# A Testing and Implementation Framework (TIF) for Climate Adaptation Innovations

## Initial Version of the TIF

## Deliverable 5.1

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# List of Acronyms

| | |
|---|---|
| **CIW** | Climate Innovation Window |
| **DOA** | Description of Action |
| **EC** | European Commission |
| **EU** | European Union |
| **IPCC** | International Panel on Climate Change |
| **ISP** | Innovation Sharing Platform |
| **MAF** | Market Analysis Framework |
| **PI** | Performance Indicators |
| **PPIF** | Public-Private Investment and Financing Model |
| **R&D** | Research and Development |
| **TIF** | Testing and Implementation Framework |
| **UN** | United Nations |
| **UNISDR** | United Nations International Strategy for Disaster Reduction |
| **WP** | Work Package |

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# Executive Summary

Currently there is no internationally accepted framework for assessing the readiness of innovations that reduce disaster risk. To fill this gap, BRIGAID is developing a standard, comprehensive Testing and Implementation Framework (TIF). The TIF is designed to provide innovators with a framework for innovation and guidelines for assessing an innovation's technical effectiveness, its social acceptance, and its impact on key socio-economic and environmental sectors. The vision is that the TIF will become the standard framework used to assess the effectiveness of climate adaptation innovations and the European quality label for testing.

This report focuses on the initial methodological development of the testing and implementation framework (TIF) for increasing the socio-technical readiness of climate adaptation innovations and assessing their impact on different socio-economic and environmental sectors. The Description of Action (DOA) describes this Deliverable 5.1 as follows:

> *"Initial version of the TIF: Report containing the probable range of (normalized) test conditions and uncertainties (from T5.1), and variability in institutional cultures across Europe on a local, regional, and national scale (from T5.2) resulting in guidelines for assessing the general effectiveness of innovations (from T5.3). These guidelines form the initial version of the TIF."*

# 1 Introduction

The objective of **BRIGAID** is to **BRI**dge the **GA**p for **I**nnovations in **D**isaster resilience by providing integral, on-going support for climate adaptation innovations. BRIGAID aims to guide the development of innovations from prototype to commercial deployment by providing innovators with methods and tools designed to increase the social, technical, and market readiness of their innovations. These tools will include: (1) a testing and implementation framework (TIF) that provides guidelines for evaluating the socio-technical effectiveness of innovations and the organizational and governance requirements pertaining to their uptake; (2) business development (MAF+) and financial (PPIF) frameworks for increasing market readiness; and (3) an interactive, online innovation sharing platform (ISP) that connects innovators, end-users, qualified investors, and grant and fiscal incentive advisors throughout Europe. This report focuses on the initial development of the TIF.

## 1.1 Background

Europe is particularly vulnerable to climate change. The IPCC (Alcamo *et al.*, 2007; Kovats *et al.*, 2014) predicts that under climate change, higher sea levels and winter wind speeds will increase flooding in coastal regions; increased precipitation in northern Europe will lead to more frequent river and flash floods; decreased precipitation and warmer, dryer conditions in southern Europe will lead to more frequent and longer drought periods (as well as a longer fire season and increased fire risk); and decreased precipitation and warmer, dryer conditions in central Europe may lead to catastrophic wildfires. It is predicted that climate-related hazards will lead to systematic failures across Europe. Within BRIGAID, these hazards have been grouped into three categories: floods, droughts, and extreme weather (see Table 1-1).

*Table 1-1 Definitions of climate-related hazards included within BRIGAID (adapted from EEA 2010).*

| **Category** | | **Definition** |
|---|---|---|
| Floods | Coastal Flood | A flood resulting from high sea water levels and wave impact that exceed flood protection levels; these hydraulic conditions are generally caused by storm surges. |
| | River Flood | A flood resulting from high-river discharges (that exceed flood protection levels); the high-river discharges are caused by heavy precipitation and/or snow melt in the river basin. |
| Droughts | | A sustained and extensive occurrence of below average water availability, whether atmospheric, surface, or ground water caused by climate variability. Droughts can result in water scarcity when the drought conditions cause long-term imbalances between water availability and demands. |
| Extreme Weather | Heat wave | A prolonged period of excessively hot, and sometimes also humid, weather relative to normal climate patterns of a certain region. |
| | Wildfire | An uncontrolled fire in an area of combustible vegetation that occurs in the countryside. Fire ignition and spread are both enhanced by cumulated drought, high temperature, low relative humidity and the presence of wind |
| | Storm | Natural events characterized by strong winds, often in combination with heavy precipitation (e.g., heavy rainfall, hail, etc.). |
| | Heavy Precipitation | Rainfall events that result in (1) (urban) floods due to exceedance of drainage capacity, and (2) flash floods, defined as rapid flooding of low lying areas, generally within a few hours after a heavy rainfall events such as thunderstorms. |

The effects of climate change have already been observed in Europe, especially higher than average temperatures, increased frequency and intensity of extreme heat waves and droughts (e.g., June-August 2003), heavier precipitation events in northern Europe, increased river flooding in northern and central Europe (e.g., May 2016), and decreased precipitation and river flows in southern Europe (EEA, 2004). In the face of climate change, some areas of northern Europe (e.g., Netherlands) have already taken steps to decrease flood risk (Kovats *et al.*, 2014); however, there is limited evidence that Europe's resilience to droughts and extreme weather has improved significantly.

In addition to its direct effects the frequency and intensity of hazards in Europe, climate change is predicted to have adverse impacts on multiple sectors, including health, agriculture, forestry, energy production and use, transport, tourism, labor productivity, and the built environment (Kovats *et al.*, 2014). European ecosystems are especially vulnerable to extreme seasons (e.g., hot and dry summers, mild winters), short-duration events (e.g., extreme rainfall), and slow, long-term climate trends (e.g., sea level rise) (Alcamo *et al.*, 2007). While the direct impacts of climate change will vary substantially across different geographic regions and (social and economic) institutions, it is generally predicted that southern Europe will be more severely affected than northern Europe (EEA, 2004).

The observed and projected impacts associated with climate change have resulted in efforts by the European Union, national, regional, and local governments, businesses, and non-governmental organizations (NGOs) to stimulate and support mechanisms for climate adaptation (Kovats *et al.*, 2014). While numerous innovations have been developed that aim to reduce the risks associated with climate change, many innovations fail to reach their intended market, because they have not been rigorously tested or because innovators misjudge the degree to which institutions (policy and decision makers) and societies would want to implement an innovation.

These problems are compounded by an enduring dilemma of control that faces all emerging technologies (Collingridge, 1980). The dilemma points to the desirability of controlling undesirable impacts before they can occur, but the difficulty of not knowing what they will be until the technology has been fully developed. The distance between the development of the new knowledge and its uptake by the market is often referred the "Valley of Death."

BRIGAID aims to address the challenge of climate adaptation by developing frameworks and providing financial support to help innovators increase the technical, social, and market readiness of climate adaptation innovations (see Table 1-2). In doing so, BRIGAID will "bridge the gap" between innovators and end-users (see Figure 1-1).

*Table 1-2 Definitions for technical, societal, and market readiness adopted by BRIGAID*

| **Category** | **Definition** |
|---|---|
| Technical Readiness | Technical readiness is the performance and effectiveness of an innovation to reduce climate-related risks, as shown in field tests and operational environments. |
| Societal Readiness | Societal readiness is the condition of preparing an innovation for a favorable public reception |
| Market Readiness | Market readiness is the potential of an innovation to develop a solid business case and attract investors. |

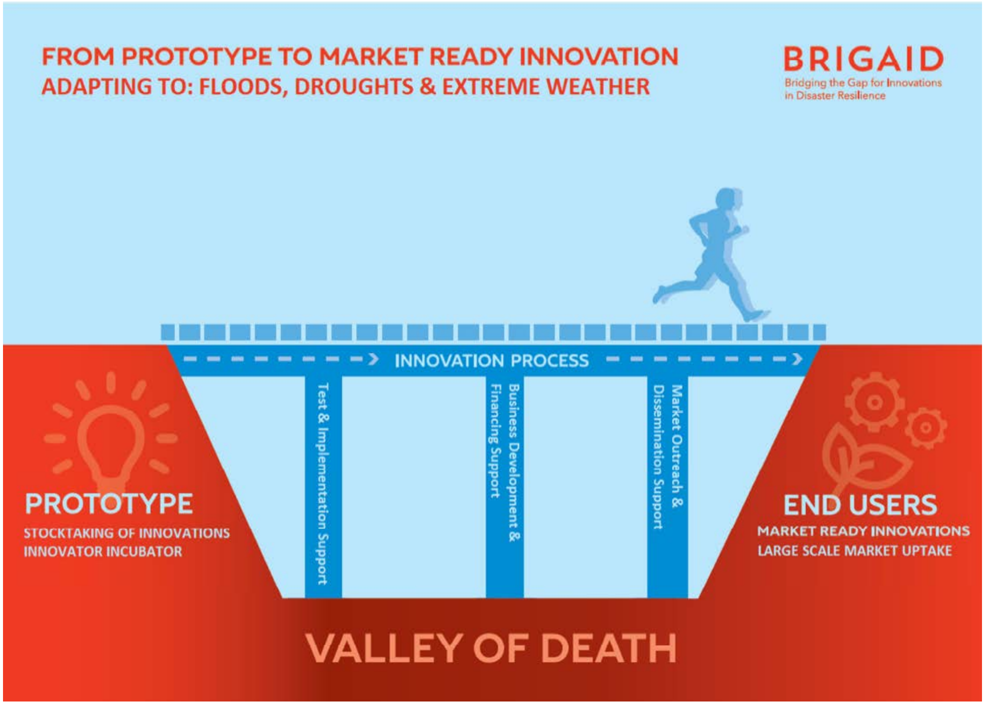



*Figure 1-1 Bridge across the Valley of Death*

Currently there is no internationally accepted framework for assessing the readiness of innovations that reduce disaster risk. To fill this gap, BRIGAID is developing a standard, comprehensive Testing and Implementation Framework (TIF). The TIF is designed to provide innovators with a framework for developing an innovation and guidelines for assessing an innovation's technical effectiveness, its social acceptance, and its impact on key socio-economic and environmental sectors. The vision is that the TIF will become the standard framework used to assess the effectiveness of climate adaptation innovations and the European quality label for testing.

The technical effectiveness of climate adaptation innovations will be measured in terms of their ability to reduce risk from one or more of the climate-related hazards identified in Table 1-1. In BRIGAID, we have adopted the definition of risk proposed by the European Environment Agency (EEA) in order to overcome differences in standard definitions among various disciplines (e.g., engineers, social scientists, and urban planners) (Klijn *et al.*, 2015). In this context, risk is defined as a function of hazard potential and vulnerability, where hazard potential is qualified by the likelihood of a hazard and its intensity, and vulnerability is qualified by the number of exposed elements (i.e., the people, their property (e.g., infrastructure) and activities (e.g., economy)) in an area at risk, their susceptibility, and their coping (or adaptive) capacity (see Figure 1-2).

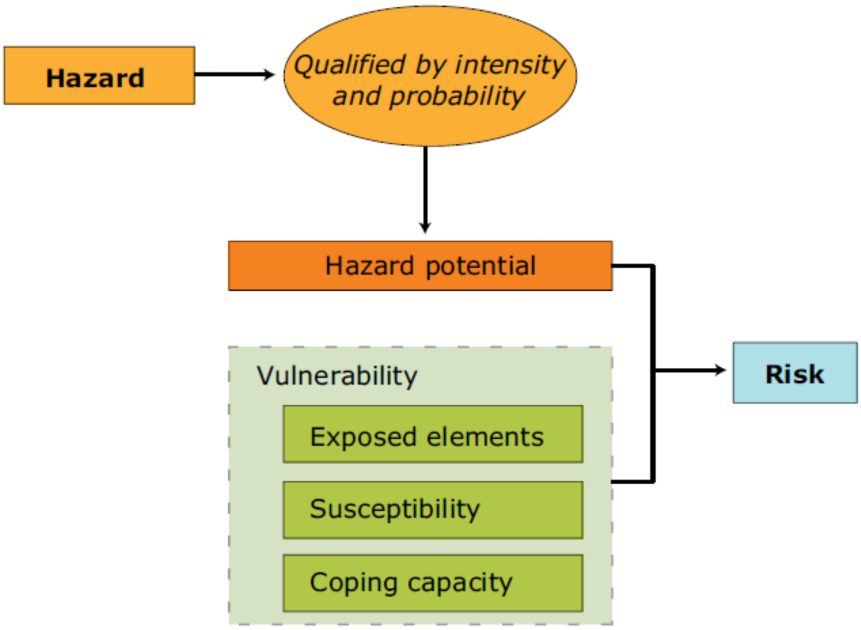



*Figure 1-2 The concepts of risk, hazard potential, and vulnerability in the risk-hazard framework. Note that exposure is shown here as part of vulnerability, but in some definitions of risk (or in risk frameworks) exposure may also regarded as separate from the vulnerability assessment* (EEA, 2012)*.*

Over the project duration (48 months), BRIGAID is committed to improving the socio-technical readiness of 75-100 innovations. Of these, BRIGAID will select 25-30 innovations to further improve their market readiness. The innovations will be selected by BRIGAID based on a set list of criteria (see reports by WP2-4) in order to facilitate testing of methodologies across a variety of climate-related hazards and innovation categories. Most of the innovations considered by BRIGAID are incremental (i.e., additional to existing risk reduction measures), anticipatory (i.e., applied in anticipation of hazards) and local in nature. There is a balance between those that are structural in form and those that are social (see Table 1-3 for examples). During Cycle 1, most of the structural innovations chosen by BRIGAID are either engineered or technological, while most of the social innovations are informational. There are no institutional innovations under consideration by BRIGAID at this time. Therefore, in this report, we primarily consider engineered/built environment, technological and informational innovations.

*Table 1-3 Categories and examples of measures for climate adaptation (adapted from Noble et al., 2014)*

| **Category** | | **Examples of options** |
|---|---|---|
| Structural/ physical | Engineered and built environment* | Sea walls and coastal protection structures; flood levees and culverts; water storage and pump storage; sewage works; improved drainage; beach nourishment; flood and cyclone shelters; building codes; storm and waste water management; transport and road infrastructure adaptation; floating houses; adjusting power plants and electricity grids |
| | Technological* | New crop and animal varieties; genetic techniques; traditional technologies and methods; efficient irrigation; water saving technologies including rainwater harvesting; conservation agriculture; food storage and preservation facilities; early warning and response systems; building insulation; mechanical and passive cooling; renewable energy technologies; second-generation biofuels |

| | | |
|---|---|---|
| | Ecosystem-based | Ecological restoration including wetland and floodplain conservation and restoration; increasing biological diversity; afforestation and reforestation; conservation and replanting mangrove forest; wildfire reduction and prescribed fire; green infrastructure (e.g., shade trees, green roofs); controlling overfishing; fisheries co-management; assisted migration or managed translocation; ecological corridors; ex situ conservation and seed banks; community-based natural resource management; adaptive land use management |
| | Services | Social safety nets and social protection; food banks and distribution of food surplus; municipal services including water and sanitation; vaccination programs; essential public health services including reproductive health services and enhanced emergency medical services; international trade |
| Social | Educational | Awareness raising and integrating into education; gender equity in education; extension services; sharing local and traditional knowledge including integrating into adaptation planning; participatory action research and social learning; community surveys; knowledge-sharing and learning platforms; international conferences and research networks; communication through media |
| | Informational* | Hazard and vulnerability mapping; systematic monitoring and remote sensing; climate services including improved forecasts; downscaling climate scenarios; longitudinal data sets; integrating indigenous climate observations; community-based adaptation plans including community-driven slum upgrading and participatory scenario development |
| | Behavioral | Accommodation; household preparation and evacuation planning; retreat and migration, which has its own implications for human health and human security; soil and water conservation; livelihood diversification; changing livestock and aquaculture practices; crop-switching; changing cropping practices, patterns, and planting dates; sylvicultural options; reliance on social networks |
| Institutional | Economic | Financial incentives including taxes and subsidies; insurance including index-based weather insurance schemes; catastrophe bonds; revolving funds; payments for ecosystem services; water tariffs; savings groups; microfinance; disaster contingency funds; cash transfers |
| | Laws and regulations | Land zoning laws; building standards; easements; water regulations and agreements; laws to support disaster risk reduction; laws to encourage insurance purchasing; defining property rights and land tenure security; protected areas; marine protected areas; fishing quotas; patent pools and technology transfer |
| | Government policies and programs | National and regional adaptation plans including mainstreaming climate change; sub-national and local adaptation plans; urban upgrading programs; municipal water management programs; disaster planning and preparedness; city-level plans, district-level plans, sector plans, which may include integrated water resource management, landscape and watershed management, integrated coastal zone management, adaptive management, ecosystem-based management, sustainable forest management, fisheries management, and community-based adaptation. |

*Innovations from these categories have been identified in the first cycle of stocktaking in BRIGAID.

## 1.2 Report Context and Objectives

The present report is the Deliverable D5.1 and belongs to Work Package (WP) 5. The objective of WP5 in the Description of Action (DOA) is as follows:

> *"The objective of WP5 is to develop a comprehensive, standardized methodology (the TIF) for testing and implementing climate adaptation measures, in particular to assess their potential to reduce risks from floods, droughts and extreme weather. The methodology enables the innovator to assess the socio-technical effectiveness of innovations on various geographical scales and in various sectors. The ambition is that the TIF becomes the European quality label for climate adaptation measures."*

The DOA describes the Deliverable 5.1 as follows:

> *"Initial version of the TIF. Report containing the probable range of (normalized) test conditions and uncertainties (from T5.1), and variability in institutional cultures across Europe on a local, regional, and national scale (from T5.2) resulting in guidelines for assessing the general effectiveness of innovations. These guidelines form the initial version of the TIF."*

This report focuses on the initial methodological development of the testing and implementation framework (TIF) for increasing the socio-technical readiness of climate adaptation innovations and assessing their impact on different socio-economic and environmental sectors that are expected to feel the consequences of climate change. Further sub-objectives were to:

- model the current and future socio-technical boundary conditions across Europe;
- develop socio-technical Performance Indicators (PI) that can be used to evaluate innovations and can be applied to all categories of innovations within BRIGAID, including clusters of innovations;
- develop testing protocols used to evaluate and/or quantify these PI;
- provide guidelines to measure the impact of innovations on various socio-economic and environmental sectors, including: energy, forestry, nature/ecology/environment, agriculture, health, infrastructure, and tourism; and
- provide guidelines (e.g., in the form of questionnaires, testing templates, and spreadsheets) for creating an innovation profile based on the PI and impact evaluations.

## 1.3 Approach

The work performed prior to the delivery of this report has been divided among three tasks:

- The objective of the first task (T5.1) was to establish socio-technical test conditions for innovations. In this task, the technical boundary conditions for testing innovations in Europe at the local, regional, and national scales for current and future conditions were developed. The social boundary conditions in Europe are grounded in the literature on Cultural Theory. An overview of the results of this task are provided in Chapter 2 and more details are provided in Appendix A.

- The objective of the second task (T5.2) was to establish an instrument for assessing acceptance of innovations among end-users. The guidelines provided in the initial version of the TIF are based on an in depth review of the literature on technological acceptance and rejection in different countries in Europe. An overview of the results are provided in Chapter 7.

- The objective of the third task (T5.3) was to develop a method for assessing the socio-technical effectiveness of innovations based on their potential to reduce climate-related risk(s) in Europe. The initial version of the TIF included in this report also incorporates guidelines for assessing the potential impact of innovations on different socio-economic and environmental sectors. These initial guidelines were developed based on a review of the literature on technical performance, reliability, environmental assessments methods, health effects, energy footprints, agriculture, ecology, forestry, and monetary impacts on the tourism and transport sectors. As part of the activities performed in this task, the first concept TIF was applied to four innovations during a workshop conducted prior to the BRIGAID Project Meeting in Leuven (2016). The results of this workshop and lessons learned are described in Appendix C.

Future versions of the TIF (i.e., Deliverable 5.2) will focus on the development of support tools for innovators. These support tools will be built to help guide the innovators through the development of a test plan (e.g., via interactive questionnaires), testing (e.g., via templates), and assessment of the socio-technical readiness at the end of each testing phase (e.g., via an interactive scoring template). The scoring template will provide tangible results that will be included in the Innovation Sharing Platform (ISP) (i.e., BRIGAID Window (WP7)) (see Chapter 3).

## 1.4 Report Organization

The following chapters provide a summary of the theoretical background and development of the initial version of the TIF. Chapter 2 provides an overview of the probable range of (normalized) boundary conditions and variability of institutional cultures across Europe. Chapter 3 provides an overview of the different components of the TIF, including an overview of the planned testing phases. Definitions for the (initial) Performance Indicators (PI) are provided in Chapter 4, which also includes a description of how the test results will be integrated into the Innovation Sharing Platform (ISP) (in WP7). Elaborated guidelines for testing are provided in Chapters 5-7. Specifically, guidelines for assessing the technical effectiveness of innovations are provided in Chapter 5; guidelines for assessing the impact of an innovation on socio-economic and environmental sectors that will feel direct consequences of climate change are provided are provided in Chapter 6; guidelines for assessing the societal acceptance of innovations in Chapter 7.

The appendices to this report provide background, methods for testing, and elaborated examples of their application to case study innovations.

# 2 Testing Conditions

In addition to providing guidelines for testing, BRIGAID aims to provide tools to assist the innovator in the R&D process that occurs prior to the development of an innovation prototype or test plan. These tools are particularly helpful in determining the size of the market for an innovation (and are thus also integrated into activities proposed by WP6) and the potential boundary conditions associated with climate-related hazards in Europe now and in the future. In the following subsections, an overview of the socio-technical boundary conditions in Europe is provided. For further methodological discussion, the reader may refer to Appendix A.

## 2.1 Variability in Loading Conditions Across Europe

To evaluate the technical effectiveness of climate adaptation innovations in Europe, innovations dealing with different hazards need to be analyzed in a way that allows a direct comparison of their utility. This requires normalized loading conditions for seven indicators which represent the flood, drought, and extreme weather hazards included within BRIGAID (Table 2-1).

*Table 2-1 Climate-related hazards and their loading condition indicators*

| Hazard | Indicator |
|---|---|
| Coastal Floods | Storm surge height with a 100-year return period in meters above water levels with a 10-year return period under historical climate |
| River Floods | River water level with a 100-year return period in meters above water levels with a 10-year return period under historical climate |
| Droughts | Maximum number of consecutive days when precipitation is less than 1 mm |
| Heat waves | Total number of heat waves in 30 years, where heat wave is a period of more than 5 consecutive days with daily maximum temperature exceeding the mean maximum temperature of the May to September season for the control period (1971–2000) by at least 5°C. |
| Wildfires | Average daily Forest Fire Danger Index |
| Windstorms | $99^{th}$ percentile of daily wind speed in m/s |
| Heavy Precipitation | Daily precipitation with a 5-year return period in mm |

Normalization is carried out by establishing the spatial distribution of each indicator at three geographic scales: local, regional and national (Table 2-2). Each level represents a different aspect of Europe's social and political landscape: local and national decision-making levels as well as the main socio-economic divisions of each country (i.e., regional). For the local and regional levels, normalization was first carried out by averaging the indicators' values for every local/regional unit within Europe. Then, an empirical probability distribution of each aggregated indicator was obtained. At the national level, a given innovation will likely need to be universally applicable in a country's territory to be picked up by a central government agency looking for a universal solution. Thus, for the national level, the 95th percentile of hazard intensity within a given country was calculated so that an innovator can estimate the number of countries in which a given innovation can be applied. The full methodology for the development of the indicators and normalization process is described in Appendix A.

*Table 2-2 Three geographic scales over which normalization was performed*

| Scale | Representation of… | Units (Source) | No. of Units |
|---|---|---|---|
| Local | Level of local-community decision-making | Eurostat's Local Administrative Units, level 2 (LAU 2) | 117,522 |
| Regional | Main administrative, economic, or cultural divisions of countries | Eurostat's Nomenclature of Territorial Units for Statistics, level 3 (NUTS 3) | 1,382 |
| National | Level of central-government decision-making | Countries | 33 |

For each indicator, loading conditions have been prepared for three scenarios: historical climate (1971–2000) and two future climate scenarios (2071–2100) under different socio-economic development assumptions (RCP 4.5 and 8.5). After normalization, their statistical distributions over Europe were established for the local, regional and national levels. An example is shown in Figures 2-1 and 2-2 for coastal floods:

- One large map of the hazard indicator at the regional level for the historical scenario, and two smaller maps showing relative change in the future (Figure 2-1); and
- Six histograms showing the absolute values of the indicator at local and regional levels for the two emissions scenarios, and one graph comparing the three scenarios at the national level (Figure 2-2).

The normalized indicators provide important information about the loading conditions that an innovation could be subjected to and where they might occur within Europe[1] now and into the future, and can also be used to determine the size of the market for a particular climate adaptation innovation (in WP6). Such information can be utilized by an innovator to help determine the functionality requirements and design parameters of an innovation prior to the technology development process (or design entrenchment) and testing.

Take, for instance, a temporary flood barrier intended to protect against a (coastal) water level of 0.5 meters. Everywhere in Europe there is some basic resilience against floods; however, the coastal flood indicator informs the innovator of the difference between existing flood protection and a flood event bigger by one order of magnitude. Using this information[2], the innovator will determine that the innovation will be applicable in 91% of European municipalities or their equivalents in 1971–2000, but that this value is projected to decline to less than 5% by 2071–2100 (mainly due to sea level rise associated with climate change under a high greenhouse gas scenario). The innovator may therefore choose to re-design his innovation for higher water elevations, depending on the intended lifetime of his innovation or target market.

[1] Based on data availability, the European domain has been defined here as European Union and European Free Trade Agreement member countries, and Macedonia, without some outlying regions (see Appendix A for details).

[2] The indicator was based on assumption of existing flood protection against 10-year floods and the desired flood protection standard of 100 years. However, the information is also applicable for other flood protection levels that differ by one order of magnitude (see Appendix A for details).

