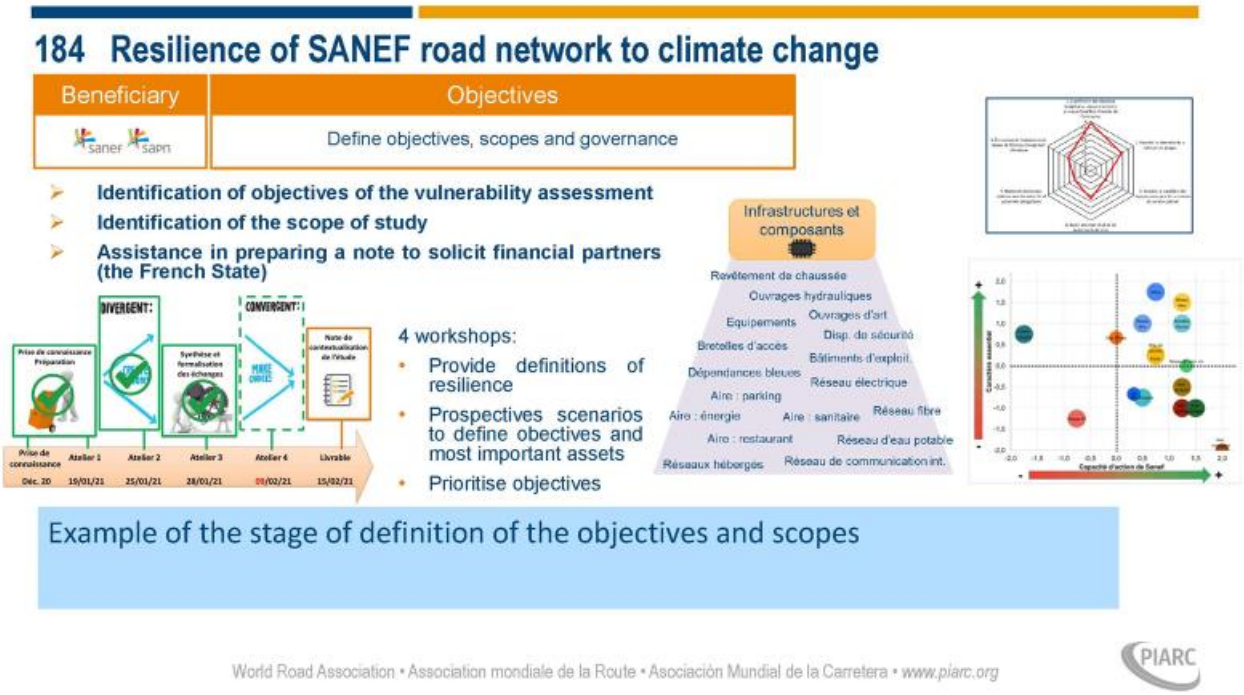
**80km national concessionary road network**
- **12 climate hazards**

Good example to illustrate stage 2.1 vulnerability assessment amongst others, and more generally, good example for stages 1 and 2.

Examples of adaptation measures following this vulnerability assessment are available.