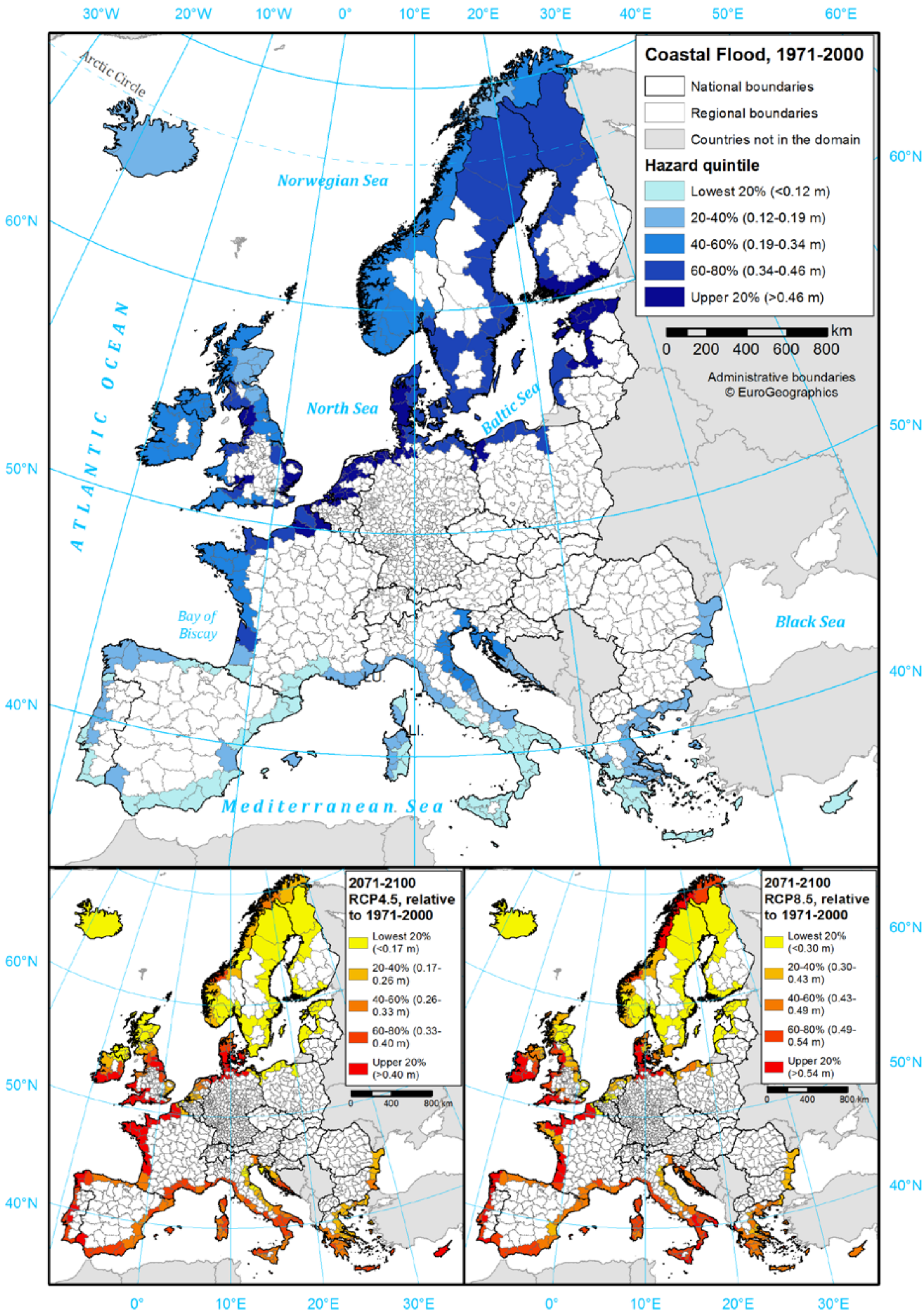



*Figure 2-1 Quintiles of normalized coastal flood hazard indicator at regional level for historical scenario (main map) and relative change (subtraction) between 2071–2100 and 1971–2000, in two scenarios.*

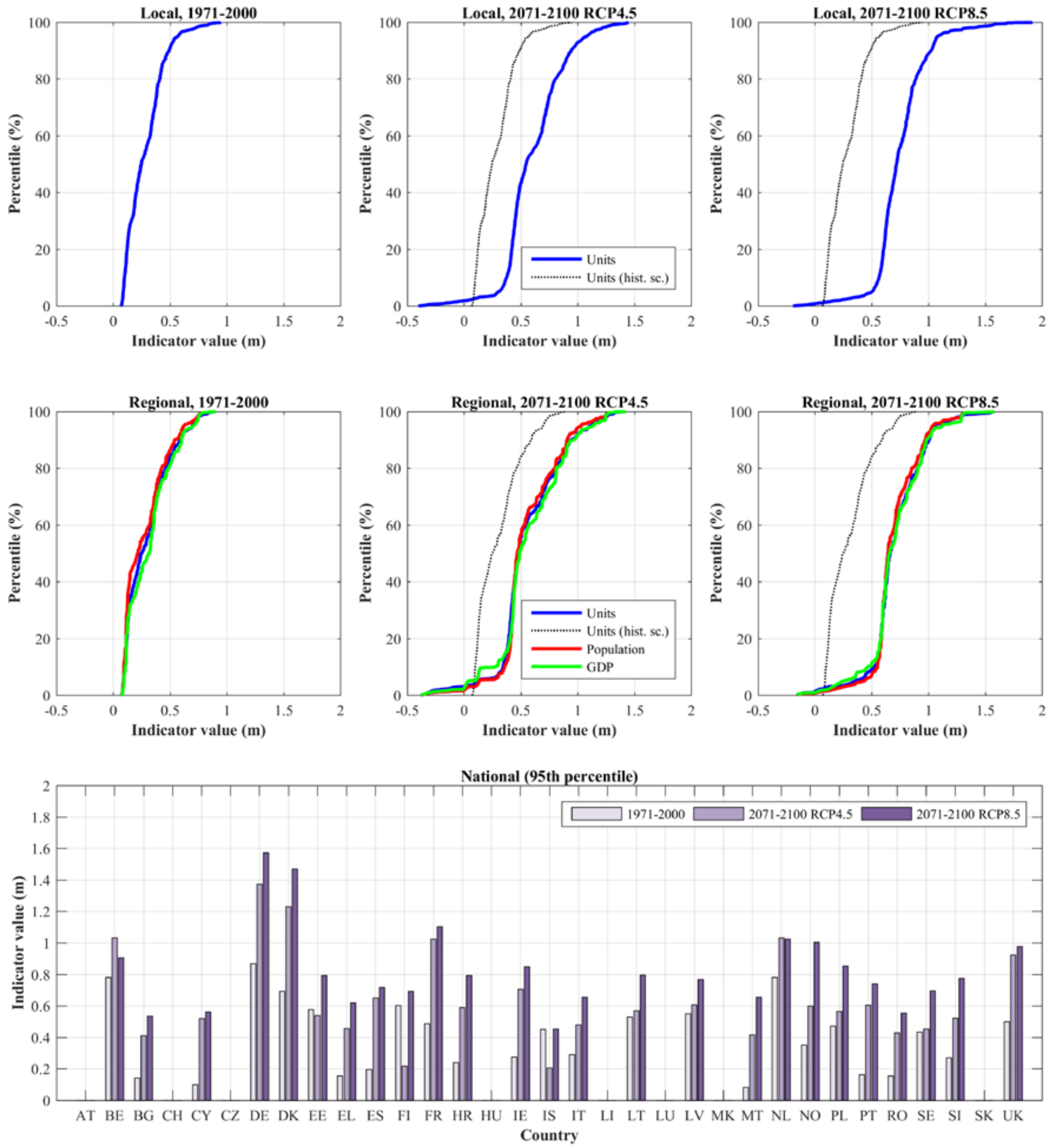



*Figure 2-2 Normalized coastal floods hazard indicator at local, regional and national level, by climate change scenario. Histograms only for units connected to the coastline (6275 local, 394 regional). For country codes, see Appendix A.*

## 2.2 Variability in Institutional Cultures Across Europe

The acceptability of climate adaptation innovations in Europe will be determined as much by social concerns as by technical concerns. An innovation might be deemed technically effective, for instance, but at the same time be completely unacceptable to stakeholders by being incompatible with their values. This demands an understanding of the different social contexts into which innovations will be launched. In particular, it requires an understanding of decision making cultures and how they vary across Europe at different scales. The national scale is often used as the unit of analysis in studies of decision making cultures but this presupposes somewhat static and homogenous cultures with innate qualities that are necessary to their national identities. National cultures are in reality an always changing mixture of competing institutional cultures that are common to all countries at different scales (Rayner, 1991). For example, anti-fracking protest groups in the UK have much more in common with those in Germany than they do with personnel from the UK shale gas industry. In other words, the differences within nations are greater than those between nations.

Social theories of institutional culture often differentiate between hierarchical and market institutions. Hierarchical institutions are characterized by bounded groups of hierarchized individuals and market institutions are characterized by loose networks of equal individuals. Advances in social theory have identified one further relevant institutional culture: egalitarian (Rayner, 1995). This is characterized by bounded groups of equal individuals. These three elementary institutional cultures can be found to varying degrees within all national cultures at different regional and local scales. They each maintain distinctive perceptions of the risks posed by climate variability and change and corresponding preferences over how to respond to them. Market institutions see nature and climate as robust and its risks as opportunities. Hierarchical institutions see nature and climate as tolerant and its risks as controllable through management. Egalitarian institutions see nature and climate as fragile and its risks as catastrophes to prevent. These risk perceptions and adaptation preferences can be mapped onto a triangular preference space (see Figure 2-3).

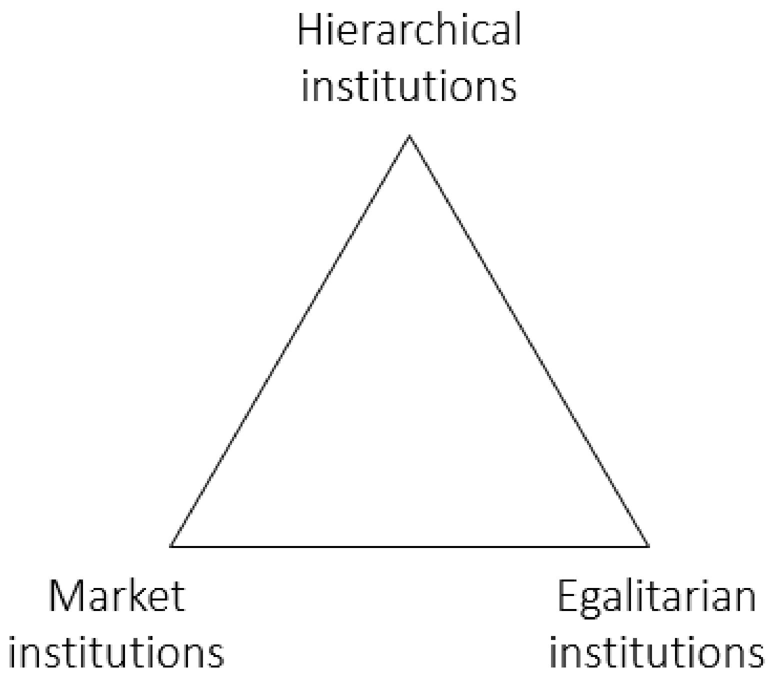



*Figure 2-3 Three institutional cultures across Europe*

The three institutional cultures also maintain distinctive perspectives on innovation acceptance and rejection: technocratic, techno-optimistic and techno-sceptic, respectively. Each of these perspectives describes one possible context in which climate adaptation innovations could be implemented and one set of preferred technological characteristics. These institutional perspectives are described in more detail in Chapter 7 of this report as part of the social testing guidelines. The guidelines have been developed to help innovators prepare their innovations for a favorable societal reception. The testing will show where they can expect to meet societal acceptance and resistance while also helping them to evaluate whether they are maintaining a sufficiently diverse portfolio of technological characteristics. This flexibility will go some way to addressing the dilemma of control that faces emerging technologies: the desire to control for undesirable impacts before they happen combined with the difficulty of not knowing with any confidence what these will be until an innovation has been deployed and 'locked-in' (Collingridge, 1980).

# 3 Testing and Implementation Framework (TIF)

The purpose of BRIGAID's Testing and Implementation Framework (TIF) is to provide innovators with guidelines and tools for evaluating the socio-technical effectiveness of an innovation in terms of its ability to reduce risks from floods, droughts, or extreme weather in an operational environment, and guidelines for assessing an innovation's impact across various geographic scales and socio-economic and environmental sectors. The goal of testing is to increase the technology readiness level (TRL) of the innovation, while simultaneously evaluating its societal acceptance and its potential for market uptake. Testing of each innovation will result in the creation of an innovation profile based on Performance Indicators (PI) (see Chapter 4).

Section 3.1 presents a short review of the TRL scale, its function for measuring and guiding the research and development (R&D) of innovations, and the advantages and disadvantages of using the TRL scale in its current form. Section 3.2 provides a brief overview of the general testing framework applied in subsequent chapters of this report. Finally, Section 3.4 introduces the idea of sociotechnical readiness and identifies three soft stage gates that can be applied within the R&D process.

## 3.1 Technology Readiness Levels (TRLs)

Technology Readiness Levels (TRLs) are a metric used to assess the maturity of an innovation during R&D. The TRL scale was originally developed by the National Aeronautics and Space Administration (NASA) in the 1970-80s to support the planning of space technologies. It has since been adopted by numerous governmental organizations (e.g., U.S. Department of Defense, U.S. Department of Energy, Environmental Science Agency) and large companies (e.g., Boeing, Lockheed Martin) to evaluate progress in the development of different technologies (Graettinger *et al.*, 2002; ESA, 2008; EARTO, 2014; GAO, 2016). It was also recently adopted by the EU Horizon2020 Work Programmes as a tool to evaluate and manage the results and expectations of different projects (European Commission, 2014).

Generally, the scale consists of nine levels where each level characterizes the progress in the development of an innovation, from the initial idea (Level 1) to the introduction of the innovation into the market (Level 9+) (see Table 3-1). The TRL scale is a well-accepted framework and can be considered a proven method for assessing the technical maturity of a technology. However, there are also some limitations to adopting the TRL scale without adaptation.

First, the TRL scale assumes that the technology development process is linear when, in practice, the development of an innovation is an iterative process (EARTO, 2014). Realizations (or complications) in later stages of the development of the innovation often force an innovator to go back to the drawing board and make changes to earlier designs; an innovator may even return to the original prototype to further optimize the design to meet end-user or market requirements.

*Table 3-1 Descriptions for Technical Readiness Levels (TRLs) (adapted from the European Commission)*

| Phase | TRL | Description |
|---|---|---|
| Desk Study | Level 1 | ***Basic principles observed***. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties. |
| | Level 2 | ***Technology concept formulated***. Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies. |
| | Level 3 | ***Experimental proof of concept***. Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative. |
| Laboratory Testing | Level 4 | ***Technology validated in lab***. Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in the laboratory. |
| | Level 5 | ***Technology validated in relevant environment***. Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include "high-fidelity" laboratory integration of components. |
| Operational Testing | Level 6 | ***Technology demonstrated in relevant environment***. Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment. |
| | Level 7 | ***System prototype demonstration in operational environment***. Prototype near or at planned operational system. Represents a major step up from TRL 6 by requiring demonstration of an actual system prototype in an operational environment. |
| | Level 8 | ***System complete and qualified***. Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation (DT&E) of the system in its intended weapon system to determine if it meets design specifications. |
| Market Uptake | Level 9 | ***Actual system proven in operational environment*** (competitive manufacturing). The solution is used successfully in a structurally operational environment. The user can and wants to recommend the solution to others. |
| | Level 9+ | ***Market introduction***. The product, process or service is launched commercially, marketed to and adopted by a group of customers (including public authorities). |

Second, the technical maturity of a technology does not necessarily reflect its readiness, especially with regards to social or market demands. In fact, anecdotal evidence suggests that an innovation can reach TRL 7 or 8 without ever considering social or market readiness (or evaluating impacts) (EARTO, 2014). The U.S. Government Accountability Office (GAO) suggests that by neglecting to resolve such issues until product development can result in a ten-fold cost increase; and, delaying them until after the start of production can result in a hundred-fold cost increase (Graettinger *et al.*, 2002).

Finally, many studies suggest that the nine-level TRL scale may be too granular for guiding testing and that the TRL-based definitions of readiness are often limited to a single type of technology. EARTO (2014) recommends redefining the TRL levels to incorporate market and business assessments, providing examples to facilitate the communication of TRLs for different types of technology and development of testing guidelines.

To overcome the limitations listed above, the initial testing framework proposed by BRIGAID has been divided into four phases: desk study, laboratory testing, operational testing, and full scale deployment (see Table 3-1). Building on the existing TRL scale, the BRIGAID TIF relies on the four testing phases to promote iterative design to better represent the reality of R&D, as well as integrate social readiness with technical maturity.

## 3.2 General Testing Framework

Testing has been divided into four phases based on the definitions associated with the TRL scale as shown in Figure 3-1. Soft and hard "stage gates" have been proposed at the end of each phase to control the R&D process of the innovation. These stage gates represent suggested minimum testing and assessment that should be completed before moving forward in the testing framework. When the minimum requirements are not met or significant negative impacts are foreseen, the innovator is advised to re-design and re-iterate within that phase. The goal of the stage gates is to help the innovator avoid the pitfalls that usually occur during the innovation process, such as proceeding too far in technical development without considering impacts or social acceptance. Innovations that succumb to these pitfalls and never reach the market are colloquially considered to as having fallen into the "Valley of Death."

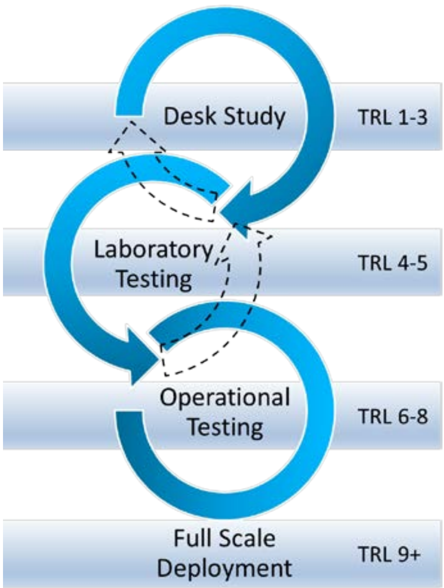



*Figure 3-1 Conceptual model showing the four testing phases based on TRL definitions.*

The testing phases are further described below.

I. **Desk Study, TRL 1-3:** This phase consists of a desk study in which the innovation, its functionality (e.g., intended hazard and intended capacity to reduce risk), and Performance Indicators (PI) are qualitatively analyzed. This qualitative assessment may be guided by the innovation questionnaires (see Appendix B) and must be completed prior to entering the BRIGAID testing cycles. The minimum requirement to reach TRL 4 is the generation of a prototype, a clear description of its intended functionality (e.g., design criteria), the identification of possible failure modes, a preliminary theoretical social acceptance assessment, and an initial screening of the potential impact of the innovation on each sector (see Chapters 5-7).

II. **Laboratory Testing, TRL 4-5:** In this phase the innovation is analyzed based on the design criteria identified during the Desk Study. Laboratory testing of the technical PI is performed and, for those impacts that require further testing, simple semi-quantitative or more detailed qualitative evaluation of impacts is performed (e.g., pollutant analysis). A preliminary social acceptance check should be completed which may be based on interactions with representative stakeholder groups.

III. **Operational Testing, TRL 6-8:** In this phase the innovation is analyzed using the boundary conditions associated with the (intended) operational and market environment. This phase consists of analyzing the PI under operational boundary conditions, and demonstrating the performance of the innovation when placed in a simulated operational environment and/or during real events. A more detailed impact assessment may be conducted using the existing conditions at the location. Social acceptance testing may be performed with stakeholders or end-users from the environment where the innovation is intended to be implemented. These tests represent a significant step in demonstrating the technical effectiveness and social readiness of the innovation.

IV. **Full Scale Deployment, TRL 9+:** This phase is not included within BRIGAID; however, preliminary recommendations for mid- and long-term monitoring of innovation performance (including impacts on different socio-economic and environmental sectors) are provided along with suggestions for providing operation and maintenance protocols.

To be included within BRIGAID, an innovation must be at or above a TRL 4 and thus have completed an initial desk study.

## 3.3 Sociotechnical Readiness

Climate adaptation innovations should be thought of as sociotechnical systems, that is to say, they should be thought of as assemblages of technical artifacts and social arrangements that act together as a single system (Bijker et al., 1989). The initial TIF therefore adopts a broader concept ‘sociotechnical readiness’: the readiness of both implementation contexts (the social arrangements) and technological characteristics (the technical artifacts).

After each testing phase, a ‘soft’ stage-gate mechanism exists to ensure that both social and technical issues have been identified and addressed before further R&D takes place (Cooper, 1990). The stage-gates should be considered ‘soft’ in that innovators cannot of course be stopped from proceeding in research and development if they so wish but that it is in their best interests to evaluate social and technical indicators at these key junctures before proceeding and 'locking-in' their innovation to designs that are socially or technically inappropriate.

*Table 3-2 Socio-Technical Readiness Levels and 'soft' stage gates*

| Testing Phases | Description |
|---|---|
| **Desk Study (I)** | Innovation concept proven and relevant stakeholders identified |
| ***Stage-gate 1*** | Social and technical issues addressed before proceeding to Phase II |
| **Laboratory Testing (II)** | Innovation validated in laboratory testing with stakeholders |
| ***Stage-gate 2*** | Social and technical issues addressed before proceeding to Phase III |
| **Operational Testing (III)** | Innovation demonstrated in operational testing with stakeholders |
| ***Stage-gate 3*** | Social and technical issues addressed before proceeding to deployment |

# 4 Performance Indicators

The technical effectiveness of an innovation and its impact on various socio-economic and environmental sectors will be evaluated based on Performance Indicators (PIs). While the tests performed to assess the PI for individual innovations may be different, PIs should be globally applicable and relevant for all innovations which are included in the Innovation Sharing Platform (ISP) (WP7).

The sections below provide initial definitions for the technical (Section 4.1) and impact (Section 4.2) PI used within BRIGAID. Social PIs are defined in Chapter 7. Each innovation will be tested and evaluated on each PI, and the scores will be summarized in an innovation profile (Section 4.3). More detailed methods and guidelines for testing and evaluating each PI are described in Chapters 5 (technical), 6 (impact) and 7 (societal), respectively.

## 4.1 Technical

Technical readiness is based on the performance of an innovation and its effectiveness in reducing climate-related risks, as shown in field tests and in operational environments. To evaluate the technical readiness of an innovation, technical PIs have been developed. In developing these PIs, different frameworks for evaluating the effectiveness of engineered or built environment innovations, such as temporary flood barriers (Lendering, Kok and Jonkman, 2013; Wibowo and Ward, 2016), and technological and informational innovations, such as early warning systems (Sättele, Bründl and Straub, 2015), were reviewed. Four primary indicators have been identified within the technical portion of the TIF: technical effectiveness, reusability, reliability, and exploitability. A description of each indicator and the factors involved are provided below. Preliminary guidelines and methods for testing and evaluating the indicators are further discussed in Chapter 5 and two examples are provided in Appendix D of this report.

*Table 4-1 Indicators of technical readiness for climate adaptation innovations.*

| Indicators | Definition | Factors involved | Key references |
|---|---|---|---|
| Technical Effectiveness | A metric to evaluate the intended functionality of the innovation when used to reduce climate-related risks. | hazard; risk reduction capacity; | Margareth & Romang (2010); Sätelle et al. (2015); Sätelle et al. (2016) |
| Reusability | A metric that encompasses the temporary- or permanent-nature of the operation of the innovation. | lifetime; durability; operation and maintenance requirements; | - |
| Reliability | A metric that describes the likelihood that an innovation fulfills its intended functionality during its intended lifetime. | Inherent reliability; structural failure; implementation and technical failure modes | Lendering et al. (2015); Sättele et al. (2015); Wibowo & Ward (2016) |
| Exploitability | A metric that encompasses the capacity of the innovation to be sold/deployed in other locations than originally envisioned i.e., the size of the European market for the innovation. | hazard; risk reduction capacity; reliability; material components; modularity (and cost) | |

### 4.1.1 Technical Effectiveness

Technical Effectiveness is a metric to evaluate the intended functionality of the innovation when used to reduce climate-related risks. The intended functionality is determined by the innovation typology (e.g., engineered/built environment or technological/informational), the hazard type (e.g., floods, droughts, or extreme weather), and the intended capacity to reduce risk (e.g., reducing flood levels or increasing warning time). Following the definition of risk introduced in Chapter 1, the technical effectiveness of an innovation will be assessed by its capacity to reduce: (i) the probability or likelihood of the hazard or (ii) the consequences associated with a given hazard event (see Figure 1-2). Following this line of reasoning, technical effectiveness is measured as:

1. For *engineered or built environment innovations*: the ability of the innovation to reduce the probability of a hazard. For example, a temporary flood barrier reduces the probability of occurrence of a flood by providing protection for water levels up to its design height.

2. For *technological and informational innovations*: the ability of the innovation to reduce the consequences of (e.g., exposure or vulnerability to) a hazard. For example, a flood warning system increases the lead time prior to a flood which enables an end-user to take flood-mitigating actions (e.g., evacuation or deployment of temporary flood barriers) thereby reducing the exposure and vulnerability to flooding.

### 4.1.2 Reusability

Reusability is a metric that encompasses the temporary- or permanent-nature of the operation of the innovation; it is measured by whether an innovation is designed for single or repetitive use and how durable the structural components of the innovation are. It also provides information about the lifetime — determined by either the lifetime of its structural components or the innovation's climate lifetime[3] — and the long-term operation and maintenance requirements of the innovation.

In BRIGAID, three types of reusability are considered for *engineered or built environment innovations*:

1. *Permanent*: innovations that are permanently implemented and/or constantly operated. These innovations are designed to withstand the hazard event and daily loading without (or with minimal) repairs (e.g., a permanent dike or flood warning system);

2. *Semi-permanent*: innovations that are permanently implemented at the location, but are only operated during the hazard event (e.g., a storm surge gate); and

3. *Temporary*: innovations that are operated prior to (and during) the hazard event, but removed completely after the hazard has passed (e.g., a temporary flood barrier).

And two types of reusability are considered for *technological and informational innovations*:

[3] An innovation's climate lifetime is the time at which the intended design capacity (e.g., height, volume) of the innovation is exceeded by climate change impacts. For example, a temporary flood barrier (TFB) intended to reduce the risk of coastal floods has been designed to withstand 0.25 m of water; it's climate lifetime is the time at which the TFB is no longer effective because it has been exceeded by sea level rise.

1. *Continuous operation*: innovations which are permanently operated (e.g., monitoring systems); and

2. *Operation prior to/during a hazard event*: innovations which are activated prior to a hazard event or only operated (temporarily) during the hazard event.

### 4.1.3 Reliability

Reliability is a metric that describes the likelihood that an innovation fulfills its intended functionality during its intended lifetime. By definition, reliability is the probability of successful operation, which can also be expressed as the complement of the probability of failure during operation (i.e., reliability = 1 – probability of failure during operation). For example, the reliability of a temporary flood barrier (TFB) is evaluated by determining the probability that the TFB fails to retain water levels to its design height (and safety level). Similarly, the reliability of a flood warning system (FWS) is evaluated by determining probability that the FWS (system or its components) are unavailable and fail to function, and that the system fails to predict flooding or to achieve the intended lead time prior to a flood (Sättele, Bründl and Straub, 2015).

A common aspect of all reliability assessments is the identification of failure modes, i.e., modes/mechanisms that lead to failure to fulfill the intended functionality of the innovation. By quantifying the probability of each failure mode, the reliability of an innovation can be estimated. There are many methods that can be used to qualitatively and quantitatively assess reliability (see Chapter 5). For the climate adaptation innovations included within BRIGAID, we consider two general failure modes:

For *engineered or built environment innovations*:

1. *Structural failure*: the failure to fulfill the intended function of the innovation during operation; and

2. *Implementation failure*: the failure to (correctly) implement an innovation *before* the onset of the hazard. Implementation failure is, by definition, only relevant for semi-permanent or temporary innovations.

For *technological and informational innovations*:

1. *Inherent failure*: the failure of the system to distinguish between positive signals and background noise, or to provide an accurate hazard estimate (i.e., to fulfil its intended function); and

2. *Technical failure*: the failure of the system or its components to perform (i.e., operate) prior to or during a hazard event (e.g., due to power outages, external failures, software malfunction).

After estimating the (current) reliability of an innovation, an innovator may want to optimize the innovation in order to maximize the reliability and/or minimize the consequences of the hazard.

### 4.1.4 Exploitability

Exploitability is a metric that encompasses the capacity of the innovation to be sold or deployed in other locations than originally envisioned, i.e., the potential size of the European market for the innovation. The exploitability of the innovation is directly based the intended risk reduction capacity of the innovation (i.e., technical effectiveness), the modularity, and the availability and cost of material components of the innovation. The size of the market is measured as the percent of regions in Europe where the innovation is effective under current and future climate conditions (see Chapter 2 and Appendix A) and takes into consideration modularity and material component costs, where:

- Modularity is the degree to which the components of an innovation can be separated and refitted for a specific location; and
- Material component costs may be dependent on location and indicate the difficulty of exploiting the innovation to new markets (in which case the innovator should report the maximum cost per unit in the foreseen market(s)).

## 4.2 Impacts

The implementation of climate adaptation innovations will have – positive or negative, direct or indirect[4], and temporary or permanent – impact(s) on critical socio-economic and environmental sectors that are expected to be negatively affected by climate change, including: energy, forestry, agriculture, health, infrastructure, tourism, nature/ecology, and the environment. Innovations are designed to directly offset the effects of climate change in one or more of these sectors and may also have (unintended or unforeseen) co-benefits in others. To evaluate the impact of the innovation, several indicators have been developed for each sector. The indicators will be used to evaluate whether the innovation may have foreseen impacts on the sectors relative to the present situation (i.e., reference situation) and to the *business as usual* approach over the short and long-term.

It is important to note that the effect of climate change and the local, regional, and national impact(s) of an innovation on the different socio-economic and environmental sectors will be highly dependent on the implementation of the innovation at a specific geographic location. Its impact will also depend on the duration and severity of a hazard event together with the exposure, vulnerability and resilience of the socio-economic sector(s) and their components.

The relevant the PIs for each sector are shown in Table 4-2 below. The following subsections provide a brief overview of each sector and description of the relevant PIs. An Impact Assessment Framework and preliminary guidelines and methods for assessing impacts are presented in Chapter 6. More detailed background information and evaluation methods for each sector can be found in Appendix E.

*Table 4-2 Indicators of innovation impact on socio-economic and environmental sectors*

| **Sector** | **Factors Involved (Indicators)** | **Key References** |
|---|---|---|
| Energy | $CO_2$ footprint of the preparation and construction of the innovation; energy demand of operation (after implementation), energy consumption indicator; energy efficiency indicators; monetized effects | |
| Forestry | Forest Capacity Maintenance (i.e., wood production, non-wood production, protective functions); risks to forests (i.e., | RCM (2015) |

[4] Direct impacts are those caused by the preparation, construction, or operation of an innovation at a particular location. Indirect impacts are those that occur away from the location of the innovation (in space or in time) as a consequence of the implementation or operation of an innovation.

| | | |
|---|---|---|
| | changes in the vulnerability of forests to wildfires, windstorms, pests, and disease); monetized effects | |
| Nature/ Ecology | Quality and quantity of habitats; quality and quantity of Natura 2000 (or otherwise protected species) (e.g., birds, vegetation, fish, mammals, other animals); quality and quantity of soil fauna; monetized effects | EEA (2012); EU (2016) |
| Environment | Surface water quality and quantity; ground water quality and quantity; sea water quality; soil quality; air quality; landscape quality; monetized effects | EEA (2017); European Commission (2016b); iSQAPER(2017) |
| Agriculture | Quality and quantity of area for sustainable agricultural production; type of crops and yield; monetized effects | Dumanski et al. (1998) |
| Health | Avoided Deaths; affected population; monetized effects | CRED (2015) |
| Infrastructure | Built infrastructure (e.g., residential housing, urbanization patterns, commercial/industrial); networks (i.e., roads, railways, rivers/ports, communication, water supply, energy); monetized effects | EEA (2017) |
| Tourism | Quantity (and quality) of recreational area, duration of season; monetized effects | Dupeyras (2013); Copernicus (no date) |

### 4.2.1 Energy

Both energy supply and demand are sensitive to climate change, especially changes in temperature and in the frequency of extreme weather events, including heat waves, droughts, and storms (Table 1-1). For example, the efficiency and output of thermal power plants is adversely affected by a rise in temperature or a decrease in the availability of cooling water (e.g., low flows as a result of droughts). Similarly, extreme winds and increased flooding pose a challenge for the operation of energy infrastructure (EEA, 2017). Renewable energy infrastructure may also be adversely affected by climate change; for example, increased frequency of severe storms and changes in weather patterns may affect the production of bioenergy, wind energy, and solar energy (EEA, 2017). While the total energy demand in Europe is not expected to change substantially in the coming years, significant seasonal shifts (e.g. less demand for heating in winter and more demand for cooling in summer) and changes in the energy mix are expected with large regional differences (EEA, 2017).

To mitigate the effects of climate change on the energy sector, it is important to develop new energy technologies which are more climate resilient. As such, innovations which, for example, improve energy efficiency, increase cooling capacity, enhance water efficiency, increase the resilience of energy infrastructure to natural hazards, enhance demand-side management through the development of energy/water-efficient and energy-smart appliances, equipment, buildings, etc. will have beneficial impact(s) to the energy sector (because of reduced energy demand and increased resilience).

However, the energy sector is also a major source of anthropogenic greenhouse gas (GHG) emissions which directly contribute to global warming (IPCC, 2014). Currently, around 70% of GHG emissions come from combustion of fossil fuels to generate electricity for industry, buildings, and transport, and GHG emissions are projected to continue to rise during the $21^{st}$ century. In the context of evaluating the impact of innovations on the energy sector, each innovation's carbon footprint should be calculated because it represents the energy demand of the innovation and (indirectly) its contribution to climate change.

Performance Indicators to assess impact of innovations on the **Energy** sector are:

- $CO_2$ footprint during preparation and construction of the innovation;
- Energy demand/energy consumption during operation (after implementation);
- Energy efficiency indicators; and
- Monetized effects.

### 4.2.2 Forestry

There is no commonly agreed definition of the forestry sector. Ideally, the sector should encompass all economic activities that depend on the production of goods and services from forests, such as commercial activities that depend on the production of wood fiber; commercial production and processing of non-wood forest products and the subsistence use of forest products; and economic activities related to provision of forest services (FAO, 2014). The performance indicators (PI) used to measure the impact of innovations on the forestry sector in BRIGAID are based on those proposed by the Portuguese National Forest Strategy (RCM, 2015). These indicators focus on the sector's capacity to maintain wood production (including timber and biomass), non-wood production (e.g., cork, fruits, honey, hunting, mushrooms), and the protective services provided by forests which promote biodiversity, reduce soil desertification, and reduce coastal and river basins erosion.

The health of the forestry sector is expected to be negatively affected by climate change. It is predicted that climate change will increase the vulnerability of forests to pests and diseases and increase the frequency and intensity of wildfires or windstorms. As a result, the forest's productivity and its ability to sequester carbon will be affected, further contributing to climate change (Camia, Amatulli and San Miguel Ayanz, 2008; Pereira, Correia and Jofre, 2009; MAMAOT, 2013). As such, innovations which reduce the vulnerability of the forest to climate change, decrease the risk of damage to or losses in the forest (and subsequently on the forestry sector), and/or increase its capacity for production or protection will have a measurable (positive) impact on the forestry sector.

Performance Indicators to assess the impact of innovations on the **Forestry** sector are:

- Capacity maintenance for:
    - Wood production (incl., timber and biomass);
    - Non-wood production (incl., cork, fruits, honey, mushrooms, pastures, game and fishing);
    - Protective services (incl., protection against coastal and river basin erosion, desertification, and biodiversity);
- Forest Risk (incl., vulnerability to windstorms, wildfires, pests, and disease); and
- Monetized effects (tangible and intangible losses).

### 4.3.3 Nature/Ecology & Environment

An ecosystem is the basic functional unit of organisms and their environment interacting with each other and their own components as a system (Odum, Barrett and Andrews, 1971). The biotic and abiotic components in the ecosystem are linked together through nutrient cycles and energy flows, and there are many internal feedback mechanisms that keep the system stable. However, external factors, like climate change, and human interventions in the environment (water, soil, air), may cause a disturbance in the system.

Climate change is expected to have significant impacts on many aspects of biological diversity and on ecosystems and ecological interaction (Alcamo *et al.*, 2007). Temperate and tropical plants and animals, for example, may shift poleward in response to global warming, displacing native species, altering biodiversity, and impacting the ecosystem. As such, the impact of an innovation on both the quality and quantity of nature/ecology and on the environment will be evaluated using the performance indicators listed below. Its impact due the construction (i.e., natural materials, commodities) and transport to a location will not be assessed within this sector. (Instead they are included as part of the $CO_2$ footprint calculated for the Energy Sector.)

Performance Indicators to assess the impact of innovations on **Nature/Ecology** are:

- Quality and Quantity of Habitats (the natural environment in which a species or group of species lives);
- Natura 2000 (or otherwise protected) species like Birds, Vegetation, Fish, Mammals, Other animals;
- Quality and Quantity of Soil Fauna; and
- Monetized effects.

Performance Indicators to assess the impact of innovations on the **Environment** are:

- Surface Water Quality and Quantity;
- Ground Water Quality and Quantity;
- Sea Water Quality;
- Soil Quality;
- Air Quality;
- Landscape Quality; and
- Monetized effects.

### 4.3.4 Agriculture

Climate change has already had an impact on the agriculture sector and this trend is expected to continue in the future (Alcamo *et al.*, 2007; FAO, 2009; Peltonen-Sainio *et al.*, 2010; Olesen *et al.*, 2011; EEA, 2017). Climate-related effects on agricultural production are associated with the loss of cultivatable land, changes in growing seasons, uncertainty about what and when to plant, and water availability. Currently there are many local, national and international programs and projects (e.g., those initiated and funded by the EU) that are aimed at stimulating the development and adoption of climate-proof agricultural technologies. Innovations which address this challenge may be aimed at mitigating or even preventing the effects of climate change on agriculture (e.g., droughts, temperature variation, floods, extreme weather) and will have a positive impact on the agriculture sector.

It is also important to note that activities within the agriculture sector are a major source of greenhouse gas (GHG) emissions, but that agriculture can also act as a ‘sink’ for carbon, offsetting GHG emissions by capturing and storing (i.e., sequestering) carbon in the plants or soil (Wreford, Moran and Adger, 2010). Innovations which (directly or indirectly) reduce GHG emissions or increase carbon sequestration within the agricultural sector will have a positive impact.

Performance Indicators to assess the impact of innovations on the **Agriculture** sector are:

- Quality and Quantity of the area for sustainable agricultural production;
- Water availability (for agricultural production);
- Type of crops and yield; and
- Monetized effects.

### 4.3.5 Health

Climate-related disasters will have an impact on human health. During the 21st century, the number of climate-related deaths in the European Union is estimated to be as high 85,000, while the number of affected individuals is estimated at almost 4 million (CRED, 2015). Due to climate change and the expected increase in extreme events in the future, the annual average number of deaths and affected individuals will also increase. However, it is not always easy to directly attribute a health impact to a climate disaster, since the health outcome can occur days, weeks or even years after the event.

While many innovations included within BRIGAID may not be (primarily) aimed at reducing the health impacts associated with climate-related disasters, they may secondarily reduce the adverse effects of climate change on health. They could do this in one of three ways:

1. Prevent a hazardous event from happening;
2. Reduce the exposure to the affected population; or
3. Reduce the vulnerability of the affected population.

In addition, innovations may have indirect impacts on health. For example, a generator which used to prevent an area from being flooded might consume a large amount of gasoline leading to the production of air pollution, which will have an adverse effect on health. Such impacts, both adverse as well as beneficial, will also be taken into account within BRIGAID.

Performance Indicators to assess the impact of innovations on the **Health** sector are:

- Reduction in number of deaths;
- Reduction in number of people affected in their health, where a distinction can be made between:
    - Physical impact;
    - Mental/psycho-social impact; and
- Monetized effects.

### 4.3.6 Infrastructure

The term 'Infrastructure' encompasses any construction resulting from human intervention and, in a broader sense, denotes not only the natural or artificial environment in which people live, but also the effects that human action can have on the surrounding infrastructure. Based on the classification used in the Garnaut Climate Change Review (2008), the elements of the built environment can be grouped into seven general categories:

- *Buildings*: for residential, commercial and industrial use;
- *Supply Networks*: power and water processing and management infrastructure;
- *Public Transport*: transport systems and means (e.g., roads, railways, ports, airports, urban railways);
- *Telecommunications*: fixed-line networks and towers for electricity and telecommunications;
- *Public Spaces*: recreation areas, parks, and all outdoor areas that combine natural and built environments;
- *World Heritage Properties*: national heritage buildings and monuments; and
- *Other buildings*: various types of infrastructure

Climate change is expected to physically impact a number of parameters that affect the built environment (e.g., damages from extreme weather, loss of business, disruption of services, and increased operation costs in certain production sectors). Innovations may (directly or indirectly) address this challenge by increasing the resilience of the built environment to climate change through, for example, improvements in building material that decrease vulnerability to damage from extreme weather.

Transportation infrastructure is especially sensitive to the impacts of climate change. For example, rising temperatures and extended heat waves will increase the likelihood of rail buckling and pavement deterioration; increased water and snow on roads will require more frequent maintenance, repairs, and reconstruction; severe storms will generate floods or landslides leading to delays, interruptions, and detours in overland travel; sea-level rise will affect ports, waterways, and other coastal infrastructure; and, changing wind patterns and extreme weather will affect air transportation and airport infrastructure (EPA, no date). Innovations which increase the resilience of transportation infrastructure to climate change will have a positive impact on the infrastructure sector.

Performance Indicators to assess the impact of innovations on the **Infrastructure** sector are:

- Built infrastructure:
    - Residential/housing;
    - Urbanization pattern; and
    - Commercial/industrial.
- Networks:
    - Transport (roads, railways, rivers/ports);
    - Communication networks;
    - Water supply network; and
    - Energy Networks.
- Monetized effects.

### 4.3.7 Tourism

Tourism is an important and often vital source of income for many regions and countries in Europe. Its importance was recognized in the Manilla Declaration on World Tourism of 1980 as “an activity essential to the life of nations because of its direct effects on the social, cultural, educational, and economic sectors of national societies and on their international relations.” Climate is a principal resource for tourism, as it co-determines the suitability of locations for a wide range of tourist activities and, as such, makes tourism vulnerable to climate change. For example, higher temperatures, extreme weather, and drought may negatively affect the tourism industry; these effects will potentially manifest as a decline in the number of tourist arrivals and decline in average tourist length of stay. In addition, there may be requirements on the tourism sector to reduce pollution and GHG emissions in the face of climate change (Sartzetakis and Karatzoglou, 2011).

Innovations which directly mitigate the physical impacts of climate change and extreme events (e.g., flood prevention, water recycling systems) may have a positive impact on the tourism sector. Similarly, innovations which increase access to an attractive natural area or generating new attractions (i.e., in the case of a nature-based innovations) may also positively impact the tourism sector.

Performance Indicators to assess the impact of innovations on the **Tourism** sector are:

- Duration of tourist season;
- Quantity of recreational area;
- Attractiveness of area; and
- Monetized effects.

## 4.3 Building an Innovation Profile based on Performance Indicators (PI)

As a result of testing, it will be possible to generate an innovation profile based on the Performance Indicators (PI) described in the previous section. The innovation profile will reflect the scores for each performance indicator for a particular innovation (see Figure 4-1). To connect innovators, end-users, qualified investors, and grant and fiscal incentive advisors, BRIGAID will build an Innovation Sharing Platform (ISP) (see Figure 4-2). Within the ISP, the innovation profile can be used to match an innovation to an end-user's specific needs or demands, or to provide an innovator with suggestions for improving his innovation. For example, after testing the socio-technical effectiveness of a temporary flood barrier, an innovator may choose to increase the strength and height of the barrier to improve its effectiveness and increase its market potential. The ISP will also allow the innovator to evaluate the strengths and weakness of their innovation relative to other innovations that are available on the market by comparing their innovation profiles. While the development of the ISP is beyond the scope of this document, more information can be found in reports provided by WP7.

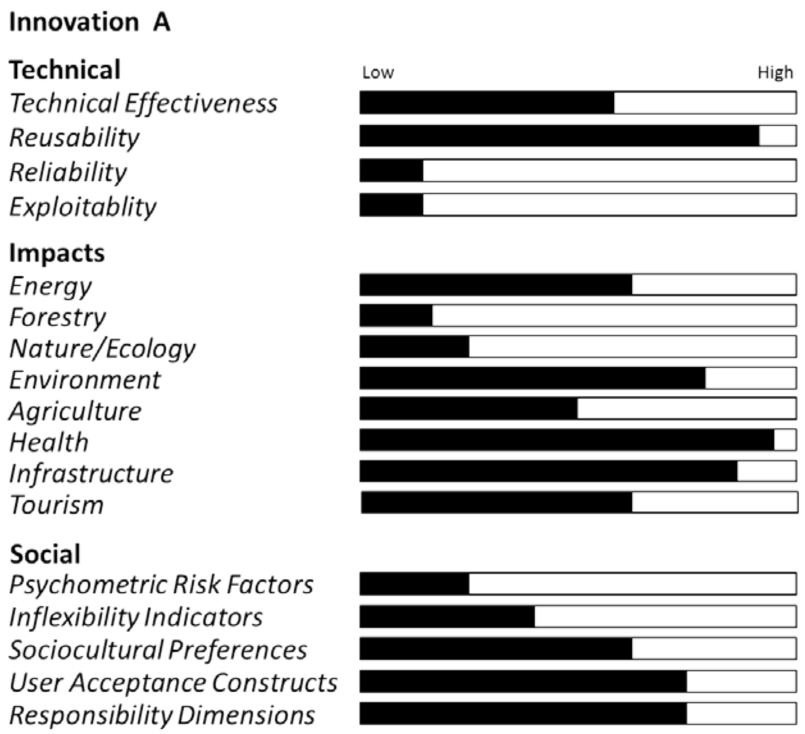



*Figure 4-1 Conceptual profile of an innovation ("A") based on initial Performance Indicators (PI). Note that the social performance indicators are described in Chapter 7.*

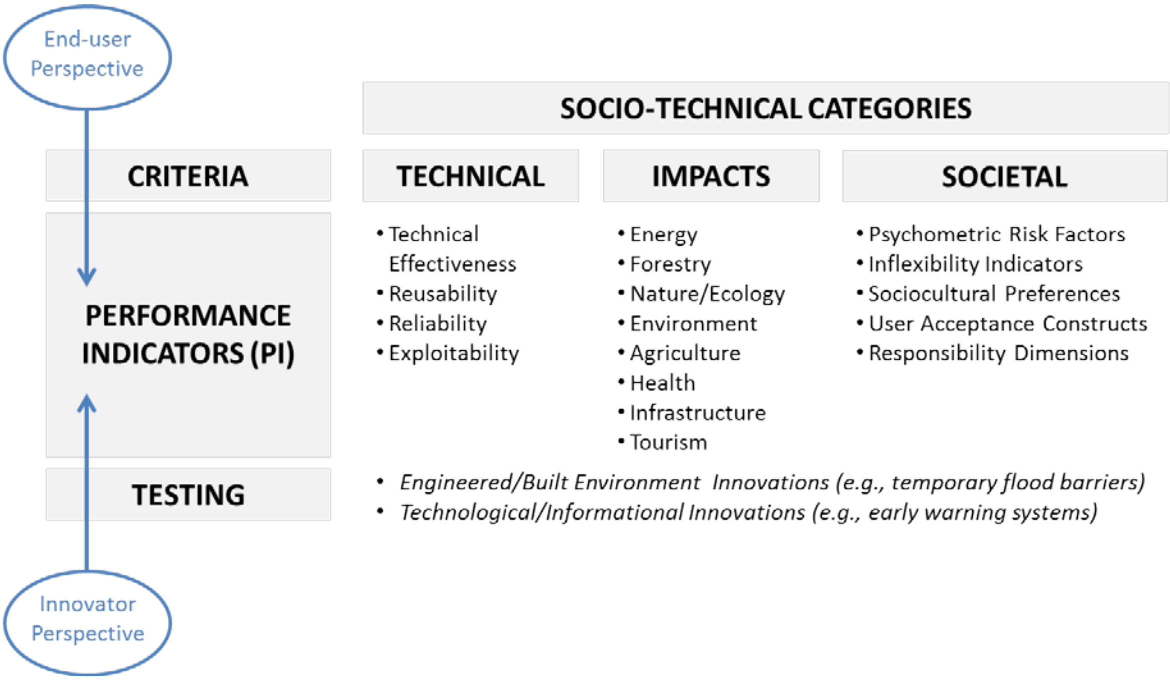



*Figure 4-2 Conceptual design of the Innovation Sharing Platform (ISP) which connects the perspectives of innovators and end-users through Performance Indicators (PI).*

# 5 Technical Testing Guidelines

## 5.1 Testing

The goal of testing is to quantitatively assess the technical PI in laboratory and operational environments, thereby demonstrating the performance of the innovation in terms of its capacity to reduce risk and increasing its technical readiness. A secondary goal of testing is to optimize the design of the innovation. The technical tests associated with each of the testing phases and their corresponding TRLs (introduced in Chapter 2) are described below:

I. **Desk Study, TRL 1-3:** This phase consists of a qualitative desk study in which the innovation, its functionality, and Performance Indicators (PI) are analyzed. This qualitative assessment may be guided by the innovation questionnaires (see Appendix B) and must be completed prior to entering the BRIGAID testing framework. The minimum requirement to reach TRL 4 is the generation of a prototype, a clear description of its intended functionality (i.e., design criteria determined by the intended hazard, intended capacity to reduce risk, and boundary conditions) and the identification of possible failure modes of the innovation (see Table 5-1).

II. **Laboratory Testing, TRL 4-5:** This phase consists of semi-quantitative testing of each of the technical PI in a laboratory environment (see Table 5-2). Preliminary calculations are used to quantify the technical PI and the dominant failure modes are tested in a laboratory (or simulated) environment for the design criteria identified in Phase I. If applicable, vulnerability to human error or external stimuli is also assessed. If structural failure occurs (or inherent reliability is deemed too low) or significant vulnerabilities are observed, adjustments to the original prototype or design criteria should be made (see Figure 5-1). Testing is considered complete if the innovator is satisfied with the current design of the innovation. This represents a significant step in demonstrating the technical effectiveness of the innovation.

III. **Operational Testing, TRL 6-8:** This phase consists of quantitatively analyzing the technical PIs in an operational environment and/or during real events (see Table 5-3). Detailed assessments are used to quantify the technical PI. This requires the innovator to determine the boundary conditions associated with the intended operational environment (e.g., market). In this phase, all failure modes are tested under the pre-determined boundary conditions. If failure occurs (or reliability is deemed to low), adjustments to the prototype should be made (see Figure 5-2). Testing is considered complete if the innovator (or intended end-user) is satisfied with the test results and current design of the innovation.

IV. **Full Scale Deployment, TRL 9+:** This phase is not included within BRIGAID; however some recommendations for mid- and long-term monitoring of innovation performance are provided along with operation and maintenance planning.

This general approach to testing can be applied to all categories of innovations; however, for more specific (technical) testing guidelines and methods, BRIGAID distinguishes between innovations that are *engineered/built environment* and *technological/informational* in nature because of differences in testing and technical vocabulary used in the associated fields (see also Table 5-3). The following distinctions are made:

- *Engineered/built environment innovations* are physically implemented at a given location (although they may be temporary or semi-permanent in nature). These innovations typically reduce risk by decreasing the probability of occurrence of a hazard.

In contrast, *technological/informational* innovations reduce risk by decreasing the consequences of the hazard by enabling, or encouraging, the end-user (or stakeholders) to take action to reduce exposure or vulnerability to a hazard. The primary difference between *technological* and *informational* innovations (in the context of BRIGAID) is as follows:

- *Technological innovations* deliver hazard or risk information (i.e., warnings) to an end-user such that the end-user is prompted (or required) to take specific actions to reduce exposure or vulnerability to the hazard. The (technical) effectiveness of the innovation is dependent on the completion/performance of these actions; and

- *Informational innovations* provide information (typically continuously) in the form of maps, web services, hazard or risk indicators, etc. to stakeholders. Stakeholders have access to this information, but the decision-making process related to mitigative actions is not predetermined or required as part of the innovation prototype and are thus not included in the measure of the (technical) effectiveness (or performance/reliability) of the innovation.

In Appendix D the testing guidelines are further elaborated and their application to two examples from the categories of innovations is described.

## 5.2 Methods

### 5.2.1 Desk Study

Prior to entering BRIGAID, a desk study must be completed. The desk study consists of a description of the system and intended functionality of the innovation, followed by a qualitative assessment of the technical PI. At a minimum, the questions in Box 5-1 should be answered before proceeding to laboratory testing. The answers to the questions will help determine the location of testing and type of testing that should be undertaken in the following phases. For reusability and reliability, the questions have been divided among those that apply to engineered/built environment innovations and technological/informational innovations, respectively.