PIARC

*Further information:*




*Further information:*

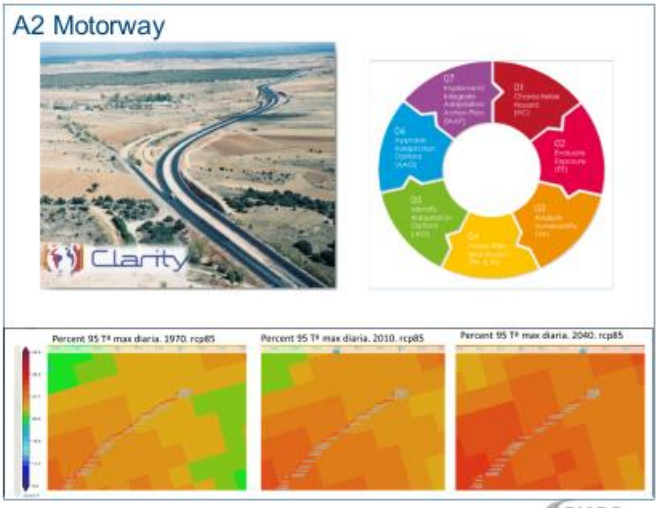
### 8.3. ASSET OR SITE SPECIFIC

- Climate change risk assessment report. A2 Motorway from Guadalajara to Alcolea del Pinar
- Water-related damage to E6 Birri-Otta
- 3R-method - Simplified resilience approach
- Analysis of the dynamics of erosion focus on the North Coast (Québec) […} adaptations along Route 138
- Submersible pavement design
- ForeSEE Project (Future proofing strategies FOr RESilient transport networks against Extreme Events
- Mondego Mobility System – Climate Assessment
- A9 highway, section Orange-Lunel – Resilience assessment to climate change

## 143 – Climate change risk assessment report. A2 Motorway from Guadalajara to Alcolea del Pinar

The report is focused on the assessment performed in a 77 km section of the Spanish motorway A2 from Guadalajara to Alcolea del Pinar, according to the methodology proposed in the CLARITY project (H2020)

The main output is the identification of the elements with a high risk, mainly related to intense rainfall episodes.

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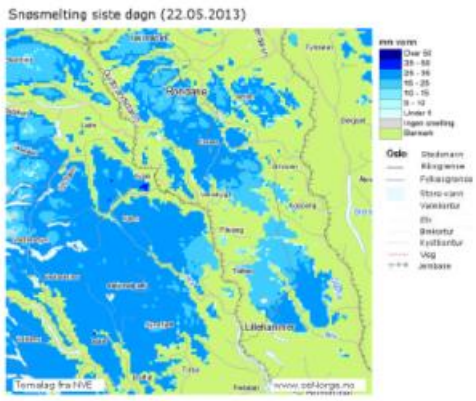
*Further information:*

*https://clarity-h2020.eu/*

*(English language)*

## 146 Water-related damage to E6 Birri-Otta




Figur 7: Snøsmelting siste døgn, 22.05.2013 (www.xgeo.no).

This case study can be used as an illustration of erosion damage, and the use of meteorological maps to explain the reasons for the damage.



*Further information:*

*https://vegvesen.brage.unit.no/vegvesen-xmlui/handle/11250/2659280*

*(Norwegian language)*

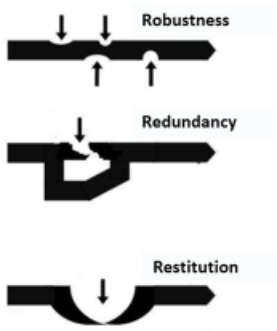
## 155 3R-method - Simplified resilience approach

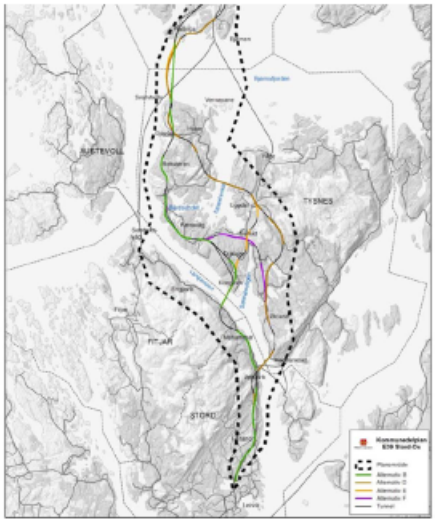
**Robustness:**
standard of the existing road? Standard of the new /renewed road?

**Redundancy** – in the existing and the future project?
Adequacy of alternative routes as compared to the real needs.

**Recovery** – how quickly can we restore the situation?
Short term? Long term?

Scoring, algorithm for final score
Inclusion in guidelines



Topics to include?
How to include issues concerning the performance of the road already in the planning phase. Traditionally, robustness and redundancy have not been assessed together and by the same team.