*Box 5-1 Questions used in BRIGAID about the general technical readiness of innovations*

| | |
|---|---|
| Technical Effectiveness refers to the intended capacity of the innovation to reduce risk from a specific hazard(s) | What type of hazard(s) does the innovation address (Table 1-1)? Which characteristic(s) does the innovation have (Table 1-3)? How will the innovation reduce the risk of the hazard(s)? What is the intended (quantitative) level of risk reduction? Has the innovation been tested previously and can the innovation achieve the intended level of risk reduction without failure? What is the current estimated technical readiness level (TRL) of the innovation (Table 2-1)? |
| Reusability refers to the intended use and lifetime of the innovation | *Engineered/Built Environment Innovations:* Is the innovation permanent, semi-permanent, or temporary? If the innovation is semi-permanent or temporary, what percent of the innovation needs to be replaced after each event? What are the storage requirements for the innovation? What is the expected lifetime of the innovation based on its structural components? What are the maintenance requirements for the innovation to reach its maximum lifetime? |

| | |
|---|---|
| | *Technological/Informational Innovations:* Is the innovation continuously operated or is it only operated prior to/during a hazard event? If the innovation is only operated prior to/during a hazard event, what is the intended operation (protocol) of the innovation? What is the expected lifetime of the innovation based on its components? What are the maintenance requirements for the innovation to reach its maximum lifetime? |
| Reliability refers to the likelihood that the innovation fulfills its intended functionality over its lifetime | *Engineered//Built Environment Innovations:* What are the loads that act on the innovation? What are the possible structural failure modes of the innovation? If the innovation is semi-permanent or temporary, what are the possible implementation failure modes? Which failure modes are most likely to occur or are most critical (see methods of analysis in Table 5-3)? Is there a facility where these failure modes can be tested (see Figure 5-3)? Which failure modes cannot be tested?<br><br>*Technological/Informational Innovations*: What are the inputs/outputs to the innovation? (Which inputs/outputs can be controlled by the innovator?) What are the possible technical failure modes of the innovation? If the innovation is only operated prior to/during a hazard event, what are the possible implementation failure modes? Which failure modes are most likely to occur or are most critical (see methods of analysis in Table 5-3)? Is there available historical data against which to test the innovation? During testing, will the innovation be tested in real-time? |
| Exploitability is a refers to the capacity of the innovation to be sold/deployed in other locations than originally envisioned | Where will the innovation be marketed/sold? What is the (potential) size of the market for the innovation under current climate conditions (see Appendix A)? under future climate conditions? Is the innovation made up of modular components (or, alternatively, are the innovation's components customizable)? Does the innovation require significant adjustment to be installed in a new location/used at different sites throughout Europe? Are the material components of the innovation easily obtained within the potential market(s)? What is the material cost of the innovation? |

### 5.2.2 Example Protocols for Laboratory and Operational Testing

During Laboratory Testing, the technical PI will be evaluated under the design criteria developed by the innovator and identified in the Desk Study. The steps below could be followed for Laboratory Testing:

*Table 5-1 Example Laboratory Testing Protocol for Technical Readiness Indicators*

| Recommended Steps | Description |
|---|---|
| Step 1: Evaluate the technical effectiveness under design criteria | Based on the answers to the desk study questions about technical effectiveness (Box 5-1), identify the design criteria with which to evaluate the performance of the innovation. Here, the design criteria represent the intended hazard and (quantitative) reduction in risk (i.e., based on change in hazard probability or consequences), the reusability (i.e., based on the planned operation and maintenance), and reliability (e.g., a safety factor).<br><br>For *engineered/built environment innovations*: the technical effectiveness is measured in terms of reduction in probability of occurrence of a hazard (e.g., by reducing water levels, water volumes, temperatures, evaporation). These boundary conditions are typically expressed as a load to be resisted. Using preliminary engineering calculations, the innovator can determine a safety factor that reflects how much stronger the innovation is than the minimum required for the intended load. For example, the design of a temporary flood barrier could be able to withstand water levels up to 0.5 |

| | |
|---|---|
| | meters with a safety factor of 1.1.<br><br>For *technological/informational innovations*: the technical effectiveness is measured in terms of reduction in consequences (i.e., exposure or vulnerability) (e.g., by increasing lead time, facilitating evacuation). To measure technical effectiveness, it is necessary to collect historical hazard data or simulate hazard data using existing (predictive) models prior to testing. These data are used to validate the effectiveness of the innovation. |
| Step 2: Evaluate the reliability of the innovation under the design criteria | Based on the answers to the desk study questions about reliability (Table 5-1), draw a sketch of the system and conduct a reliability analysis (see methods in Table 5-4). (Note that more rigorous reliability analyses rely on methods that allow the innovator to identify the dominant failure modes and visualize the dependencies between failure modes.)<br><br>For *engineered/built environment Innovations*:<br>• (if applicable) for implementation vulnerability: analyze the vulnerability of the innovation to human errors or external stimuli; determine whether adjustments could be made to the innovation to reduce vulnerability to implementation error (e.g., by altering the operation and maintenance recommendations or the prototype itself) (see Figure 5-1); and<br>• for structural reliability: evaluate the stability of the innovation during operation when subjected to the design criteria (i.e., loads); determine whether adjustments should be made to the innovation prototype to increase structural reliability (see Figure 5-1).<br><br>For *technological/informational Innovations:*<br>• for inherent reliability: evaluate the performance of the innovation when subject to the design criteria (e.g., historical or simulated events from another (conventional) model) (see Table 5-5); determine whether adjustments can be made to the innovation prototype to increase inherent reliability (see Figure 5-1); and<br>• for technical reliability: analyze the vulnerability of the innovation to human error or external stimuli; determine whether adjustments could be made to the innovation prototype to reduce vulnerability to implementation error (see Figure 5-1). |
| Step 3: Evaluate the reusability under the design criteria | Evaluate whether the reusability estimated during the Desk Study (Table 5-1) holds under the design criteria. (For example, for a temporary flood barrier, is the innovation estimated to be reusable after each hazard event still hold?) If not, determine whether to alter the innovation description, provide additional operation and maintenance requirements, or modify or further optimize the innovation prototype. If satisfied with the current design of the innovation, proceed to Operational Testing (TRL 6). |
| Step 4: Evaluate the exploitability under the design criteria | Evaluate whether the exploitability described during the Desk Study (Table 5-1) holds under the design criteria. If not, determine whether to alter modify or optimize the innovation prototype to increase the size of the market for the innovation. If satisfied with the current design of the innovation, proceed to Operational Testing (TRL 6). |

During Operational Testing, the technical PI will be (re-)evaluated under boundary conditions associated with the intended operational (or market) environment defined by the innovator or end-user and/or in real-time. The steps below could be followed for Operational Testing:

*Table 5-2 Example Operational Testing Protocol for Technical Readiness Indicators*

| Recommended Steps | Description |
|---|---|
| Step 1: Define the (intended) operational environment | For *engineered/built environment innovations:* this phase requires the innovator to define the boundary conditions for the (intended) operational environment (or market) and identify a testing facility where they can be appropriately simulated (see Figure 5-3) (or a real-world environment where they occur). Note: The operational boundary conditions may be (slightly) different than the design criteria defined in the Desk Study and tested in Laboratory Testing<br><br>For *technological/informational Innovations:* Depending on how technical effectiveness will be measured, it may be necessary to collect historical (or simulated) data prior to testing, it may be necessary to collect historical data for a particular location where the innovation will be marketed or deployed. The performance of the innovation could also be evaluated in real-time. |
| Step 2: Evaluate the technical effectiveness of the innovation under operational conditions | For *engineered/built environment innovations*: detailed assessments and engineering calculations are made to evaluate whether the innovation can withstand the loads associated with the operational environment. For example, a temporary flood barrier could be designed to withstand water levels up to 0.5 meter during laboratory testing; however, in the intended operational environment the water levels reach up to 0.6 meters and there will be wave impacts, causing the safety factor to reduce. A safety factor below 1.0 results in instability for the considered load and requires the innovator to make changes to the innovation or consider another operational environment. (Refer to the maps of European hazards provided in Appendix A.)<br><br>For *technological/informational innovations:* If the operational environment (or end-user) is known, the effectiveness ($E_w$) of the innovation can be measured as a function of the overall risk without the innovation in place (R) and the risk with the innovation in place ($R^{(w)}$) (i.e., $E_w = 1- R^{(w)}/R$) |
| Step 3: Evaluate reliability under operational conditions | For *engineered/built environment Innovations*: repeat the tests performed in the previous phase under the new boundary conditions;<br>• for structural reliability: evaluate the stability of the innovation during operation; quantify the reliability using a safety factor or probability of failure; evaluate whether the reliability is sufficient (e.g., determine whether adjustments should be made to the innovation prototype to increase structural reliability (see Figure 5-2); and<br>• (if applicable) for implementation reliability: analyze the vulnerability of the innovation to human errors or external stimuli in the operational environment (e.g., weather conditions); quantify the reliability using the probability of failure; determine whether adjustments need to be made to the innovation to reduce vulnerability to implementation error (e.g., by altering the operation and maintenance recommendations or the prototype itself) (see Figure 5-2).<br><br>For *technological/informational Innovations:* repeat the tests performed in the previous phase using the new data or in real-time;<br>• for inherent reliability: evaluate the performance of the innovation in the operational environment (e.g., historical or simulated events from another (conventional) model for the (intended) operational environment) or in real-time (see Table 5-5); determine whether adjustments should be made to the innovation prototype to increase inherent reliability (see Figure 5-2); calculate the inherent reliability; and |

- for technical reliability: analyze the vulnerability of the innovation to human error or external stimuli in the operational environment; determine whether adjustments could be made to the innovation prototype to reduce vulnerability to implementation error (see Figure 5-2); calculate the technical reliability.

| | |
|---|---|
| Step 4: Check that the reusability established in laboratory testing still holds for the operational conditions | Evaluate whether the reusability estimated during Laboratory Testing still holds in the operational environment. If not, determine whether to alter the innovation description, provide additional operation and maintenance requirements, or modify or further optimize the innovation prototype. If satisfied with the test results and current innovation design, proceed to full scale deployment (TRL 9). |
| Step 5: Check that the exploitability established in laboratory testing still holds for the operational conditions | Evaluate whether the exploitability estimated during Laboratory Testing still holds in the operational environment. If not, determine whether to alter modify or optimize the innovation prototype to increase the size of the market for the innovation. If satisfied with the test results and current innovation design, proceed to full scale deployment (TRL 9). |

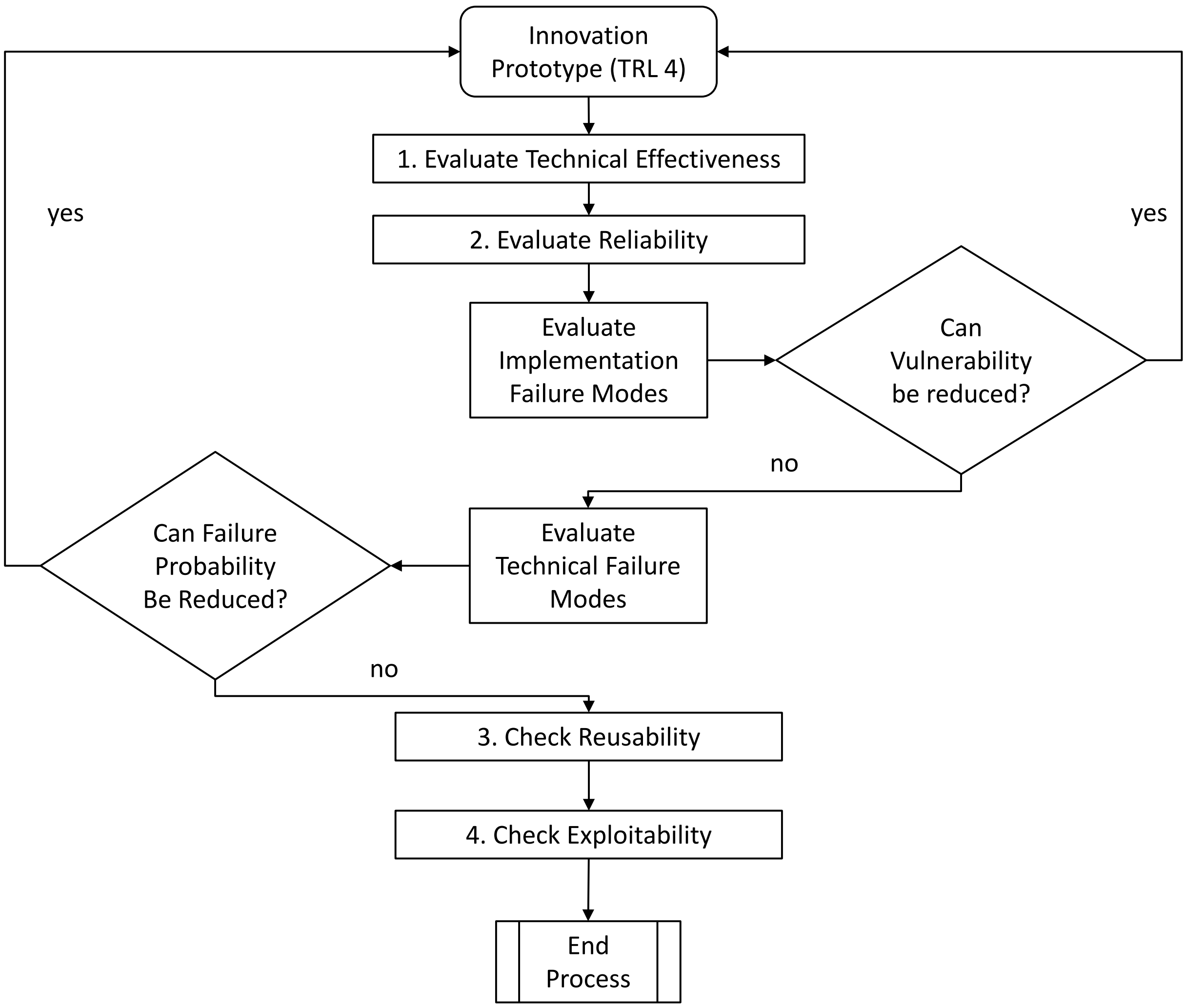



*Figure 5-1 Overview of iterative process introduced in laboratory testing.*

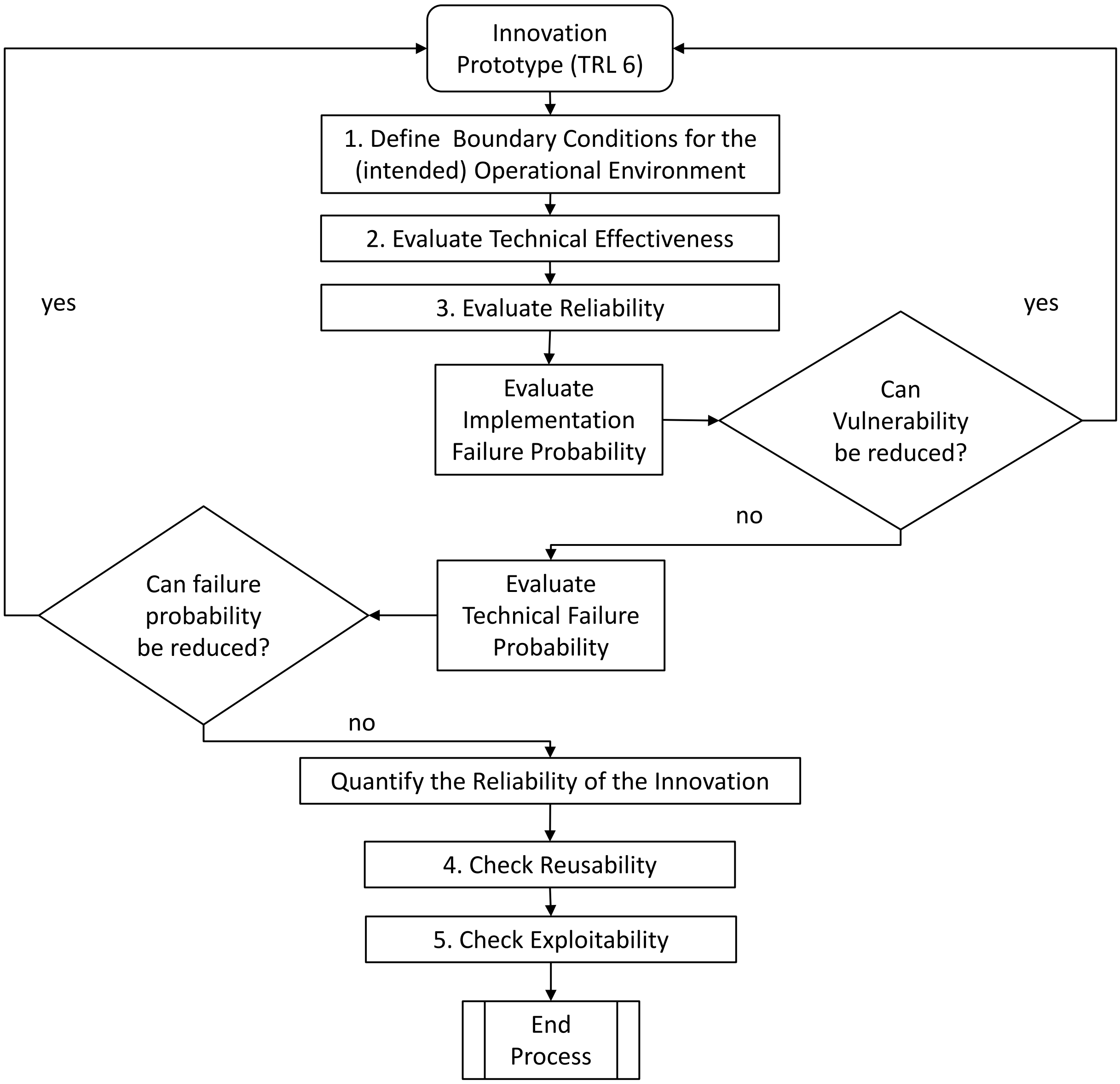



*Figure 5-2 Overview of iterative process introduced in operational testing.*

### 5.2.3 Methods Toolbox

To (qualitatively) evaluate reliability, the innovator should sketch the system (or process) and identify potential failure modes of the system (or process) (Step 2 Table 5-2). During Laboratory Testing, it is important to (at a minimum) identify and test the governing failure modes, but also to analyze and understand how different failures may interact, how cascading failures occur, or what can lead to catastrophic failure of the innovation. Table 5-4 provides a selected list of analytical methods that an innovator can apply for these steps.

*Table 5-3 Selected analytical methods to (qualitatively) analyze reliability (step 2 in Laboratory testing)*

| Method | Brief Description | Typical Strengths | Typical Weaknesses |
|---|---|---|---|
| Event Tree Analysis (ETA) | Deductive, top-down method to relates one event to all possible outcomes (i.e., failure or success) | Graphical; dependencies between sub-failure modes explicit | |
| Fault Tree Analysis (FTA) | Deductive, top-down method aimed at analyzing the effects of initiating failures on a system | Graphical; dependencies between sub-failure modes explicit; high potential for evaluating cascading failures; can be used to solve for reliability quantitatively; considers external events | Focuses on a single "top event" and only on failure probability |
| Failure Modes, Effects and Criticality Analysis (FMECA) | Inductive, bottom-up analysis aimed at analyzing the effects of each potential failure mode in the system to determine its effects and classify (or rank) its severity in a table, can be used to construct a fault tree | Good for cataloguing initiating failures and local effects; good for early identification of potential failure modes | Not good for examining multiple failures or their effects at a system level; does not consider external events; failure modes may be overlooked |
| Software Failure Modes, Effects, and Criticality Analysis (SFMECA)/ Software Error Effect Analysis (SEEA) | Same as FMECA, but applied to software | Similar to FMECA | Little "bang for buck;" is not straightforward; not graphical; failure modes may be overlooked |
| Process Decision Program Chart (PDPC) | Used to identify the impact of failure, consequences of the failure, and create contingency plans to limit risks | Similar to FMECA | Doesn't rate the relative level of risk for each potential failure mode |
| Reliability block-diagram (RBD) analysis/ Dependence Diagram (DD) | Inductive, bottom-up analysis to show how component reliability contributes to the success or failure of a system using a series of blocks connected in parallel or series where each block represents a component of the system with | Graphical; dependencies between failure modes explicit; high potential for evaluating cascading failures; can be used to solve for reliability quantitatively | Does not consider external events |

| | | |
|---|---|---|
| | a given failure rate | |
| Risk Management of Large Infrastructure Projects (RISMAN) | A tool to assist the innovator in identifying risks and what mitigation measures can be taken to reduce risks | Designed for big infrastructure projects, but also applicable to systems or processes |
| Risk Assessment Matrix (RAM) | A tool to help the innovator determine which risks to develop a response for/to mitigate based on their likelihood of occurrence and impact | Graphical |

To calculate reliability (Step 4 in Table 5-3), there are many different methods available to the innovator. Table 5-5 provides an overview of some of the most popular approaches and a list of typical strengths and weakness of each.

*Table 5-4 Selected methods to quantitatively calculate reliability of the innovation (step 3 in Operational testing)*

| Method | Brief Description | Typical Strengths | Typical Weaknesses |
|---|---|---|---|
| Engineering Calculation (Safety Factors) | Calculating the resistance of innovations to specific loads, for specific failure mechanisms and expressing the resistance in a dimensionless safety factor | Insight in the ratio of the resistance of the innovation for the considered load; simple | Deterministic, does not provide a probability of failure |
| Calibration/Validation Value (e.g., R2/NSE) | Comparison of the performance of a technological/informational system against available data; R2 value or NSE value | Applied to technological/informational innovations | Does not consider false alarms |
| POD/PFA | Applied to measure the inherent reliability of early warning systems | Good for technological/ informational innovations | |
| Monte Carlo simulation | Simulation of a large number of random events to compute a probability of failure | stochastic, provides a probability of failure | Requires insight in pdf of all variables; complex |
| Bayesian Networks | | | |
| Human Reliability Analyses using Rasmussen | To estimate human error probabilities based on performance levels of human behavior(i.e., implementation reliability) | Simple, pragmatic approach that gives insight in order of probabilities | Easy to over or underestimate probabilities |

## 5.3 Testing Facilities in Europe

Figure 5-3 shows the location of testing facilities in Europe that are associated with BRIGAID. Following versions of the TIF will include a description of the testing facilities shown; including what can be tested at different locations.

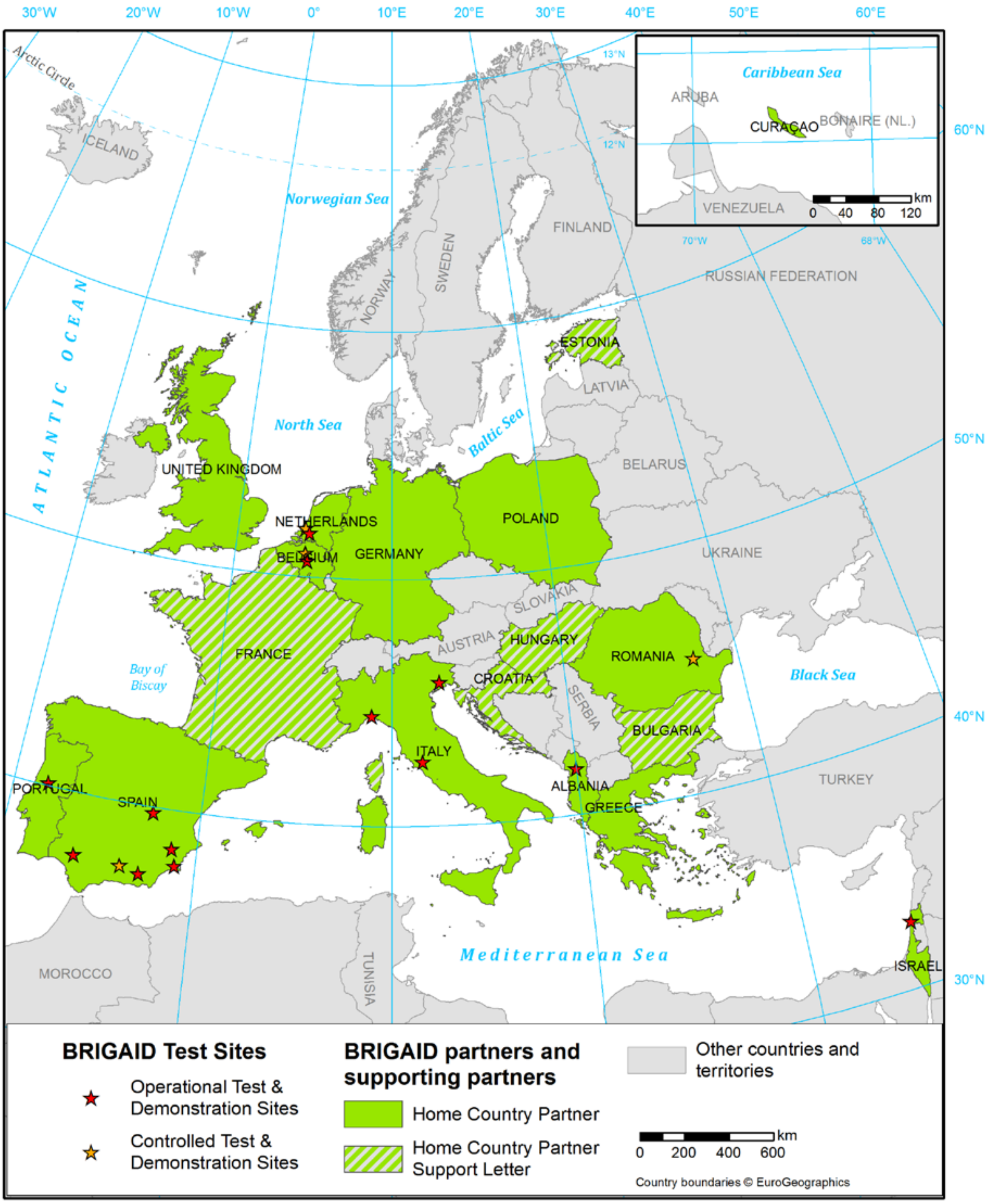



*Figure 5-3 Location of potential testing facilities in Europe that are connected to BRIGAID. Note: This is not a comprehensive list and more locations will be added as they become available.*

## 5.4 Example

In this section, a desk study is performed for a theoretical Temporary Flood Barrier (TFB). The desk study and subsequent steps for testing the TFB in a laboratory and operational environment are elaborated in more detail in Appendix D.

### 5.3.1 System and Functionality Description of a Temporary Flood Barrier (TFB)

A TFB is designed to temporarily retain water levels to prevent flooding of the area behind the barrier. The TFB is placed prior to arrival of a flood and is removed (completely) after the flood has passed. It is made of one or more flexible canvas tubes that obtain their stability through self-weight when filled with water (see Figure 5-4).

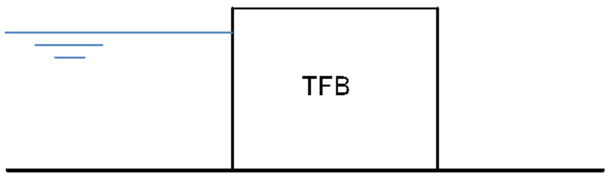



*Figure 5-4 Schematic cross section of a theoretical Temporary Flood Barrier (TFB) (left) and a picture of a TFB (right) (source: www.tubebarrier.com)*

The following steps need to be successfully completed for the TFB to function as intended:

1. transport to implementation location;
2. implementation/installation on site;
3. anchoring to the subsoil; and
4. filling with water.

### 5.3.2 Qualitative Description of Technical PI for a TFB

Below, the results of the qualitative desk study for each technical performance indicator are described:

- **Technical Effectiveness**: the risk reduction capacity of a TFB is expressed as a water level (e.g., 0.5 meter) and wave height (e.g., 0.2 meter) that the structure is able to resist.
- **Reusability**: by definition, a TFB is a temporary innovation because the whole innovation has to be implemented prior to arrival of the flood. It is estimated that after each use minor repairs (< 10%) may be required; such repairs could include patching a rip in the canvas material or refilling tubes with water. The technical lifetime of the water-filled tubes depend on the canvas material; in this case, assuming this is some kind of plastic/vinyl material, a technical lifetime of 10 years is estimated.
- **Reliability**: the water-filled tubes must be implemented prior to arrival of a flood. To assess the reliability of the innovation, both implementation and structural failure are qualitatively assessed using fault tree analysis:

a. *Implementation failure* can occur due to logistical issues during transport of the innovation to the location, (human) errors during installation, or equipment failure. For water-filled tubes, logistical issues can occur due to the unfamiliarity with the location where the tubes are installed or obstruction of the location. The installation of the tubes is fairly easy as no real complex operations are required, however, installation does depend on human error. Filling of the tube is dependent on the presence and correct functioning of certain equipment (e.g., a pump to fill the tube with water).

b. *Structural failure* could occur due to instability of the tube (e.g., due to sliding or turning over), ruptures of the material, or seepage/leakage of water under the tube. The stability of the structure depends highly on the subsoil upon which it is placed (i.e., operational environment). Considering that these structures are gravity structures, structural failure modes that are most likely to occur are: 1) sliding failure, 2) rotational failure and 3) failure due to seepage. For example, placement on clay/peat material can result in horizontal sliding because of insufficient friction. In comparison, placement on sand can result in significant seepage/leakage under the tube.

- **Exploitability**: considering the hazard (floods), risk reduction capacity and expected reliability, TFB's can be applied at a large number of locations throughout Europe. The exploitability highly depends on the availability and cost of the canvas material. The innovation is highly modular, because it consists of small sections of several meters.

### 5.3.3 Identifying Failure Modes of a TFB and Constructing a Fault Tree

Using the qualitative description in Section 5.3.2, the following failure modes for implementation and structural failure of the temporary flood barrier have been identified and included in the fault tree  in Figure 5-5:

| Failure mode | Sub Failure Mode | Description | Ranking |
|---|---|---|---|
| Implementation failure | Insufficient time | failure to implement the tubes due to insufficient time for transport and implementation/installation of the tube at the operational site | 2 |
| | Equipment failure | forgetting to bring the necessary equipment for implementation or failure of the equipment (e.g., pump breakdown) | 4 |
| | Obstruction | the tubes cannot be implemented due to obstructions on site (e.g., cars or trees) | 5 |
| | Human error | failure to implement the tubes correctly due to human error | 1 |
| Structural failure | Overflowing/ overtopping | water overflowing the tube | 6 |
| | Instability | rotational instability (toppling over), horizontal instability (sliding) or vertical instability (settlements) | 3 |
| | Seepage/ leakage/ piping | seepage flow under the tube may cause a leakage and/or backwards erosion and ultimately failure due to instability | 7 |
| | Structural failure | ruptures of the canvas/vinyl material due to insufficient bending resistance or stiffness of the materials used, or due to impact loads (e.g., debris) | 8 |

Considering the likelihood (or ranking) of failure modes, the governing failure modes are:

- human error;
- insufficient time; and
- instability due to rotation/ sliding.

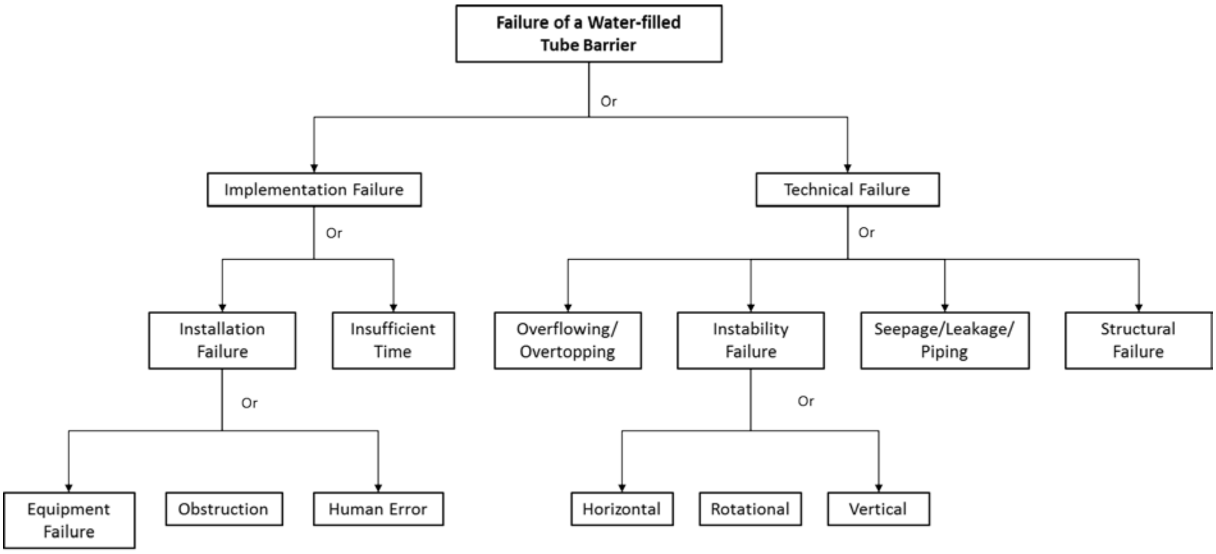



*Figure 5-5 Example fault tree for a water filled tube barrier (TFB)*

# 6 Impact Assessment Guidelines

## 6.1 Assessment

The objective of the impact assessment is to evaluate the foreseen (positive or negative) impact(s) of the innovation on the different socio-economic and environmental sectors and to aid the innovator in design optimization (e.g., by enhancing its performance or co-benefits) when desired. The following assessments associated with each of the testing phases and their corresponding TRLs (introduced in Chapter 2) are described below:

I. **Desk Study, TRL 1-3**: This phase consists of a desk study in which the innovation, its functionality, and Performance Indicators (PI) are qualitatively analyzed. This qualitative assessment may be guided by the innovation questionnaires (see Appendix B) and is intended to act as an initial screening (e.g., ++/+/0/-/--) of the potential impact of the innovation on each sector (even if the final implementation location is still unknown). The desk study is intended to help the innovator determine whether additional testing or further evaluation may be needed for each sector and what (types of) activities should be considered in the development of a test plan.

II. **Laboratory Testing, TRL 4-5:** For those sectors which have impacts that should be further tested or evaluated, this phase consists of simple semi-quantitative or detailed qualitative evaluation of the PI. When necessary (or possible), detailed quantitative testing may be conducted in a laboratory environment to further evaluate the likelihood of negative impacts (e.g., performing tests to calculate emissions or pollutants released by the innovation). In this phase, the innovator may choose to optimize the design of the innovation prototype to enhance co-benefits for different sectors.

III. **Operational Testing, TRL 6-8:** This phase consists of analyzing the relevant PI in an operational environment. In this phase, detailed qualitative and quantitative evaluations of impacts are performed using available information for the foreseen operational environment or known end-user requirements. The innovator may choose to optimize the design of the innovation prototype to enhance co-benefits for a specific operational environment.

IV. **Full Scale Deployment, TRL 9+:** This phase consists of monitoring the mid- and long-term impacts of the innovation on the socio-economic and environmental sectors. Although this phase is not included within BRIGAID, suggestions for monitoring these mid- and long-term impacts are provided.

To be included within BRIGAID, an innovation must be at or above a TRL 4; however, it is presumed that most innovators have focused primarily on technical aspects during the initial development of an innovation prototype and paid little (or no) attention to potential impacts on different sectors. Therefore, the focus of the (initial) TIF is on guiding the innovator through a preliminary qualitative screening of the potential impacts during the Desk Study (TRL 1-3). For more detailed assessments of impacts during the Laboratory (TRL 4-5) and Operational (TRL 6-8) testing phases, the input of experts will likely be required.

More detailed background information, evaluation methods, and examples are provided in Appendix E of this document.

## 6.2 Methods

### 6.2.1 Preliminary Screening Questions (TRL 1-3)

It is presumed that prior to entering BRIGAID a description of the innovation is available (via the questionnaire), including, for example, detailed information about the dimensions of the innovation (i.e., footprint), construction materials and chemical characteristics, and the physical (e.g., space) and environmental alterations that will be necessary to implement the innovation. To determine whether an innovation will directly impact socio-economic sectors and the environment, a number of questions are proposed to help the innovator perform an preliminary screening (Box 6-1). The answers to these questions will help the innovator assess whether further (qualitive or quantitative) analysis is needed in the laboratory or operational environment. When no direct or indirect impacts are foreseen, then there is no need for a detailed impact assessment.

When answering these questions, it is important to keep in mind that the impact of innovations on different sectors may be:

- **positive** or **negative**;
- **direct** (effects that are caused by the preparation, construction or operation of an innovation at a particular location) or **indirect** (effects that occur away from the immediate location or time of implementation the innovation, or as a consequence of the operation of the innovation);
- **temporary** or **permanent**;

In addition, temporary impacts may last over the **short term** or **long term**.

*Box 6-1 Preliminary Screening Questions*

Does the physical implementation of the innovation (or the actions induced by the operation of the innovation) have direct or indirect impact(s) (positive or negative) on the energy sector, forestry sector, nature/ecology or environment, agriculture, health situation, infrastructure (including transport), or tourism sectors?

If yes, fill in the Impact Assessment Framework qualitatively (Table 6-1):

- Is the foreseen impact positive or negative?
    - If negative, explore whether adjustments can be made to minimize the impact(s) or whether re-designing the innovation prototype could reduce the negative impact(s); if negative impacts cannot be reduced, determine whether to proceed with the current prototype while quantifying the impacts (e.g., Figure 6-1 for environmental impacts);
    - If positive, determine whether it is possible to further induce positive impacts by improving the design of the prototype or proceed to the following question.
- Are there foreseen tensions with existing legislation on nature/ecology, the environment, or other sectors?
    - If yes, then try to quantify this impact with the help of experts (see Section 6.2.3 and Appendix E);
    - If no, then proceed to the following question.
- Can the (positive or negative) impacts be monetized the with help of experts (see Table 6-2)?
- Can laboratory testing provide additional information about these impacts (e.g., volume of chemical release)?

If no, then there is no need to fill in the Impact Assessment Framework.

As part of the impact assessment, BRIGAID will also provide guidelines for considering socio-economic and environmental issues that may arise during innovation. These guidelines are intended to reduce uncertainty in relation to what needs to be documented to meet legal requirements, enable dialogues and build mutual understanding between stakeholders (e.g., innovators, end-users and policymakers), and stimulate long-term and large-scale perspectives on climate adaptation strategies and measures. A typical decision tree for a determining whether or not an environmental impact assessment should be performed is provided in Figure 6-1.

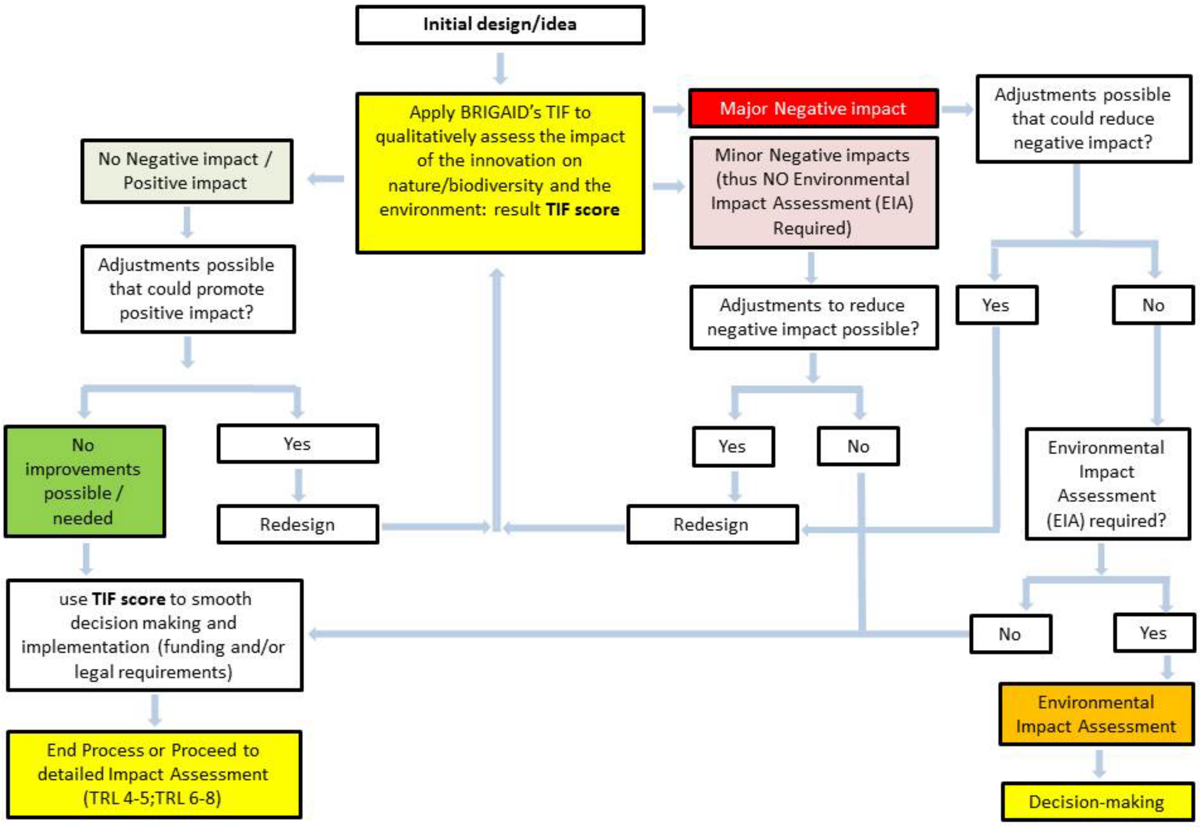



*Figure 6-1 Example decision tree to evaluate whether there are foreseen impacts on nature/ecology or the environment*

### 6.2.2 Impact Assessment Framework (TRL 4-5)

If, during preliminary screening, the innovator foresees that the innovation will have an impact on a given sector, the next step will be to qualitatively fill in the Impact Assessment Framework for that sector (see Table 6-1). Both symbols (e.g., ++, +, 0, - , --) and colors are used to present the outcomes in a clear and accessible way. Depending on the results for each indicator, the innovator may then choose to optimize the design of his innovation prototype to reduce negative impacts or increase co-benefits in different sectors.

It is important to note that the exploitability of the innovation in the European market will be highly dependent on whether the innovation has foreseen impacts at different locations. Because the current situation at a given location forms the reference situation for determining whether the innovation will have an impact on a given sector, a detailed description of the current situation in the intended operational (or market) environment is very important for the impact assessment. A discussion with local experts and/or stakeholders to determine the current situtation would be valuable for the completion of the impact assessment in this phase.

After filling in a score for each performance indicator (PI), a total score (T) for each sector can be calculated as a weighted average of the relevant performance indicators. To do so, a indicator function must be defined to combine the multiple indicators per sector. The chosen indicator function translates the ordinal scale to a linear range around zero. The overall performance of the innovation strongly depends on the weights assigned to each sector and for each indicator. A review of policy documents and discussion with local experts and stakeholders within a given market can help to assign weights to the sectors and criteria. When no differences in weights are foreseen between the sectors or indicators, then a weight of 1 is recommended.

Box 6-2 provides some helpful desk study questions to assist the innovator in qualitatively filling in the Impact Assessment Framework. In Boxes 6-3, 6-4, and 6-5 portions of the framework are applied to some example innovations.

### 6.2.3 Operational Testing (TRL 6-8)

After completing the impact assessment and any necessary laboratory testing, a next step would be to analyze the physical impact of the innovation during and after implementation in an operational environment (i.e., *ex-post* assessment) (TRL 6-8). Such an analysis (by experts) begins with a detailed analysis of the current situation, which forms the reference situation, and follows with a quantitative analysis of the impact of the innovation on the performance indicators for each of the relevant socio-economic and environmental sectors. In this phase, mid- and long-term impact monitoring (by experts) is recommended, and may continue beyond the length of the testing cycle within BRIGAID.

*Table 6-1 Preliminary Impact Assessment Framework (TRL 4-5)*

| Sector | Performance Indicator (PI) | Description of Current Situation (at a specific location)* | Impact of Innovative Measures | | | | | Score |
|---|---|---|---|---|---|---|---|---|
| | | | Direct/ Indirect | Temporary/ Permanent | Short/ Long term | Probability | Reversibility | |
| Energy | $CO_2$ footprint of the preparation and construction of the innovation | | | | | | | |
| | Energy consumption = $CO_2$ footprint of operation (after implementation) | | | | | | | |
| | Energy efficiency | | | | | | | |
| | Monetized effects | | | | | | | |
| | *Total Score (T)* | | | | | | | |
| Forestry | Capacity maintenance of: | | | | | | | |
| | *- Wood production (includes timber and biomass);* | | | | | | | |
| | *- Non-wood production (includes cork, fruits, honey, mushrooms, pastures, game and fishing);* | | | | | | | |
| | *- Protection (includes forest areas for protection of coastal line, desertification, river basins, biodiversity)* | | | | | | | |
| | Risk (change in the vulnerability to wildfires, windstorms, pests and diseases) | | | | | | | |
| | Monetized effects | | | | | | | |
| | *Total Score (T)* | | | | | | | |
| Nature / Ecology | Quality and Quantity Habitats | | | | | | | |
| | Natura 2000 (or otherwise protected) species: | | | | | | | |
| | *- Birds* | | | | | | | |
| | *- Vegetation* | | | | | | | |
| | *- Fish* | | | | | | | |
| | *- Mammals* | | | | | | | |
| | *- Other animals* | | | | | | | |
| | Quality and Quantity Soil Fauna | | | | | | | |
| | Monetized effects | | | | | | | |
| Total Score (T) | | | | | | | | |
| Environment | Surface Water Quality and Quantity | | | | | | | |
| | Ground Water Quality and Quantity | | | | | | | |
| | Sea Water Quality | | | | | | | |

| | | | | |
|---|---|---|---|---|
| | Soil Quality | | | |
| | Air Quality | | | |
| | Landscape Quality | | | |
| | Monetized effects | | | |
| | | | *Total Score (T)* | |
| Agriculture | Quality and Quantity of areal for sustainable agricultural production | | | |
| | Water availability for agricultural production | | | |
| | Type of crops and yield | | | |
| | Monetized effects | | | |
| | | | *Total Score (T)* | |
| Health | Deaths | | | |
| | People affected in their health | | | |
| | Monetized effects | | | |
| | | | *Total Score (T)* | |
| Infrastructure | Build infrastructure | | | |
| | *- Residential housing* | | | |
| | *- Urbanization pattern* | | | |
| | *- Commercial/industry* | | | |
| | Networks | | | |
| | *- Roads* | | | |
| | *- Railways* | | | |
| | *- Rivers/Ports* | | | |
| | *- Communication networks* | | | |
| | *- Water supply network* | | | |
| | *- Energy Networks* | | | |
| | Monetized effects | | | |
| | | | *Total Score (T)* | |
| Tourism | Quantity of recreational area | | | |
| | Duration of season | | | |
| | Attractiveness of area | | | |
| | Monetized effects | | | |
| | | | *Total Score (T)* | |

| | | | |
|---|---|---|---|
| * | Current situation forms the Reference Situation | - | worse than reference situation |
| ++ | much better than reference situation/current situation | -- | much worse than reference situation |
| + | better than reference situation | +/- 0/+ 0/- | impact (better or worse than reference situation) depends on local situation |
| 0 | no impact (comparable to reference situation) | --/++ | potential huge impact (better or worse), however, this depends on local situation |

*Box 6-2 Helpful questions to fill in the Impact Assessment Framework (TRL 4-5)*

- **Energy**: Can the changes/losses be monetized?
- **Forestry**: What is the area and tree species (in case of wood production) or product (in case of non-wood production) affected by the innovation? Is the impact Direct or Indirect? Is the impact Positive, Negative or Neutral? Is the impact Temporary or permanent? Has it effects on the Short (during construction), Medium, or Long term (during exploitation or after)? Does you innovation affects the vulnerability of the forest to any of these risks (wildfire/windstorm/pests and diseases)? Can the changes/losses be monetized?
- **Nature/Ecology:** What type of habitat is present on the foreseen location? (e.g. Cropland and grassland, Woodland and forest, Heathland and shrub, Sparsely vegetated land, Wetlands, Rivers and lakes, Marine, Urban, Mountains, Islands)? Does the innovation reduce or change the present areal of this habitat? Is the foreseen location protected, or does it have a special status? Does the innovation affect protected species (birds, vegetation, fish, mammals or other animals)? Does the innovation affect the soil flora and fauna present? Is the ecosystem approach applicable?
- **Environment:** Does the innovation produce pollutants (including excessive nutrients) that affect the quality of the surface water (e.g. eutrophication), ground water, sea water, the chemical soil quality, or the air quality? Does the innovation buffer or streamline extreme discharges? Does the innovation affect drainage patterns/capacity (e.g. buffer or streamline extreme discharges)? Does the innovation increase the water retention capacity at the foreseen location (or at connected locations)? Does the innovation improve the quality of the landscape? (e.g. by restoring nature, or conservation of cultural elements) Can the changes/losses be monetized?
- **Agriculture:** What type of agriculture is present on the foreseen location? Does the innovation reduce or change the present agricultural area? Does the innovation increase local conditions for agricultural production? Does the innovation favour the harvesting? Does the innovation affect water availability during dry periods (e.g. irrigation, water retention)? Does the innovation prevent inundation or stimulate drainage during extreme rainfall? Does the innovation produce pollutants (including excessive nutrients) that affect the quality of the surface water (e.g. eutrophication), ground water, or soil quality? Can the changes/losses be monetized?
- **Health:** What is the size of the population that is affected by the innovation? How does the innovation affect the population (preventing climate event, reducing exposure, reducing vulnerability)? Which health impacts can be prevented, and by which mechanism? Does the innovation produce pollutants? Does the innovation use chemical compounds that are harmful to humans? Does the innovation increase the risk of accidents / injuries (e.g. due to a slippery surface)?
  Can the changes/losses be monetized? Can the changes/losses be monetized?
- **Infrastructure:** Does the innovation (directly or indirectly) improve the transportation network by reducing its susceptibility to damage from climate events? (e.g., permeable pavement,); Does the innovation reduce the need for maintenance? Does the innovation increase the reliability of the transportation network? Can the changes/losses be monetized?
- **Tourism:** Does the innovation create or enhance recreational space which may benefit tourism? Can the changes/losses be monetized?

*Box 6-3: Example Impact Assessment of a Wide Green Dike (Hybrid Solution) on Nature/Ecology, Environment, and Agriculture Sectors*

In the Netherlands most coastal dikes along the Wadden Sea have a seaward slope of 1:4 and a stone or asphalt revetment along the dike toe (even when salt marshes are present). A Wide Green Dike (as present along the German Wadden Sea coast), on the other hand, has a grass-covered gently sloped seaward face, that merges smoothly into the adjacent salt marshes. As part of the Wadden Sea Delta program, the potential costs and benefits of just such a 'Wide Green Dike', were compared to the 'Traditional Dike' (Van Loon-Steensma & Schelfhout, 2017*).* A photograph is shown in Box 6-6.

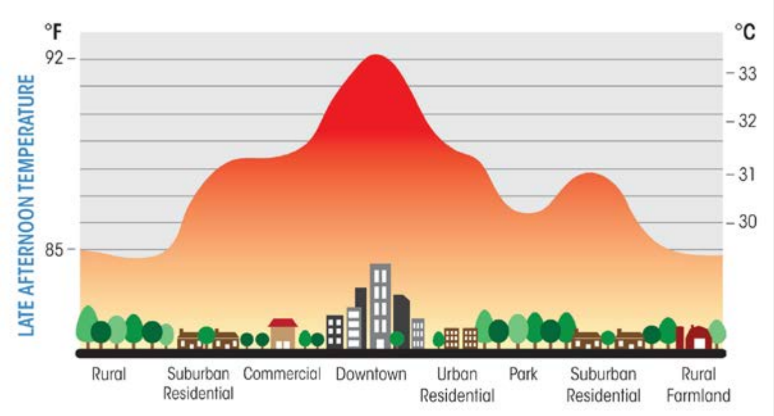
| Sector | Indicator | Impact of Innovative Measures | Score |
|---|---|---|---|
| Nature/Ecology | Quality and Quantity Habitats | A Wide Green Dike provides no valuable grass or herb vegetation, but it does offer more space for grass vegetation and forbs than an asphalt-covered dike. Constructing a Wide Green Dike along the Dutch Dollard would lead to a loss of an additional 11 ha of salt marsh compared to a Traditional Dike. | - |
| | Natura 2000 (or otherwise protected) species: | | |
| | *Birds* | No substantial impact on feeding, breeding and refuge area. However, the mining of clay from the adjacent salt marshes could affect the bird feeding, breeding and refuge area. | 0 |
| | *Vegetation* | The natural marsh vegetation from the higher salt-marsh zones would probably grow in the lower zone of the dike, which merges into the adjacent salt marsh. However, construction of a Wide Green Dike would negatively affect the present salt-marsh vegetation. | - |
| | *Fish* | Unknown. | |
| | *Seals* | No difference, as seals normally do not use the zone close to the dike. | 0 |
| | *Other animals* | unknown. | |
| | Quality and Quantity Soil Fauna | better, because no asphalt present | + |
| | | *Total Score (T)* | -1 |
| Environment | Surface Water Quality and Quantity | not foreseen | 0 |
| | Ground Water Quality and Quantity | no | 0 |
| | Sea Water Quality | no | 0 |
| | Soil Quality | no asphalt on seaward face | + |
| | Air Quality | no | 0 |
| | Landscape Quality | The Wide Green Dike blends in better with the Wadden Sea landscape. | ++ |
| | | *Total Score (T)* | +3 |
| Agriculture | Area for sustainable agricultural production | Potentially more grazing area for sheep. | + |
| | Agricultural production | No difference. | 0 |
| | Monetized effects | Unknown. | |
| | | *Total Score (T)* | +1 |

| | | | |
|---|---|---|---|
| * | Reference Situation | - | worse than reference situation |
| ++ | much better than reference situation/current situation | -- | much worse than reference situation |
| + | better than reference situation | +/- 0/+ 0/- | impact (better or worse than reference situation) depends on local situation |
| 0 | no impact (comparable to reference | --/++ | potential huge impact (better or worse), |

*Box 6-4: Example Impact Assessment of "Green in the city as a climate buffer against heat stress" on the Health Sector*

Exposure to high ambient temperatures leads to an increase in mortality, as was seen by the heatwave that affected Europe in 2003 and caused more than 15,000 excess deaths in France alone. A study showed that for a 1 °C increase in temperature above a city-specific threshold, mortality increases by almost 2%. In addition, heatwaves lead to an increase in hospital admissions and an increase in symptoms in general, especially among the elderly. Around 50% of elderly people perceive their indoor environment as too warm during a heatwave, and there is a strong relationship between high outdoor and high indoor temperatures.

Due to the urban heat island effect, temperatures are usually several degrees Celsius higher in cities than in rural areas, even when they experience the same climate. Within cities, temperature differences between areas are caused by differences in building density and levels of vegetation. One way to reduce the urban heat island effect in a city area is by increasing the amount of trees and vegetation. In this example, the amount of vegetation in a city center (with a population of ± 1000 individuals) is increased, due to which the temperature extremes during the summer period are reduced by 2 °C.