*Further information:*

*https://proceedings-calgary2022.piarc.org/en/search.php?q=simplified+resilience+approach*

*(English language)*

*https://www.regjeringen.no/contentassets/13a80858d58a47e1a23e944b7144ee9b/tilleggsoppdrag-9-samfunnssikkerhet.pdf*

*(Norwegian language)*

## 195 Analysis of the dynamics of erosion focus on the North Coast (Québec) in order to identify adaptation solutions along Route 138

Measurements taken on the coast of the Côte-Nord indicate the presence of coastal segments where the rate of retreat is clearly greater than the adjacent segments. These type of erosion can form rapidly and cause a decline of 50 m from the coast in less than a decade (Bernatchez and Fraser, 2012; Bernatchez et al., 2008).

Understanding their origin and location are crucial in determining the road segments at risk since the development of these centers can have an impact on the management of road infrastructure.



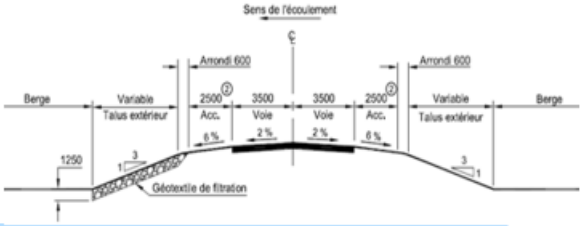

*Further information:*

*http://www.bv.transports.gouv.qc.ca/mono/1235270.pdf*

*(French language)*

## 196 Submersible pavement design [Conception de chaussées submersibles]

- Describe various methods, among those available worldwide, for the design and construction of submersible or flood-resistant pavements.
- Identify the parameters necessary to identify areas at risk of flooding as well as the most important design parameters.
- Propose a design method including typical sections recommended for Quebec.




A solution adapted to the Quebec context is proposed, based on the literature review, and a theoretical example is presented. The design criteria are divided in two broad areas: geotechnical and hydraulic.



*Further information:*

*www.bv.transports.gouv.qc.ca/mono/1240598.pdf*
*http://www.bv.transports.gouv.qc.ca/mono/1235270.pdf*

*(French language)*

**ForeSEE Project (Future proofing strategies FOr RESilient transport networks against Extreme Events**

FORE SEE PROJECT

**Purpose**

FORESEE is an EU collaborative research project funded by Horizon 2020 which will develop a toolkit to improve road and rail asset management schemes for authorities and infrastructure operators with the following goals:

-Establish preventive maintenance and upgrading strategies able to improve resilience of transport infrastructures towards human (accidents) and natural hazards (extreme weather events, landslides and earthquakes)
-Predict and alert of potential risk scenarios at different time scales considering age, conditions and residual life of engineering components
-Reduce the social and economic impact on critical transport assets (bridges, tunnels, pavement, slopes, terminals) when those disruptive events happen
-Facilitate the deployment of mobility contingency protocols for citizens and freight in such critical situations to ensure safe and efficient evacuation including emergency operations and contingency plans
-Demonstrate positive costs and benefits balance associated to resilience investments during the full lifecycle of the infrastructure

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**ForeSEE Project**
**Case Study and Tool Fact Sheets**
**Background document for the Stakeholders' Reference Group (SRG) Final Event in January 2022**

FORE SEE PROJECT

**Purpose**

This document will present the fact sheets for the case studies and associated main results that have been validated as part of the Future proofing strategies For RESilient transport networks against Extreme Events (FORESEE) project.