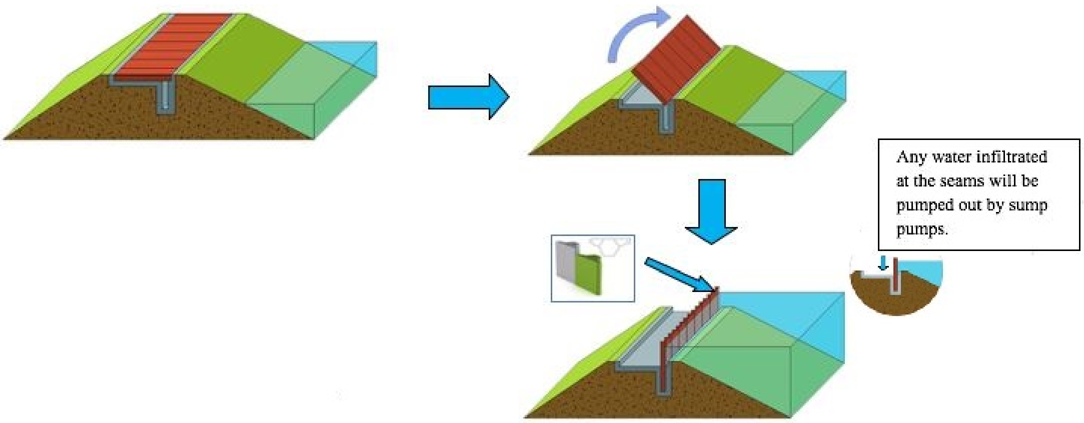



| Sector | Indicator | Impact of Innovative Measures | Score |
|---|---|---|---|
| Health | Deaths | Due to the relatively small population that is covered, the reduction in the number of deaths do to extreme heat will not be massive. However, in the long term (over several years), there will be a reduction in the number of people who died. | + |
| | People affected in their health | As seen above, around 50% of elderly people experience symptoms during a heatwave. By lowering the temperature to which they are exposed, the number of symptoms will decline significantly | ++ |
| | Monetized effects | Although it's difficult to estimate the monetized effects, there might be a positive effect due to a reduced demand in health care. | + |

| | |
|---|---|
| * | Current situation forms the Reference Situation |
| ++ | much better than reference situation/current situation |
| + | better than reference situation |
| 0 | no impact (comparable to reference situation) |
| - | worse than reference situation |
| -- | much worse than reference situation |
| +/- 0/+ 0/- | impact (better or worse than reference situation) depends on local situation |
| --/++ | potential huge impact (better or worse), however, this depends on local situation |

*Box 6-5: Example Impact Assessment of the "Flip Flap Cofferdam" on the Infrastructure Sector*

Due to climate change, the frequency and intensity of river floods have increased throughout Europe. The Flip Flap Dam is designed to prevent river flooding in urban areas (see Appendix C). It is intended to be implemented in large river basins where the flood wave is known in advance. When not in operation, the Flip Flap Cofferdam will be used as boardwalk for pedestrian and/or bicycle traffic. In the table below, a preliminary assessment of the impact of the Flip Flap Cofferdam on the Infrastructure sector is provided.




| Sector | Indicator | Impact of Innovative Measures | Score |
|---|---|---|---|
| Infrastructure | Build Infrastructure | Depending on the altitude of the buildings as compared to the level of the river there could be considerable damage prevention to the building infrastructure | ++ |
| | Networks | The road, railway as well as electrical and communication networks should benefit considerably from lack of damages due to flooding. | ++ |
| | Monetized effects | There should be a positive effect due to reduced damages done by flooding. | ++ |

| | |
|---|---|
| * | Current situation forms the Reference Situation |
| ++ | much better than reference situation/current situation |
| + | better than reference situation |
| 0 | no impact (comparable to reference situation) |
| - | worse than reference situation |
| -- | much worse than reference situation |
| +/- 0/+ 0/- | impact (better or worse than reference situation) depends on local situation |
| --/++ | potential huge impact (better or worse), however, this depends on local situation |

### 6.2.3 Methods for (Quantitatively) Evaluating Monetized Effects

There are many methods available to assess impacts quantitatively, i.e., based on costs (or benefits, in case of positive costs). Although some methods are only applicable for specific sectors, most evaluation methods and techniques can be generically applied. The majority, however, require primary data and/or secondary data collection and, therefore, also require the assistance of experts.

Within BRIGAID we provide an overview of applicable cost assessment methods to calculate the monetized impactions of innovations on different sectors. Here, three cost categories are considered:

1. **Direct costs** are costs or benefits to the socio-economic sectors or to the environment due to direct physical implementation (preparation, construction or operations in a particular location).

2. **Indirect costs** are costs or benefits induced by either direct costs or benefits or interruption of the socio-economic sectors. They can occur away from the immediate location or timing of the proposed action, or as a consequence of the operation of the innovative measure. These losses include, for example, include production losses of suppliers and customers of companies directly affected by the implementation of the measure.

3. **Intangible costs** refer to costs and benefits for goods and services that are not measurable (or at least not easily measurable) in monetary terms because they are not traded on a market.

Some cost-estimate methods can be regarded as a mixture of these categories. For example, the Ecosystem Services Approach is based on the idea that nature offers – besides its intrinsic value – a broad range of benefits for human beings (i.e., ecosystem services) (Figure 6-2) (Millenium Ecosystem Assessment, 2005). For example, nature can help mitigate climate change by provide a natural buffer against extreme events. Therefore, protecting and restoring ecosystems can help to reduce the extent of climate change and to cope with its impacts, and may therefore have a monetary value (European Commission, 2016a). Adaptation measures that deliberately use ecosystems and the services they provide are called Nature-based Solutions (NbS). Some of their benefits can be monetized, while other impacts are intangible.

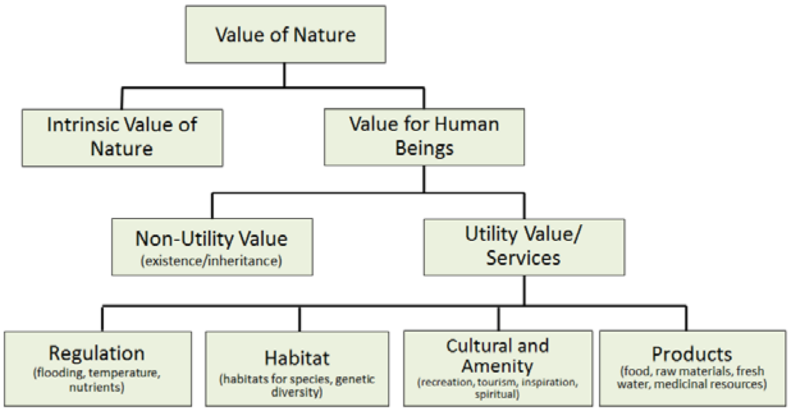



*Figure 6-2 Value of nature for human beings (adapted from the Millennium Ecosystem Assessment (2005))*

It is important to keep in mind that whether or not an innovation has an impact on a given sector is highly dependent on the severity and duration of the hazard event together with the exposure, vulnerability, and resilience of the socio-economic or environmental sector and its sub-indicators. Meyer et al. (2013) indicate that in practice the evaluating monetized effects for different types of hazards is often incomplete and biased, as direct costs receive a relatively large amount of attention, while intangible and indirect effects are rarely considered. Furthermore, all parts of cost assessment entail considerable uncertainties due to insufficient or highly aggregated data sources, along with a lack of knowledge about the processes leading to damage and thus the appropriate models required.

Another important constraint in the monetizing the impact of innovations is discount rates. Recent economic theory suggests that appropriate social discount rates should decline with time. There are several rationales for time-declining rates, but the most important is that the future state of the economy, and thus the appropriate future discount rate, is uncertain. This new body of theory is highly relevant to, e.g., forestry economics where time horizons are long and the discount rate plays a central role (Litman, 2006).

*Table 6-2 Preliminary[1] Selected Methods for Evaluating Monetized Effects (for more detailed information, see Appendix E)*

| Method | Brief description | Typical strengths | Typical weaknesses | References | Energy | Forestry | Nature/Ecology | Environment | Agriculture | Health | Infrastructure | Tourism |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Direct*** | | | | | | | | | | | | |
| Observations of market-based transactions, productions function | calculating the change in agricultural (or forestry) production multiplied by the market price of the agricultural product | | | Rodríguez et al. (2012); Karamanos et al. (2011); Mieczkowski (1985) | | × | | | × | | | |
| Dose-response functions | Multiplying the physical dose-response function by the price or value per unit of the impact (i.e., physical damage) to give a monetary damage function | suitable for use in instances where the relationship between change in an environmental variable and the resultant impact on a good or service can be established | It can be a costly technique to use where manipulation of large databases for physical and economic modelling is required | | | | | | × | | | |
| Cost-Benefit analysis | Compares total incremental benefits with total incremental costs | is not limited to a single objective or benefit | it is necessary to monetize (measuring in monetary units) all relevant impacts; it is important to specify the Base Case | Delucci (1996); FHWA (1997); FHWA (1998); Litman (2002) | | | | | | | × | × |
| Lifecycle Cost Analysis | | It incorporates the time value of money; allows programs or projects to be compared that have benefits and costs occurring at different times | | | | | | | | | × | × |

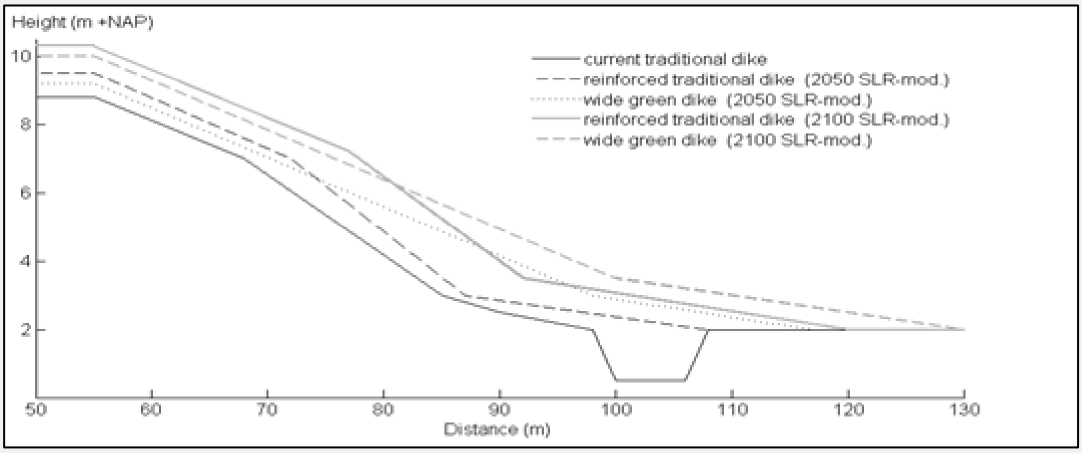
[1] These methods will be detailed further during project months 12-18.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cost-Effectiveness | | | All relevant costs need to be converted into appropriate, comparable monetary units | | | | | | | | × | × |
| ***Indirect*** | | | | | | | | | | | | |
| Derived demand functions | | because the buyer can buy as much as desired at the price schedule, it is possible to derive inferences on willingness to pay and demand | It can be costly | | | | | | × | | | |
| Benefits transfer method | to estimate benefits for one context by adapting an estimate of benefits from some other context | often used when it is too expensive and/or there too little time available to conduct a full valuation study | Can only be as accurate as the initial study | | | | | | | | | |
| Hedonic pricing | | has a sound theoretical basis and is capable of producing valid estimates of benefits; has been employed to produce reliable estimates of the values of actual environmental changes | rests on a number of stringent assumptions | | | | | | × | | | |
| Averting behavior and defensive expenditures | | it is a potentially important source of valuation estimates as it gives theoretically correct estimates that are gained from actual expenditures | can give incorrect estimates of value where they fail to incorporate the technical and behavioral alternatives | | | | | | × | | | |
| Residual imputation approach and variants | | it is most suitable for use in cases where the residual input contributes significantly to output; Calculation of residual values requires considerable information and accuracy in allocating contributions among the range of resource inputs | is extremely sensitive to small variations in assumptions concerning the nature of the production function or prices | | | | | | × | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Replacement cost/cost savings methods | | is used widely because the data required are usually readily available from actual expenditures or estimated costings | it can be criticized on the grounds that it assumes implicitly that demand will be unresponsive to changes in costs | | | | | | × | | | |
| ***Intangible*** | | | | | | | | | | | | |
| Contingent valuation method | | It can be employed to calculate both use and non-use values; it generates its own data | it is subject to biases; are costly and entail an inevitable compromise between expense and quality | | | | | | × | | | |
| Contingent ranking and conjoint analysis | | | The task of arriving at a complete ranking is very difficult | | | | | | × | | | |
| Multiple Accounts Evaluation | | It is considered easier to understand and more transparent | it tends to be less precise and more susceptible to errors such as double-counting | | | | | | | | × | × |
| Disability Adjusted Life Years (DALYs) | | | | | | | | | | × | | |
| Quality Adjusted Life Years (QALYs) | | | | | | | | | | × | | |
| Ecosystem Service Approach | Method to evaluate the services that nature provides for human beings | | | MEA (2005); TEEB (2010) | | × | × | × | × | × | | × |

## *Box 6-6: Example of the calculated impact of Wide Green Dikes on salt-marsh habitat*

The extra space needed for a Wide Green Dike compared with a Traditional Dike can be calculated based on the required dike profile (Van Loon-Steensma and Schelfhout, 2017). This extra space will come on the account of the adjacent salt marsh. A Wide Green Dike has thus a larger areal footprint, and would overlap more of the Natura 2000 area than a Traditional Dike. Although construction of a Wide Green Dike would certainly disturb the present salt-marsh vegetation, the lower zone of the dike, which merges into the adjacent salt marsh, would probably be settled by species from the higher salt-marsh zones within a few years. This zone is covered by asphalt for a Traditional Dike. A detailed survey of the present salt-marsh vegetation and of the grass cover of the dike, and monitoring of the changes, would provide more insight in the impact on biodiversity on the mid- and long-term.



# 7 Social Testing Guidelines

Innovations can fail for not attending to societal concerns just as much as for not attending to technical ones. An innovation might be technically effective, reusable and reliable, for instance, but at the same time be completely unacceptable to society for its psychological impacts, resistance to desirable changes, incompatibility with societal values, inattention to user needs and controversial origins. The purpose of these societal testing guidelines is to help innovators think about how they might ensure that their innovations are acceptable to different publics: stakeholders who may not directly procure or operate an innovation but nevertheless benefit (or suffer) from its effects. For help on how to make innovations marketable to direct users, innovators should consult the Market Analysis Framework (MAF+). By using the guidelines laid out in this chapter of the Test and Implementation Framework (TIF), innovators will be in a position to assess their *societal readiness*: the condition of preparing an innovation for a favorable public reception.

This chapter is structured as follows: Section 7.1 provides an overview of the academic literature upon which the societal testing guidelines are based. Section 7.2 develops a survey instrument for innovators to self-assess the societal readiness of their innovations. Section 7.3 then helps innovators to interpret the results. To close, Section 7.4 describes a menu of tools for deepening understandings of public perceptions.

## 7.1 Societal acceptance

A review of the academic literature on the societal acceptance of innovations reveals five major themes of issues across a range of disciplinary perspectives including the psychology of risk, the sociology of technology, management science, science studies and social anthropology.

The first major theme concerns **psychometric risk factors**. It comprises issues that could affect how a technology is viewed with respect to three key factors described as dread, uncertainty and stigma. These issues are derived from psychometric approaches to the psychology of risk perception, most notably developed by Baruch Fischhoff and colleagues (1978), Vince Covello and colleagues (1989) and Paul Slovic (1992). How dreaded an innovation is seen as being is influenced by whether or not it: poses catastrophic risks; is personally controllable; exposes people voluntarily; has effects on children; effects future generations; has identifiable victims; instils dread; has reducible risks; poses escalating risks; has uneven impacts; could cause fatalities; has a history of accidents; would draw media attention; poses risks caused by people; is controlled by trustworthy institutions; has reversible impacts. How uncertain an innovation is seen as being is influenced by whether or not an innovation: uses familiar technology; is well understood by science; has observable effects; creates awareness among those exposed to its effects; poses new circumstances; has immediate effects; has clear benefits. How stigmatic an innovation is seen as being is influenced by whether or not an innovation: is visible; changes over time; disrupts lifestyles; is aesthetically pleasing.

The second major theme concerns **inflexibility indicators**. It comprises technical and organizational issues that could affect how flexible an innovation is. These issues are derived from approaches to the sociology of technology first problematized by David Collingridge (1980) as the 'control dilemma'. This recognizes that while it is desirable to control for the undesirable impacts of an innovation before they can happen, it is difficult, if not impossible, to know what these impacts will be until it has been fully developed. By this time it can be too difficult to change the innovation and control for the impacts. In questioning what might be known about the impacts of an innovation before it is fully developed, Collingridge proposed a set of indicators of inflexibility that, if avoided, could make late changes easier, including: levels of capital intensity; lengths of lead times; required scales; and infrastructure requirements. The UK's Royal Commission on Environmental Pollution (2008) added whether or not an innovation released materials into the environment to this list. To these technical indicators Simon Shackley and Michael Thompson (2011) added a set of organizational indicators that apply to those responsible for innovation implementation, including whether or not an organization: has a single mission; is open to criticism; hypes up the innovation; and adopts a hubristic view of failure.

The third major theme concerns **sociocultural preferences**. It comprises issues that could affect how acceptable innovations are seen as being by different institutional cultures. These issues are derived from sociocultural theoretic approaches to social anthropology, most notably developed by Mary Douglas (1986), Steve Rayner and Robin Cantor (1987) and Michiel Schwarz and Michael Thompson (1990). The theory posits three ideal type cultures: hierarchical, market and egalitarian (see also the section on the variability in institutional cultures across Europe in Chapter 2). These cultures each have preferences for particular implementation contexts (what should be protected by an innovation, who should pay for it, who should implement it and how compensation should be made in the event of failure) and particular sets of technology characteristics. Rather than seeing people as simply technophiles or technophobes, the theory sees people as techno-selective, accepting or rejecting innovations through their particular institutional-cultural lenses: technocratic (hierarchical cultures), techno-optimistic (market cultures) or techno-sceptic (egalitarian cultures).

The fourth major theme concerns **user acceptance constructs**. It comprises issues that could affect how useful and usable an innovation is seen as being. These issues are derived from psychometric constructs for management science, particularly in relation to information technologies, most notably developed by Fred Davis (1989) and Viswanath Venkatesh and colleagues (2000; 2003). How useful an innovation is seen as being is influenced by whether or not a user finds the innovation: improves their job performance; brings personal benefits; has outcomes with a pay-off in the future; is better than using its predecessor; elevates their status in their organization; has demonstrable results; and/or provides a sense of personal accomplishment. Judgements of usability are influenced by whether or not a user finds the innovation: brings positive feelings; is supported by their colleagues; is free from effort; is easy to operate; is complex to understand; is supported by other conditions in the operational environment; is visibly used by others in the organization; is consistent with the values of their organization; is usable voluntarily; and/or evokes anxious or emotional reactions.

The fifth major theme concerns **responsibility dimensions**. It comprises issues that could affect how responsible the research, development, demonstration and deployment of an innovation is seen as being. These issues are derived from relational approaches to science studies. The most notable of these are frameworks for 'responsible research and innovation', which have recently gained prominence with the European Commission and in particular its Horizon 2020 framework programme. Jack Stilgoe and colleagues (2013) outline four key dimensions of responsible innovation in their synthesis framework: anticipation of (un)intended impacts; unpacking different framings; including diverse stakeholders in deliberation; and modifying the pace and direction of innovation in response to changing societal values. Phil Macnaghten and colleagues (2015) similarly develop a narrative approach, identifying five familiar stories that underpin and structure public talk: "be careful what you wish for"; unleashing "Pandora's Box"; "messing with nature"; being "kept in the dark"; and letting "the rich get richer". Rob Bellamy (2015) develops a framework for climate change innovations in particular, proposing a need to: reflect on different imagined uses; seek robust performance against diverse criteria rather than optimal performance against narrow criteria; and gain legitimacy by involving all those who would be affected by an innovation.

The five themes of issues in the societal acceptance of innovations – psychometric risk factors, inflexibility indicators, sociocultural preferences, user acceptance constructs and responsibility dimensions – are summarized in Table 5-1 below.

*Table 7-1 Themes and issues in the societal acceptance of innovations*

| Themes | Issues | Key references |
|---|---|---|
| **Psychometric risk factors** | Catastrophic potential; familiarity; understanding; personal controllability; voluntariness of exposure; effects on children; effects manifestation; effects on future generations; victim identity; dread; trust in institutions; media attention; accident history; equity; benefits; reversibility; origin; reducibility; variability; fatality potential; observability; knowledge of exposure; novelty; concealability; time course; disruptiveness; aesthetic qualities | Fischhoff et al. (1978); Covello et al. (1989); Slovic (1992) |
| **Inflexibility indicators** | Capital intensity; lead times; scale; infrastructure requirements; encapsulation; single mission outfits; openness to criticism; hype; hubris | Collingridge (1980); RCEP (2008); Shackley & Thompson (2011) |
| **Sociocultural preferences** | Hierarchical, market and egalitarian perspectives on trust for implementation; liabilities for failure; consent for use; technology characteristics | Douglas (1986); Rayner & Cantor (1987); Schwarz & Thompson (1990) |
| **User acceptance constructs** | Attitude toward behavior; subjective norm; perceived usefulness; perceived ease of use; extrinsic motivation; intrinsic motivation; perceived behavioral control; job fit; complexity; long term consequences; affect towards use; social factors; facilitating conditions; relative advantage; results demonstrability; visibility; image; compatibility; voluntariness of use; outcome expectation; self-efficacy; affect; anxiety | Davis (1989); Venkatesh & Davis (2000); Venkatesh et al. (2003) |
| **Responsibility dimensions** | Anticipation of (un)intended impacts; opening up framings; inclusive deliberation; responsive pace and direction; be careful what you wish for; Pandora's Box; messing with nature; kept in the dark; the rich get richer; reflection on imaginaries; robust performance; object legitimacy | Stilgoe et al. (2013); Macnaghten et al. (2015); Bellamy (2016) |

## 7.2 Societal testing survey

Key issues in the five themes of societal acceptance can be operationalized as performance criteria for assessing the readiness of innovations using a simple survey instrument (see Box 7-1). Innovators should complete these twenty yes/no and multiple choice self-assessment questions to screen their innovations for possible societal acceptance issues. Once completed, innovators can proceed to Section 7.3 where guidance is provided to help them interpret the results.

*Box 7-1 Lines of questioning for the societal acceptance of innovations*

1. Does your innovation use any materials that might be considered unfamiliar (such as nanomaterials or genetically modified materials)? Yes or no
2. Will members of the public affected by your innovation be the ones to decide whether or when to use it? Yes or no
3. Does your innovation involve visible infrastructure (such as physical barriers) or visible land use changes (such as woodland removal)? Yes or no
4. Could the deployment of your innovation disrupt daily activities, for example through road closures? Yes or no
5. Does your innovation require large amounts of capital investment? Yes or no
6. Does your innovation require a long lead time between users placing an order and it becoming operational? Yes or no
7. Does your innovation require new infrastructure or significant changes to existing infrastructure? Yes or no
8. Does your innovation involve releasing any materials into the environment (such as sprays or coatings)? Yes or no
9. Are your potential users likely to have a single mission, for example to protect ecosystems? Yes or no
10. Does your innovation take less time to deploy than incumbent alternatives (such as sand bags for floods or fire nozzles for wildfires)? Yes or no
11. Would the use of your innovation require special training? Yes or no
12. Will help and support be available to users of your innovation? Yes or no
13. Innovations can either reinforce or change users' existing ways of working. Does your innovation reinforce existing ways of working? Yes or no
14. Are the effects of your innovation directly publicly tangible (such as seeing flood defenses working or hearing a warning system)? Yes or no
15. Adaptations can either be deployed permanently or temporarily. Is your innovation deployed permanently? Yes or no
16. Are members of the public involved in shaping the research, development, demonstration and deployment of your innovation? Yes or no
17. What would your innovation primarily protect? (A) public infrastructure, (B) private properties or (C) the environment
18. Who would pay for your innovation? (A) government authorities, (B) private companies or (C) local communities
19. Who would implement your innovation? (A) government authorities, (B) private companies or (C) local communities
20. How would compensation be made in the event of your innovation failing? Through (A) government compensation, (B) project insurance or (C) responsible parties

## 7.3 Interpreting the results

After completing the societal testing survey described in Section 7.2 innovators can use this section to interpret their results and identify possible societal acceptance concerns for their innovations.

Questions 1 to 16 are yes or no questions. Depending on how an innovator responds to these questions they will have either given a response associated with higher public concern or a response associated with lower public concern. Responses are given a simple quantitative score of 0 or 1 for responses associated with higher public concern or lower public concern, respectively. Table 7-2 sets out how innovators should score their responses to questions 1 to 16.

*Table 7-2 How to score responses to the societal testing survey*

| Question | 'Yes' response | 'No' response |
|---|---|---|
| **1** | 0 | 1 |
| **2** | 1 | 0 |
| **3** | 0 | 1 |
| **4** | 0 | 1 |
| **5** | 0 | 1 |
| **6** | 0 | 1 |
| **7** | 0 | 1 |
| **8** | 0 | 1 |
| **9** | 0 | 1 |
| **10** | 1 | 0 |
| **11** | 0 | 1 |
| **12** | 1 | 0 |
| **13** | 1 | 0 |
| **14** | 1 | 0 |
| **15** | 1 | 0 |
| **16** | 1 | 0 |

Innovators may score a maximum of 16 in this survey. A score of 0 – 4 indicates that an innovation has a high probability of facing societal acceptance concerns and is probably far from societal readiness (see Table 7-3). A score of 5 – 8 indicates that an innovation is likely to face societal acceptance concerns, requiring attention before it can be judged to be socially ready for deployment. A score of 9 – 12 indicates that an innovation faces fewer societal acceptance concerns and is close to societal readiness. A score of 13 – 16 indicates that an innovation faces very few societal acceptance concerns and is very close to societal readiness.

Questions 1 to 16 test particular issues or sets of issues associated with the themes of issues identified in Section 7.2: psychometric risk factors (questions 1 – 4), inflexibility indicators (questions 5 – 9), user acceptance constructs (questions 10 – 15) or responsibility dimensions (question 16). Innovators may thus score a maximum of 4 against psychometric risk factors; a maximum of 5 against inflexibility indicators, a maximum of 6 against user acceptance constructs and a maximum of 1 against responsibility dimensions (see Table 7-3).

*Table 7-3 How to interpret scores from the societal testing survey*

| Societal concerns | PRFs score | IIs score | UACs score | RDs score | Overall score | Societal readiness |
|---|---|---|---|---|---|---|
| **Many** | – | – | – | – | 0 – 4 | Very far |
| **Some** | 0 – 2 | 0 – 3 | 0 – 3 | 0 | 5 – 8 | Far |
| **Few** | 3 – 4 | 4 – 5 | 4 – 6 | 1 | 9 – 12 | Close |
| **Very few** | – | – | – | – | 13 – 16 | Very close |

Acronyms: PRFs (psychometric risk factors), IIs (inflexibility indicators), UACs (user acceptance constructs), RDs (responsibility dimensions)

Innovators can now explore specific areas of societal concern by consulting the guidance on responses to each question associated with higher public concern given below:

1. If your innovation uses unfamiliar materials (such as nanomaterials or genetically modified materials) it is likely to raise societal concerns. Psychological science shows that unfamiliar materials and novel impacts are associated with higher levels of public concern. Innovators should consider using familiar alternatives to lower societal concerns.
2. To the extent that members of the public affected by your innovation will not be the ones to decide whether or when to use it, it may raise public concerns. Psychological science shows that involuntary exposure and a lack of personal control is associated with higher levels of public concern. Innovators should consider recommending an appropriate level of public control over their innovation to those implementing the innovation to lower societal concerns.
3. If your innovation involves visible infrastructure (such as physical barriers) or visible land use changes (such as woodland removal), psychological science shows that it may raise public concerns. Innovators should consider developing unobtrusive infrastructure and avoid making land use changes near human settlements to lower societal concerns.
4. If the deployment of your innovation could disrupt daily activities, psychological science shows that it is likely to raise public concerns. Innovators should consider designs that work around daily activities to lower societal concerns.
5. If your innovation requires large amounts of capital investment, sociological research shows that it is likely to raise public concerns. Innovators should consider designs that do not require large amounts of capital investment to lower societal concerns.
6. If your innovation requires a long lead time between users placing an order and it becoming operational, sociological research shows that it is likely to raise public concerns. Innovators should consider ways of reducing lead times to lower societal concerns.
7. If your innovation requires new infrastructure or significant changes to existing infrastructure, sociological research shows that it may raise public concerns. Innovators should consider using existing infrastructure and minimizing any changes to lower societal concerns.
8. If your innovation involves releasing any materials into the environment (such as sprays or coatings) it is likely to raise public concerns. Sociological research shows that unrecoverable releases and irreversible actions are associated with higher levels of public concern. Innovators should consider designs that do not release materials into the environment to lower societal concerns.

9. If your users are likely to have a single mission, for example to protect ecosystems, sociological research shows that they are likely to raise public concerns about your innovation. Innovators should consider targeting their innovation at users with plural missions or joint ventures between single mission users with different missions to lower societal concerns.
10. If your innovation takes as long or more time to deploy than incumbent alternatives (such as sand bags for floods or fire nozzles for wildfires) it is likely to raise public concerns. Management science shows that longer deployment times and delayed effects are associated with higher levels of public concern. Innovators should consider designs that take less time to deploy than incumbent alternatives to lower societal concerns.
11. If the use of your innovation requires special training, management science shows that it is likely to raise public concerns. Innovators should consider designs that are less complex to lower societal concerns.
12. If help and support will not be available to users of your innovation, management science shows that it is likely to raise public concerns. Innovators should consider appropriate ways of providing help and support to users after they have procured your innovation to lower societal concerns.
13. If your innovation disrupts rather than reinforces existing ways of working, management science shows that it is likely to raise public concerns. Innovators should consider designs that minimize changes to existing ways of working to lower societal concerns.
14. If the effects of your innovation are not directly publicly tangible (such as seeing flood defenses working or hearing a warning system) it is likely to raise public concerns. Management science and psychological research shows that unseen benefits, unobservable effects and non-awareness of exposure are associated with higher levels of public concern. Innovators should consider designs that make the benefits of their innovation tangible.
15. If your innovation is deployed temporarily, management science shows that it is likely to raise public concerns. Innovators should consider designs that make their innovation a more permanent solution to lower societal concerns.
16. If members of the public are not involved in shaping the research, development, demonstration and deployment of your innovation it is likely to raise public concerns. Science studies and sociological research show that exclusion and closure to criticism are associated with higher levels of public concern. Innovators should consider ways of including members of the public and being open to criticism.

Questions 17 to 20 are multiple choice questions that test particular issues associated with implementation contexts from the sociocultural preferences theme of issues identified in Section 7.2. Depending on how an innovator responds to these questions they will have given a response associated with technocratic preferences, techno-optimistic preferences or techno-skeptical preferences. Responses are given a simple qualitative code of ‘A’ for responses associated with technocratic implementation contexts, ‘B’ for those associated with techno-optimistic contexts or ‘C’ for those associated with techno-skeptical contexts. Innovators might now locate the intended implementation context of their innovation in a triangular preference space to help them think about where they are likely to meet societal support and resistance (see Figure 7-1).

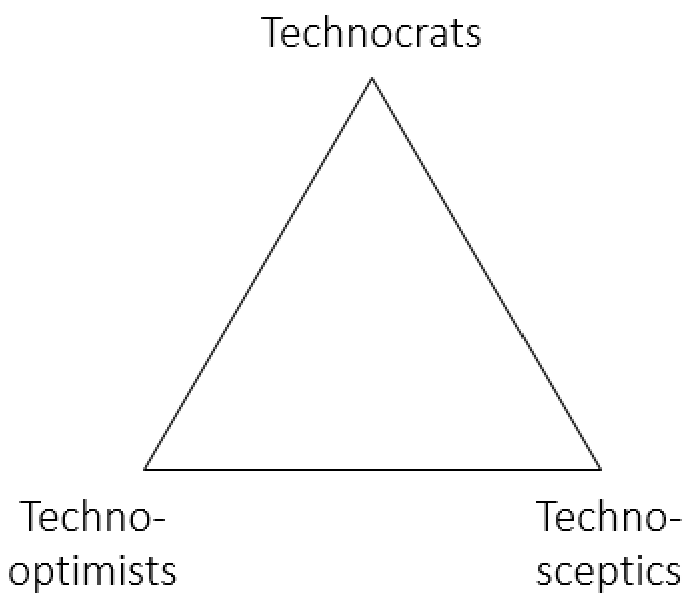



*Figure 7-1 A triangular preference space for innovations*

We have seen that people support or resist particular implementation contexts for innovations according to their institutional-cultural biases. In the same way, they accept or reject particular sets of technology characteristics. Technocrats tend to prefer long-lasting, tried-and tested and large-scale technologies with a traditional aesthetic. Techno-optimists tend to prefer rapidly replaceable, cutting-edge and profit-maximizing technologies with a striking aesthetic. Techno-sceptics tend to prefer environmentally benign, low-tech and small-scale technologies with a natural aesthetic. Innovators might now also locate the technology characteristics of their innovation in the triangular preference space to help them think about where they are likely to meet societal acceptance and rejection. The aim of this exercise is to match preferred technologies with preferred implementation contexts:

- Bureaucracy enabling, long-lasting, tried-and tested and large-scale technologies are best: used to protect public infrastructure, paid for and implemented by government authorities and held liable through government compensation.
- Individually enabling, rapidly replaceable, cutting-edge and profit-maximizing technologies are best: used to protect private properties, paid for and implemented by private companies and held liable through project insurance.
- Community enabling, environmentally benign, low-tech and small-scale technologies are best: used to protect the environment, paid for and implemented by local communities and held liable through responsibly parties.

If the intended implementation context and set of technology characteristics do not match, innovators are likely to encounter societal resistances. For example, the intended implementation context may be technocratic, but the technology characteristics are preferred by techno-optimists. Innovators should consider changing either their intended implementation context or set of technology characteristics to make sure they match. If the intended implementation context and set of technology characteristics do match, innovators are likely to encounter societal acceptance where they match and resistances where they do not. For example, a technocratic implementation context and technocratic set of technology characteristics is likely to meet societal resistances from techno-optimists and techno-sceptics. Table 7-4 provides a summary of how innovators should interpret the relationship between their intended implementation context and the technology characteristics of their innovation, showing areas of likely societal acceptance or resistance.

*Table 7-4 How to interpret the relationship between implementation and technology*

| | **Technocratic technology** | **Techno-optimist technology** | **Techno-sceptic technology** |
|---|---|---|---|
| **Technocratic implementation** | TC acceptance with resistances from TOs and TSs | Resistances from all institutional cultures | Resistances from all institutional cultures |
| **Techno-optimist implementation** | Resistances from all institutional cultures | TO acceptance with resistances from TCs and TSs | Resistances from all institutional cultures |
| **Techno-sceptic implementation** | Resistances from all institutional cultures | Resistances from all institutional cultures | TS acceptance with resistances from TOs and TCs |

Acronyms: TCs (technocrats), TOs (techno-optimists), TSs (techno-sceptics)

Box 7-2 below applies the societal testing survey to an exemplary fictional mobile flood barrier to demonstrate how it can be used to reveal the societal readiness of an innovation, specific areas of societal concern and areas within society that are likely to accept or resist the innovation.

*Box 7-2 A fictional exemplary application of the societal testing survey*

The innovator of a fictional mobile flood barrier responds to questions 1 to 16 as follows: it does not use any unfamiliar materials; members of the public affected by the innovation will not be the ones to decide whether or when to use it; it does not involve visible infrastructure; it could disrupt daily activities; it does not require large amounts of capital investment; it does not require a long lead time; it does not require new infrastructure or significant changes to existing infrastructure; it does not involve releasing any materials into the environment; its users are likely to have multiple missions; it takes less time to deploy than incumbent alternatives; it does require special training to use; help and support will not be available to users; it does not change users' existing ways of working; its effects are publicly tangible; it is deployed temporarily; members of the public are not involved in shaping the innovation process; it would primarily protect public infrastructure; it would be paid for by government authorities; it would be implemented by government authorities; compensation would be made through government compensation in the event of failure.

Against psychometric risk factors the innovation scores 2/4, posing some societal concerns associated with a lack of public control and the potential for disruption to daily activities. Against inflexibility indicators the innovation scores 5/5, posing no societal concerns. Against user acceptance constructs the innovation scores 3/6, posing some societal concerns associated with its complexity, lack of support and only temporary nature. Against responsibility dimensions the innovation scores 0/1, posing societal concerns associated with a lack of public involvement in shaping the innovation process. Overall the innovation scores 10/16, posing few societal concerns. This means that the innovation is close to societal readiness. Against sociocultural preferences the implementation context strongly resonates with technocratic preferences. However, the technology characteristics of the innovation do not match. Being an individually enabling, rapidly replaceable, cutting-edge and profit-maximizing technology it is better suited for techno-optimists. While the innovation poses relatively few societal concerns then and is close to being ready, innovators still need to better match the intended implementation context with its technological characteristics.

## 7.4 Tools for deeper analysis

If innovators require a deeper analysis of the societal acceptance issues surrounding their innovation they will need to employ social scientific experts to directly engage the public using one or more established methods for eliciting public perceptions and preferences. A selection of these methods is described in Table 7-5 below, together with their typical strengths and weaknesses.

*Table 7-5 A selection of methods for eliciting public perceptions and preferences*

| Method | Brief description | Typical strengths | Typical weaknesses |
|---|---|---|---|
| **Opinion surveys** | Large groups of participants involved in responding to short targeted questions | Statistical representation, fast | Narrow framing, superficial evidence, expensive |
| **One-to-one interviews** | Individual participants involved in responding to extended targeted questions | Inexpensive, in-depth evidence, fast | Narrow framing |
| **Focus groups** | Small groups of participants involved in short targeted discussions | In-depth evidence, fast | Narrow framing |
| **Deliberative workshops** | Small groups of participants involved in extended open discussions | Sociodemographic representation, broad framing, in-depth evidence | Expensive |
| **Scenarios workshops** | Small groups of participants involved in fore- or back-casting future scenarios | In-depth evidence, broad framing (forecasting) | Expensive, narrow framing (back casting) |
| **Deliberative mapping** | Small groups of participants involved in multi-criteria appraisal of options | Diverse representation, broad framing, in-depth evidence | Slow, expensive |

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# Appendix A. Normalized Loading Conditions in Europe

# Appendix B. Integrating Testing with the Stocktaking Process

# Appendix C. Results of the Frontrunner Workshop

# Appendix D. Detailed Guidelines and Examples for Technical Testing

# Appendix E. Additional Guidelines for Impact Assessment

# Appendix A. Normalized Loading Conditions in Europe

## Contents

# 1. Introduction

This appendix serves to: describe the indicators of pan-European, normalized loading conditions; outline the methodology of their derivation; discuss their limitations and uncertainty in their values; and present the normalized loading conditions under present and future climate at three levels: local, regional and national. The appendix is the main description of work carried out in Task 5.1 of BRIGAID. It supports the testing of innovations as part of the technical Key Performance Indicators, and also provides input for market scoping by WP6.

## 1.1 Spatial Domain

The analysis presented in this document covers the territory of Europe. However, comprehensive and spatially-consistent data, both on the loading conditions and the socio-economic environment, do not cover the entire geographical extent of the continent. The modelling domains for meteorological and hydrological hazards differ, and are presented in the releveant methodologies sections. Meanwhile, the domain for normalizing the loading conditions, and further analyses was defined as follows:

- All 28 European Union (EU) members, but without their dependencies, both in Europe and overseas[1], and also without outlying regions of Portugal and Spain: Azores, Madeira, Canary Islands, Ceuta and Melilla;
- All 4 European Free Trade Agreement (EFTA) members (Iceland, Liechtenstein, Norway, Switzerland) and
- Macedonia[2].

In case of Cyprus, the normalization was done for the entire island, however demographic and economic data used to support the normalization exclude areas controlled by the Turkish Republic of Northern Cyprus. The domain doesn't cover two home countries of BRIGAID partners, Albania and Israel, due to the lack of spatial data needed to carry out the normalization. The map of the domain is presented in Fig. A1.

[1] This exclusion covers all dependent territories of Denmark (Faroe Islands and Greenland), France (overseas departments and other possessions outside Europe), Norway (Svalbard and other polar territories), the Netherlands (territories located in the Caribbean) and the United Kingdom (Guernsey, Isle of Man, Jersey and all British Overseas Territories).

[2] Also referred to as the Former Yugoslav Republic of Macedonia (FYROM).

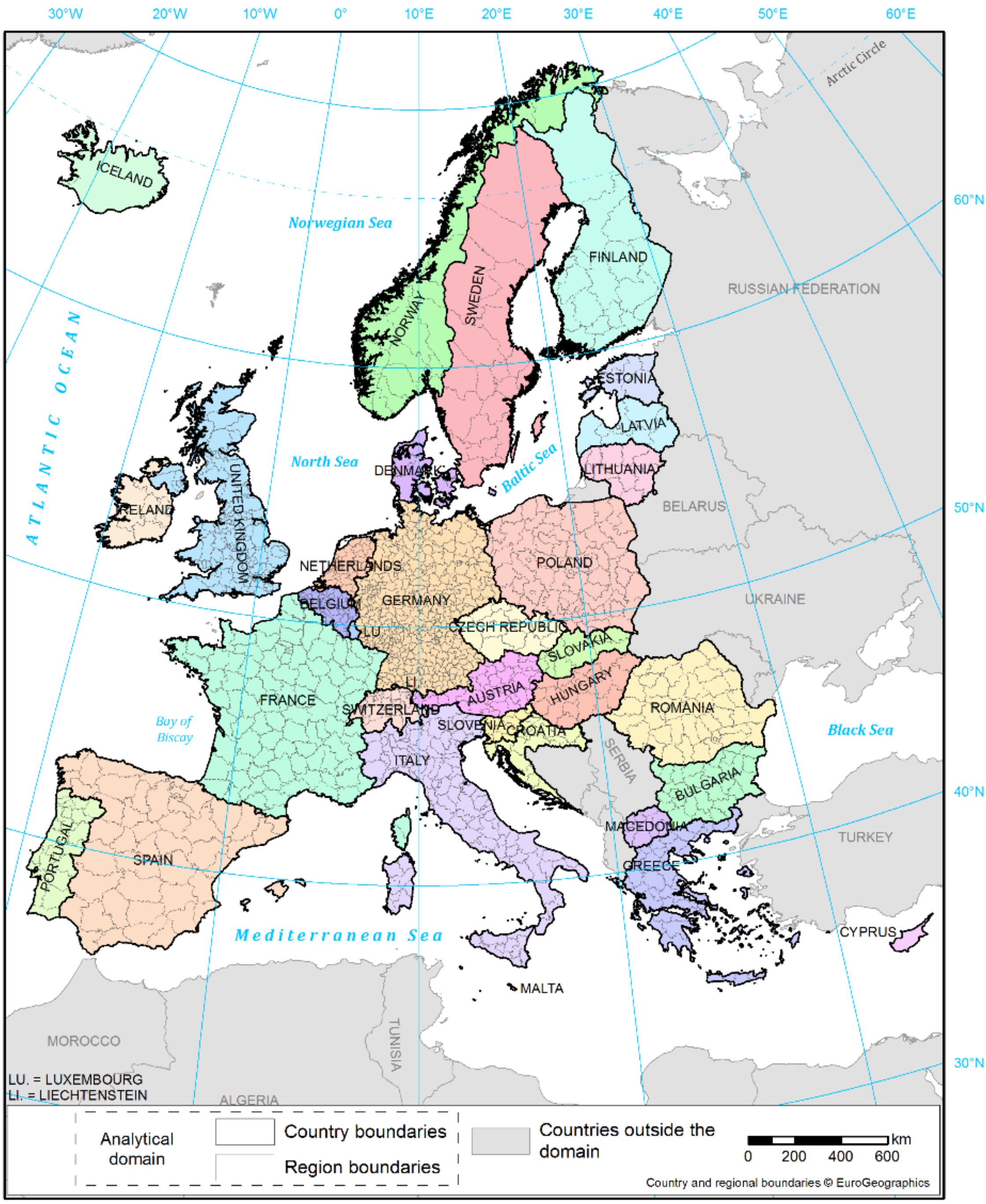


*Figure A1. Spatial domain used in the analysis*

# 1.2 Definitions of hazards

### Coastal floods

A coastal flood is the temporary covering by water of land not normally covered by water, caused by high water levels in the sea. High water level may occur due to strong winds blowing sufficiently long over an adequately large area, especially toward the coast, causing a large water run-up at the coast. Unfavourable bathymetric conditions and high astronomical tide further increase the run-up. Coastal floods include floods in estuaries and coastal lakes, caused by influx of seawater into those systems. However, compound events, i.e. the co-occurrence of high sea water levels and high river discharges in those areas, are not considered here. In deriving the future projections of hazard, changes in storminess, sea level rise and glacial isostatic adjustment are considered, but not local effects such as ground subsidence, coastal erosion and accumulation, or changes in tide-surge interactions (Paprotny et al. 2016). It should be also noted that high water levels caused by seiches or geophysical events are not considered here.

### River floods

A river flood is the temporary covering by water of land not normally covered by water, caused by high discharge in a river. High discharge may occur due to heavy precipitation and/or snowmelt in areas located upstream, that have sufficient intensity and duration, in combination with soil saturation. Rivers include also mountain torrents and Mediterranean ephemeral water courses (European Union 2007), however only river sections with catchments bigger than 100 $km^2$ were included in this study. Cases of flooding caused by ice jams were also not included in the modelling framework (Groenemeijer et al. 2016). Urban floods, caused by insufficient sewage system capacity, and flash floods, caused by very short yet intense rainfall over a small area, were considered under “Heavy precipitation”. In deriving the future projections of hazard, changes in precipitation, snowmelt and general runoff generation conditions (soil moisture, temperature etc.) are considered, but not effects of new hydraulic structures (Paprotny and Morales Nápoles 2016a).

### Droughts

Droughts are the result of a period of consecutive dry days or days with very low rainfall. Such meteorological droughts can lead to hydrological, agricultural, socio-economic droughts, depending on the types of impacts. For the climate indicators and loading conditions in this project, only the meterological drought is considered, as BRIGAID considers innovations that address many different types of meteorological drought impacts. The meteorological drought is the primany one, of relevance for any type of impact on nature and society.

### Heat waves

Heat waves are several consecutive days with very warm days. Based on the WMO definition, heat waves are defined here as periods of more than 5 consecutive days with daily maximum temperature exceeding the mean maximum temperature of the May to September season for the control period (1971–2000) by at least 5°C (Jacob et al., 2014).

## Wildfires

Global warming affects the sparking of wildfires. In fact, warmer temperatures enable fuels to ignite and burn faster, resulting in faster wildfire expansion. Wind can help the wildfire expansion, while precipitation can decrease the chances of a wildfire igniting. In this project, wildfire danger is considered, being assessed by meteorological conditions only (air temperature, wind speed, meterological drought conditions). Other local conditions that affect the wildfire danger and risk are not readily available at pan-european level. Given that the meteorological conditions are the primany factors controlling the wildfires, these were considered here for the pan-European analysis.

## Windstoms

Storms (atmospheric disturbances) are defined by strong sustained winds, which are mostly accompanied by heavy precipitation and lightning and in some case also by hail. European storms range from localized to continental events. In this project, sustained winds are considered, as this is the primany one for pan-European analysis, without consideration of gusts, lightning, hail or combination with precipitation.

## Heavy precipitation

Extreme precipitation induced hazards such as pluvial floods, flash floods, landslides, mudflows, etc. are the result of short-duration rainfall intensities when they exceed a given threshold, e.g. the threshold above which a flood initiates. This threshold corresponds to the criteria used for infrastructure design in different European countries and regions. Infrastructure such as land-based transportation and emergency services are especially vulnerable to extreme precipitation events, as they can lead to the flooding of tunnels and can damage streets, railway lines and bridges. Also electricity and telecommunication networks can be affected by heavy precipitation. For this project, precipitation above a threshold was selected as this is representative for most of these heavy precipitation related hazards.

# 2. Derivation of hydrologic loading conditions

## 2.1 Coastal floods

### Indicator

Coastal flood loading conditions were assessed using the following indicator:

**Storm surge height with a 100-year return period, in meters above water levels with a 10-year return period under historical climate.**

Those loading conditions were prepared for 3 scenarios: historical climate (1971–2000) and future climate under two socio-economic development assumptions (2071–2100, RCP 4.5 and 8.5).

However, the baseline water level doesn't change. The 10-year return period was chosen as an approximation of the lowest flood protection standards that can be found throughout Europe (see e.g. Scussolini et al. 2016). Meanwhile, the 100-year return period is very widely used in Europe as flood protection standards and scenario for flood hazard/risk mapping. A review of literature identified the use of this return period in e.g. Austria, Croatia, the Czech Republic, Finland, France, Germany, Hungary, Ireland, Italy, Poland, Switzerland and the United Kingdom. It is also the only return period explicitly mentioned in the EU's "Flood Directive" (European Union 2007).

Yet, due to the use of Gumbel distribution the indicator is scalable: the difference in water level between 100-year and 10-year return periods is representative also for other return periods with a difference of one order of magnitude, e.g. 500-year versus 50-year. Therefore, the indicator is informative of how much the flood protection needs to be increased to reduce the probability of flood by one order of magnitude.

### Methodology

The data used to calculate the indicator of coastal flood hazard were obtained from a publicly available dataset (Paprotny and Morales Nápoles 2016c) produced in project RAIN. The summarized methodology and detailed results were presented in a report by Groenemeijer et al. (2016), with more details on the methodology and elaboration on the accuracy of the storm surge modelling was presented by Paprotny et al. (2016). Below, the main aspects of the methodology are summarized.

The domain of the coastal flood calculation covered most of Europe's coast (Fig. A2). The storm surges were calculated within the EURO-CORDEX domain, spanning over the maritime waters around the continent. The coastline, along with coastal flood extents were obtained, is consistent with the river flood modelling domain (see section 2.2, "Methodology") and has a total length of 225,800 km. Coastline geometry was obtained from pan-European CCM2 dataset (de Jager and Vogt 2010).

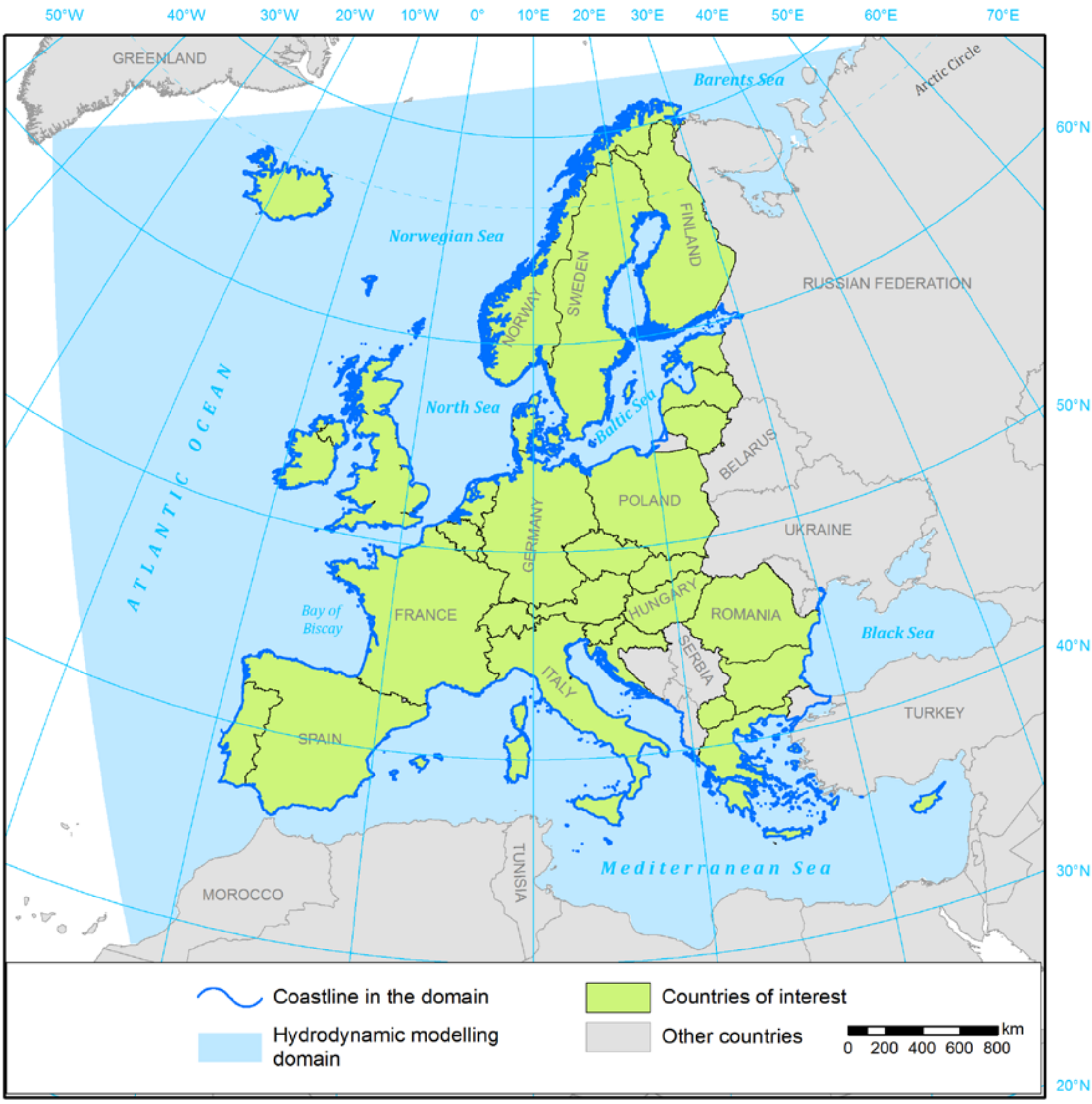


*Figure A2. Domain used in RAIN project to obtain coastal flood hazard maps. Coastline geometry from CCM2 dataset (de Jager and Vogt 2010).*

Modelling of coastal floods consisted of two steps. Firstly, a time series of 6-hourly sea levels was generated using a two-dimensional hydrodynamic model driven by meteorological data. Secondly, extreme value analysis was carried out on this time series and the resulting return periods were combined with information on sea level rise and glacial isostatic adjustment obtained from external datasets.