- ❑ CASE STUDY #1 - CARSOLI-TORANO (ITALY): A24 HIGHWAY
- ❑ CASE STUDY #2 - NAPLES TO BARI (ITALY) - A16 HIGHWAY
- ❑ CASE STUDY #3 – MONTABLIZ VIADUCT & a-67 (SPAIN)
- ❑ CASE STUDY #4 – RAILWAY TRACK 6185 (OEBISFELDE-BERLIN SPANDAU)
- ❑ CASE STUDY #5 - M30 MADRID (SPAIN)
- ❑ CASE STUDY #6 - 25TH APRIL SUSPENDED BRIDGE - LISBON (PORTUGAL)

**Result**

- ❑ Traffic Module Tool
- ❑ Fragility Functions, Vulnerability Functions and Decision Support Interpreter Module Tool
- ❑ Virtual Modelling Platform Tool
- ❑ Alerting SAS platform Tool
- ❑ Governance Module
- ❑ Risk Mapping Tool
- ❑ Bridge Flooding Model Tool
- ❑ Command and Control Center
- ❑ A Fully Stochastic Flooding Prediction Methodology
- ❑ Hybrid Data Assessment For Diagnosis And Prognosis Tool
- ❑ Cyber-attack assesment

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*Further information:*

*https://foreseeproject.eu/*

*(English language)*

## Mondego Mobility System – Climate Assessment

**Purpose**

The objective of the study was to assess the main climatic events or hazards associated to the Mondego Mobility System - Bus Rapid Transit (BRT) located in Coimbra, Portugal, to evaluate the climatic resilience of the infrastructure and to determine its contribution to the reduction of greenhouse gas emissions, over its lifetime.

**Outputs**

- Assessment of the resilience of the project to climate change and identification of the main adaptation measures to be adopted;
- Quantification of greenhouse gas emissions (GHG) avoided by the exploration phase of the BRT System.

**Benefits**

The study addressess measures to deal with rain and river floods, landslides, extreme temperatures and wildfires (in the suburban line of the project). It also quantifies the GHG emissions avoided in the exploration phase of the project.

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*Further information:*

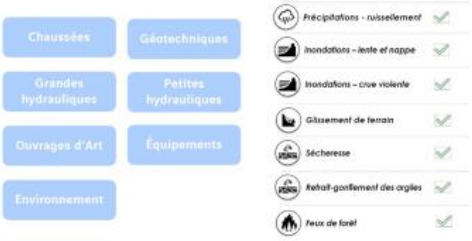
*https://www.infraestruturasdeportugal.pt/pt-pt/infraestruturas/investimentos/principais-investimentos-em-curso*

*(Portuguese language)*

## 183 A9 highway, section Orange-Lunel - Resilience assessment to climate change

| Beneficiary | Objectives |
|---|---|
| ASF | Assess exposure and current and future vulnerabilities of transport infrastructures to climate change and identify adaptation solutions |

- **Assessment of current and future vulnerabilities**
  - Assessment of current and future climate exposure: temperatures, precipitations, flooding, etc.
  - Assessment of the current and future sensitivity of 7 categories of infrastructures
- **Identification of adaptation measures related to**
  - Knowledge of the network
  - Infrastructures conception: curative, preventive adaptation for the existing and preventive for the new
  - Knowledge of hazards incl. Risk management
  - Maintenance and exploitation
  - Governance and communication

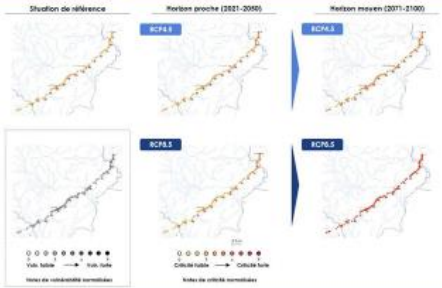



Example of a vulnerability assessment with identification of adaptation measures



183 A9 highway, section Orange-Lunel - Resilience assessment to climate change

| Beneficiary | Objectives |
|---|---|
| ASF | Assess exposure and current and future vulnerabilities of transport infrastructures to climate change and identify adaptation solutions |




Example of a vulnerability assessment with identification of adaptation measures

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