Simulations of storm surges were carried out using Delft3D software by Deltares (2013). The mathematical core of the model is comprised of a 2D derivate of de Saint-Venant equations, known as shallow water equations, which provide depth-averaged flows of water. The model was forced by data provided by the Rossby Centre of the Swedish Meteorological and Hydrological Institute. Those climate simulations utilized EURO-CORDEX framework, with RCA4 regional circulation model (Strandberg et al. 2014) forced by the EC-EARTH general circulation model, realization t12i1p1. The meterological input consisted of 6-hour series of air pressure and wind speed (northward and eastward components). The resolution of the climate data is 0.11° and the same grid was used to set-up the model in Delft3D, though the domain's size was slightly reduced for computational efficiency. Additionally, ERA-Interim climate reanalysis (Dee et al. 2011) was used to perform a calibration of the model. The validation has shown that a good accuracy of modelled storm surges when compared with observations from 161 tide gauges from around Europe. For details we refer to Paprotny et al. (2016).

From the 6-hourly series of storm surges annual maxima were calculated, and by applying extreme value analysis return periods were obtained. Generalized Extreme Value (GEV) distribution was used for the purposes of the analysis. The surge heights calculated this way are relative to local mean sea level. This indicator was used directly for the historical indicator of extreme water level, as we assumed that high tidal level is part of the “normal” conditions in a given location. For the future climate, apart from the changes in storminess two additional factors were used: sea level rise and glacial isostatic adjustment. Therefore, the indicator of storm surge (*SI*) with can be written as:

$$SI_{hist} = SURGE_{100,hist} - SURGE_{10,hist} \quad (1)$$

$$SI_{rcp4.5} = SURGE_{100,rcp4.5} - SURGE_{10,hist} + SLR_{rcp4.5} + GIA \quad (2)$$

$$SI_{rcp8.5} = SURGE_{100,rcp8.5} - SURGE_{10,hist} + SLR_{rcp8.5} + GIA \quad (3)$$

where:

*hist, rcp4.5* and *rcp8.5* are the historical scenario (1971–2000) and two future scenarios, RCP 4.5 and RCP 8.5 (2071–2100), respectively;

$SURGE_X$ is the surge height with a *X*-year return period;

*SLR* is the increase in mean sea level (2071–2100 mean level relative to 1971–2000), based on regional projections compiled from external datasets: dynamic and steric component from CNRM-CM5 general circulation model (Voldoire et al. 2013) and contributions of groundwater depletion, glacier and ice sheet mass balance, and ice sheet dynamics from estimates by Slangen et al. (2014) and Carson et al. (2016)[3].

*GIA* is the glacial isostatic adjustment, which is climate-scenario independent. It represents the vertical movement of the Earth’s crust (2071–2100 mean level relative to 1971–2000). The data were obtained from ICE-6G_C (VM5a) model output with a 1° resolution (Peltier et al. 2015).

### Limitations and uncertainty

The analysis includes several sources of uncertainties. One is related with input data. Storm surge heights are derived through a hydrodynamic model, which performance for individual stations was very diverse. For example, much lower accuracy was observed over the Mediterranean Sea, compared to North or Baltic seas. Due to the relative coarse resolution of the model (~12 km) the complicated shape of the coast of Norway, Finland or Greece couldn’t be properly incorporated.. Datasets on GIA and SLR have even coarser resolutions, causing relatively steep changes between many coastal segments.

Methodologically, several components that could locally influence surge heights were omitted, such as tide-surge interaction, the impact of sea level rise on tides or ground motion

[3] The “dynamic” component is the change in ocean circulation patterns, while the “steric” component is the evolution in ocean volume due to changes in temperature and salinity. Ice sheet dynamics and groundwater depletion projections are the same for RCP 4.5 and RCP 8.5.

other than GIA. Those effects could be locally very significant. as these are very local factors with a number of causes, and no large-scale datasets are available.

The indicator assumes that the existing flood protection corresponds to a 10-year water level, and the desired flood protection to a 100-year water level. In practice, the nominal and actual protection levels vary enourmously between locations. In the Netherlands, for instance, there are dike section that would protect against a 1 in 10,000 years event, while in Poland dikes with a protection standard lower than 10-year return period were allowed to be built between 1997 and 2007. However, as noted above, due to the use of Gumbel distribution the indicator is representative for other return periods with a difference of one order of magnitude.

Finally, there is uncertainty related to future projections. Accuracy of storm surge projections is dependent on the accuracy of air pressure and wind speed/direction projections. The difference between RCP 4.5 and RCP 8.5 scenarios is sometimes very large, to the point that opposite trends are indicated. This alone illustrates the significant uncertainty related with climate change. Meanwhile, sea level rise is a combination of several climate-related factors, which are understood and quantified to a varying degree, especially below the scale of the whole globe. Existing estimates have a low spatial resolution and large uncertainty bounds. Storm surge projections are based only one climate change model, similarly the dynamic and steric components of SLR from another model, which provide less confidence than an ensemble of climate models.

## 2.2 River floods

### Indicator

River flood loading conditions were assessed using the following indicator:

**River water level with a 100-year return period, in meters above water levels with a 10-year return period under historical climate.**

Those loading conditions were prepared for 3 scenarios: historical climate (1971–2000) and future climate under two socio-economic development assumptions (2071–2100, RCP 4.5 and 8.5). The rationale for the indicator is the same as for coastal floods; the indicator is similarly scalable to other return periods (see section 2.1, “Indicator”).

### Methodology

The data used to calculate the indicators of river flood hazard were obtained from a publicly available dataset (Paprotny and Morales Nápoles 2016a) produced in a FP7 project RAIN[4]. The summarized methodology and detailed results were presented in a report by Groenemeijer et al. (2016), with more details on the methodology and elaboration on the accuracy of the results presented by Paprotny and Morales Nápoles (2016b) and Paprotny et al. (2017). Below, the main aspects of the methodology are summarized.

The domain of the river flood calculation covered most of Europe (Fig. A3). Because RAIN project, like BRIGAID, was focused on EU countries, all river basins at least partially located in this group of states were included (including Cyprus, geographically part of Asia). Some additional neighbouring basins were added for complete coverage of Europe, except for

[4] European Union’s Seventh Framework Programme, project “Risk Analysis of Infrastructure Networks in response to extreme weather” (2014–2017).

basins located completely within the territory of the former Soviet Union. Also, the outermost regions of Madeira, the Azores and the Canary Islands were omitted because they were outside the EURO-CORDEX domain, which was used in the climate model that served as input for the hydrological model. The total domain's area is 5.67 mln km$^2$, and includes 498,420 km of rivers with catchments bigger than 100 km$^2$.

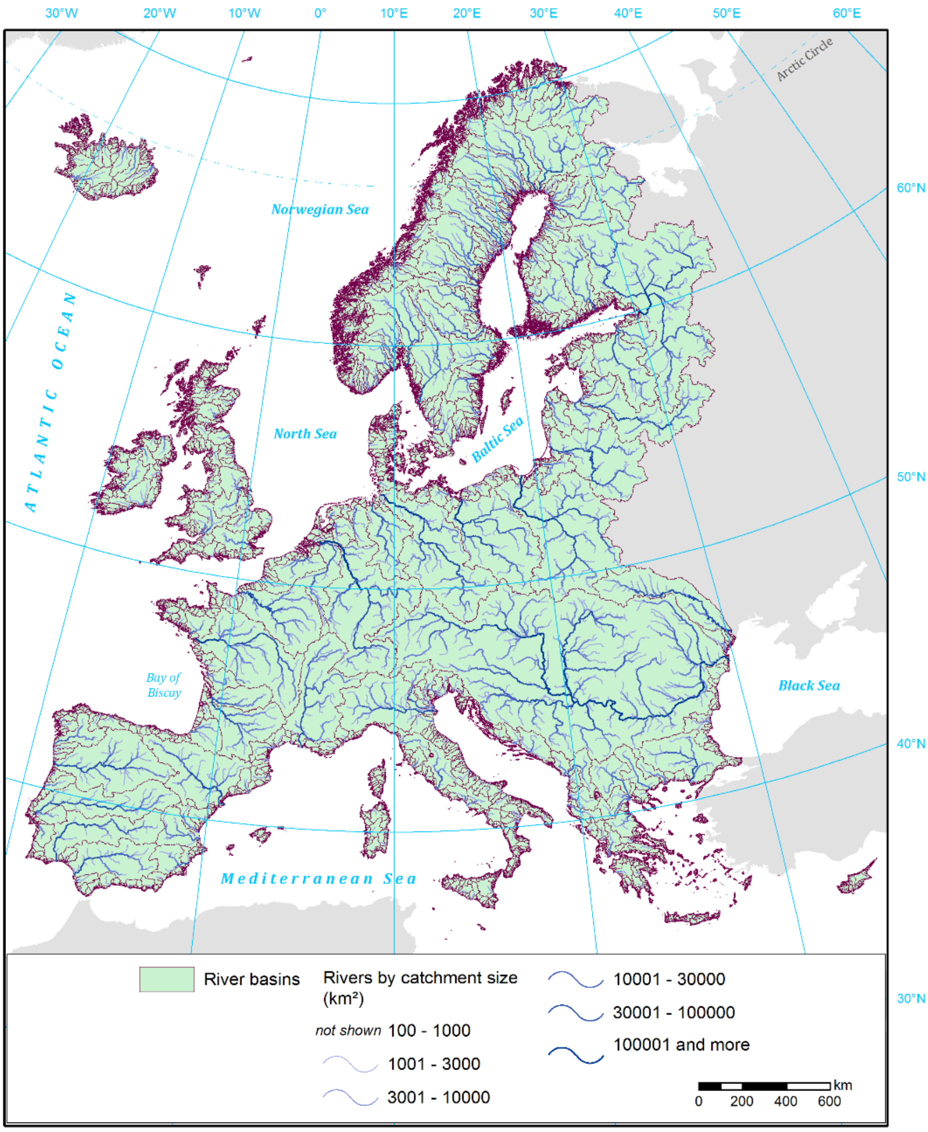


*Figure A3. Domain used in RAIN project to obtain river flood hazard maps; for the sake of clarity, only rivers with a catchment area larger than 1000 km$^2$ are presented on the map. Delimitation of rivers and basins from CCM2 dataset (de Jager and Vogt 2010).*

Modelling of river floods consisted of two steps. Firstly, extreme river discharges with given return periods were calculated using a Bayesian Network-based hydrological model, under present and future climate. Secondly, selected river discharge scenarios were used to obtain water levels through a one-dimensional hydrodynamic model.

Several statistical models of estimating river discharge were developed, to be used on various spatial scales, from local to global. However, using a non-parametric Bayesian Network (NPBN) for that purpose was first investigated by Paprotny and Morales Nápoles (2015, 2016b). The model utilizes the fact that many characteristics of catchments influence the intensity of river discharges. In the NPBN model, the probability distributions of 7 variables are used to describe the conditional probability distribution of annual maxima of daily river discharge. The model was quantified with 1841 European river gauge stations with almost 75,000 years of observations. For each gauge station, the following characteristics of their upstream catchments were calculated: area, steepness, annual maximum of daily precipitation and snowmelt, extreme runoff coefficient, fraction covered by lakes, fraction covered by marshes and fraction covered by build-up areas. Data were obtained from several pan-European and global datasets. Using the series of annual maxima of daily river discharge estimated by the NPBN, an extreme value analysis was carried out. The validation has shown that good accuracy was achieved, compared to other hydrological models, for estimating river discharges with given return periods over Europe. The method was then used to model annual maxima of river discharges in all European rivers within the domain. The hydrologic network was derived for that purpose from the pan-European river and catchment database CCM2 (de Jager and Vogt 2010), and was comprised of almost 2 mln km of rivers. Simulations were done for both present and future climate (spanning from 1951 to 2100) using climate model output from EURO-CORDEX, that employed COSMO_4.8_clm17 regional climate model forced by EC-Earth general circulation model (run by ICHEC), realization r12i1p1. The climate model resolution was 0.11° on a rotated grid, or approx. 12 km. For more details about the model we refer to Rockel et al. (2008) and Kotlarski et al. (2014).

Annual maxima of discharge were used to undertake an extreme value analysis. Return periods of discharges were calculated under the assumption that the distribution of annual maxima follows Gumbel distribution. Once those river discharge scenarios have been obtained they were used as input for SOBEK v2.13 hydrodynamic model (Deltares 2015). In order to minimize computational time, the modelling option chosen was a one-dimensional (1D), steady-state, lumped representation of the river network. The model required the following inputs:

- River network, which was derived from the CCM2 dataset. Only rivers with catchment larger than 100 $km^2$ were included.
- Calculation points, where hydraulic calculations of water flow are performed. Those were defined, on average, every 2 km of rivers.
- Upstream boundaries, where water enters the model. Those was defined using discharge scenarios calculated using NPBN model.
- Downstream boundaries, where water is withdrawn from the model. As those are located at the edge of the sea to which the river drains[5], the boundaries were defined as to represent mean sea level.
- Lateral discharge: an option to enter or withdraw water from the model at locations different than the boundaries. Extreme discharges were inserted at upstream boundaries to the model at the same time, while they in fact do not occur simultaneously. Hence, discharge in the river below the intersections of two rivers will be typically lower than the sum of the two contributing rivers. Using the lateral discharge option, the surplus water was withdrawn from the model, preserving a proper representation of flood scenarios.
- Cross-sections of the river, which were obtained from the EU-DEM digital elevation model (DHI GRAS 2014) and vary in length depending on the topography. They were

[5] The only exception were 2 rivers draining to lake Prespa in the Balkans.

defined approximately every 2 km of the river network. Due to the resolution of the EU-DEM (100 m), flood defences are mostly not included in the profiles. Because the river beds are not included in the elevation model, it was assumed that the topography in the EU-DEM represents the mean water levels in the rivers, as has been done in other pan-European studies (e.g. Alfieri et al. 2014). Consequently, mean discharges were subtracted from extreme discharges in the entire model. Mean discharge values were obtained from the same Bayesian Network as for extreme discharges, simply by replacing extreme rainfall/snowmelt and runoff coefficients by annual means.

The absolute water levels (i.e. relative to mean sea level) from the SOBEK model, available at the calculation points, were linearly interpolated along the rivers to increase the density of estimates. After the data for the 10- and 100-year return periods were extracted, the indicators of extreme water levels (EWL) were calculated as follows:

$$EWL_{hist} = WL_{100,hist} - WL_{10,hist} \quad (4)$$

$$EWL_{rcp4.5} = WL_{100,rcp4.5} - WL_{10,hist} \quad (5)$$

$$EWL_{rcp8.5} = WL_{100,rcp8.5} - WL_{10,hist} \quad (6)$$

where:

*hist, rcp4.5* and *rcp8.5* are the historical scenario (1971–2000) and two future scenarios, RCP 4.5 and RCP 8.5 (2071–2100), respectively;

$WL_X$ is the extreme river water level with a *X*-year return period.

### Limitations and uncertainty

The analysis includes several sources of uncertainties. One is related with input data. River discharge scenarios were calculated using a statistical model, which is less accurate then river gauge measurements, and has limited accuracy in very small catchments (in the range of hundreds of km$^2$). The results do not include changes in land use (build-up areas, lakes, marshes), both in historical or future scenarios. Uncertainty is also related with DEM's vertical accuracy, which also omits most flood defences. Moreover, the elevation model does not include the bed or embankments of rivers. It is assumed that the surface of DEM represents roughly the mean water level in the river, though some other studies used 'bankfull' discharge (approximated by 2-year return period of water levels). Furthermore, imperfections of the DEM and mismatch with the river layer also occasionally cause very large errors in some model runs. Those locations, where one of the simulations indicated water levels was vastly different from the remaining scenarios, were not included in the normalization. Also, estimates for river sections located on lakes, as defined by the CCM2 dataset, were excluded from the analysis.

Another source of uncertainty is the type of events analysed. As noted before, only rivers with catchments that have an area of at least 100 km$^2$ were included in the calculation, while flash floods and urban floods were also not analysed. Furthermore, we estimate the extreme river discharge based on two main factors causing flood – rainfall and snowmelt, while floods in northern Europe are also caused by ice and frazil blocking the river flow. We also do not include the reduction of the flood wave through reservoirs or bypass channels but rather consider the flow under 'natural' conditions.

Methodological limitations also apply, especially to the water level and flood extent modelling, which were obtained from the hydrodynamic model utilizing one-dimensional "steady state" simulation and GIS mapping, which is not as accurate as a full two-dimensional simulation. Validated showed a sometimes significant tendency to overestimate hazard.

The indicator assumes that the existing flood protection corresponds to a 10-year water level, and the desired flood protection to a 100-year water level. In practice, the nominal and actual protection levels vary enourmously between locations. In the Netherlands, for instance, there are dike section that would protect against a 1 in 10,000 years event, while in Poland dikes with a protection standard lower than 10-year return period were allowed to be built between 1997 and 2007. However, as for coastal floods, due to the use of Gumbel distribution the indicator is representative for other return periods with a difference of one order of magnitude.

Last but not least, there is uncertainty related with future climate projections. The difference between RCP 4.5 and RCP 8.5 scenarios is sometimes very large. This alone illustrates the significant uncertainty related with climate change and the climate models, as the latter are known to have limited accuracy for precipitation, let alone extreme rainfall. Also, the results of only one climate model were analyse, which provides less confidence than an ensemble of climate models.

# 3 Derivation of meteorological loading conditions

## 3.1 Common methodological aspects

The other indicators, for extreme precipitation (pluvial flooding), droughts, heat waves, wildfires and windstorms, are directly derived from meterological variables. The climate model simulation results that provide such variables, this time considering an ensemble approach but also climate models that are most up-to-date and available are the ones that form the basis of the 5th Assessment Report of the Intergovernmental Panel for Climate Change (IPCC, 2013, 2014). They are the climate model runs conducted by the Coupled Model Intercomparison Project of the World Climate Research Programme – Phase 5 (CMIP5). At the European scale, corresponding regional climate model simulations have been conducted by the EURO-CORDEX project. CORDEX (COordinated Regional climate Downscaling EXperiment) is an international ongoing downscaling project of the World Climate Research Programme (WCRP). One of its aims is to provide a quality-controlled data set of RCM simulations for the recent past and 21st century projections, covering the majority of populated land regions on the globe. They are based on GCM projections produced within the CMIP5. Their data archive can be found on: http://cordex.dmi.dk/.

The future climate model simulations with these models are available for the latest greenhouse gas scenarios by the IPCC, based on the Representative Concentration Pathways (RCP scenarios) (van Vuuren et al., 2011).

All climate change data were derived for the CMIP5 ensemble and the EURO-CORDEX ensemble. The CMIP5 ensemble is applied to correct the uncertainty range provided by the EURO-CORDEX ensemble, as per the methodology by Willems (2013), which is summarized next. When the full range of climate change signals derived from the EURO-CORDEX control runs are compared with the full range of climate change signals derived from the CMIP5 ensemble runs, systematic differences are found. It is assumed that these differences have two causes. The first cause is that the higher resolution RCMs provide change signals that systematically differ from the coarser resolution GCMs. Due to the higher resolution of the RCMs, their change signals may be more accurate for local impact impact analysis. The second cause is the difference in the ensemble set of models considered. The EURO-CORDEX RCMs were nested in a more limited set of GCMs than the full CMIP5 ensemble. And it is well-known that RCM results are strongly controlled by the GCM in which they are nested (Rummukainen, 2010). The climate change signals obtained from the RCM ensemble and the GCM ensemble were therefore compared in two ways: comparing the EURO-CORDEX versus CMIP5 climate change signals from the subset of common models, and comparing the CMIP5 climate change signals from this subset and the full ensemble. The subset of common models is for the CMIP5 GCMs the GCMs in which a RCM was nested for at least one of the available EURO-CORDEX runs. The comparison of climate change signals was done based by comparing the frequency distribution of all climate change signals considered, similar to the quantile mapping approach (Willems, 2013; Sunyer et al., 2015; Hundecha et al., 2016). In case a signifcant systematic difference was found between the frequency distributions of the EURO-CORDEX based climate change signals and the CMIP5 based climate change signals (for the subset of common models), correction factors or terms were derived and applied to the climate change signals of the full ensemble set of CMIP5 runs. These correction factors or terms could be derived on a quantile basis; correction terms for temperature, correction factors for the other meteorological variables. For the ensemble mean of climate change signals, for instance, the ratio of the ensemble mean for the EURO-CORDEX based changes over the mean of the CMIP5 changes was derived and considered representative for the systematic difference in climate change impact due to the higher model resolution; this factor was then applied to the ensemble mean obtained from the full CMIP5 ensemble with the aim to potentially improve or bias correct the latter mean. This type of correction was done for each meteorological variable that is considered on the basis of the hazard indicators considered in this report, and for each grid cell.

After this combined use of the CMIP5 and EURO-CORDEX ensembles and correction of the range of indicator values for each grid cell, the ensemble mean values are for each grid cell mapped as indicator values. It is important to note that these mean values should not be interpreted as the most likely future climate conditions. Different climate models may give higher or lower values. This uncertainty is not explicitly addressed here, but estimates are available through the ensemble approach, and may be considered for specific innovations and test cases at a later phase of the project.

The historical period considered is 1971–2000 and the future periods 2071-2100 (mean year 2085), 2016-2045 (mean year 2030), and 2036-2065 (mean year 2050). The changes are considered for the “median” and “high” RCP scenarios, which are the RCP4.5 and RCP8.5 scenarios.

All proposed indicators or loading conditions are derived from the following GCM/RCM output variables downloaded from the CMIP5 and EURO-CORDEX public databases: precipitation, maximum daily temperature, minimum daily temperature, mean daily temperature, wind speed, radiation, sea level pressure (SLP) and relative humidity.

Tables A1 and A2 show the list of climate model runs that were available and considered as CMIP5 and EURO-CORDEX ensembles for this study. The indicators were obtained at the resolutions of the regional and global climate models (the EURO-CORDEX runs were available at two spatial resolutions: 12 km and 50 km; both were considered here). At the end, for the tier 1 approach in this project, in order to obtain smooth spatial maps, hence to partly reduce the random uncertainty leading to variations between neighbouring cells, the results were averaged at the coarser resolution of the CMIP5 models. This avoids that additional spatial smoothing had to be conducted. The CMIP5 models have a spatial resolution that ranges between 1.12 and 3.75 degrees.

To obtain the future downscaled values of the indicators, the climate change signals derived from the climate models – as explained above – were applied to perturb the indicator values for the current climate. The indicator values for the current climate were obtained from observations and reanalysis datasets. For the heavy precipitation, heat wave and drought indicators, the E-OBS dataset of the European Climate Assessment was used, whereas the ERA-Interim reanalysis dataset was considered for the windstorm and wildfire indicators. The E-OBS dataset has the limitation that some raster cells have missing data. This leads to missing data for about 2.5% of the total set of 117,522 local units in the BRIGAID domain. The missing raster cells were not taken into account in the normalization process. For the original maps (before normalization), a version is available where the raster cells with missing data were interpolated or expanded for the cells with missing data at the border of the BRIGAID domain. The latter was done by expanding using the value of the closest raster cells. The disadvantage of the missing raster cells was considered limited in comparison with the advantage of the E-OBS data being based on station data, hence more accurate / less biased than climate model based results. Table A3 presents basic information on the datasets used for the historical climate. One note here is that because the ERA-Interim data start from 1979, the period 1979-2008 was considered as the historical period (to have also a 30-year period) for the wildfire and windstorm indicators. While perturbing the maps for the observations and reanalysis datasets with the climate change signals (which were obtained at the coarser resolutions of the climate models), the climate change signal maps were regridded to the finer resolution of the observations and reanalysis datasets. The latter resolutions are for each type of indicator reported in Table A3: 0.5 degree for the drought and heat wave indicators, 0.25 degree for the extreme precipitation indicator and 0.75 degree for the windstorm and wildfire indicators.

*Table A1. CMIP5 GCM runs used in this study for different indicators (control, RCP4.5 and RCP8.5 runs of each GCM were used)*

| GCM | Heavy precipitation / Droughts | Heat waves | Wildfires | Windstorms |
|---|---|---|---|---|
| ACCESS1-0_r1i1p1 | | ✓ | | ✓ |
| bcc-csm1-1_r1i1p1 | | ✓ | | |
| ACCESS1-3_r1i1p1 | ✓ | | | ✓ |
| bcc-csm1-1-m_r1i1p1 | ✓ | ✓ | | |
| BNU-ESM_r1i1p1 | ✓ | | | ✓ |
| CanESM2_r1i1p1 | ✓ | ✓ | | |
| CMCC-CMS_r1i1p1 | ✓ | ✓ | | ✓ |
| CNRM-CM5-r1i1p1 | ✓ | ✓ | ✓ | ✓ |
| CSIRO-Mk3-6-0_r1i1p1 | ✓ | | | |
| EC-EARTH_r12i1p1 | ✓ | | | |
| GFDL-CM3_r1i1p1 | | | | ✓ |
| GFDL-ESM2G_r1i1p1 | ✓ | ✓ | ✓ | ✓ |
| GFDL-ESM2M_r1i1p1 | ✓ | ✓ | ✓ | ✓ |
| HadGEM2-AO_r1i1p1 | ✓ | ✓ | | ✓ |
| HadGEM2-ES_r1i1p1 | ✓ | ✓ | | ✓ |
| HadGEM2-CC_r1i1p1 | | ✓ | | ✓ |
| inmcm4_r1i1p1 | ✓ | ✓ | ✓ | ✓ |
| IPSL-CM5A-LR_r1i1p1 | ✓ | ✓ | ✓ | ✓ |
| IPSL-CM5A-MR_r1i1p1 | ✓ | ✓ | ✓ | ✓ |
| IPSL-CM5B-LR_r1i1p1 | ✓ | | ✓ | ✓ |
| MIROC-ESM_r1i1p1 | ✓ | | | |
| MIROC-ESM-CHEM_r1i1p1 | ✓ | | | |
| MPI-ESM-LR_r1i1p1 | ✓ | ✓ | | ✓ |
| MPI-ESM-MR_r1i1p1 | ✓ | ✓ | | ✓ |
| MRI-CGCM3_r1i1p1 | ✓ | ✓ | ✓ | ✓ |
| NorESM1-M_r1i1p1 | ✓ | | | |

*Table A2. EURO-CORDEX RCM runs used in this study for different indicators (control, RCP4.5 and RCP8.5 runs of each RCM and indicator were used)*

| RCM | Driving GCM | Other hazard types | |
|---|---|---|---|
| | | 50 km resolution | 12 km resolution |
| SMHI-RCA4_v1 | CanESM2_r1i1p1 | ✓ | |
| CNRM-ALADIN53_v1 | CNRM-CM5_r1i1p1 | ✓ | ✓ |
| SMHI-RCA4_v1 | CNRM-CM5_r1i1p1 | ✓ | ✓ |
| CCLM4-8-17_v1 | CNRM-CM5_r1i1p1 | | ✓ |

| | | | |
|---|---|---|---|
| SMHI-RCA4_v1 | CSIRO-Mk3-6-0_r1i1p1 | ✓ | |
| SMHI-RCA4_v1 | EC-EARTH_r12i1p1 | ✓ | ✓ |
| IPSL-INERIS-WRF331F_v1 | IPSL-CM5A-MR_r1i1p1 | ✓ | ✓ |
| SMHI-RCA4_v1 | IPSL-CM5A-MR_r1i1p1 | ✓ | ✓ |
| SMHI-RCA4_v1 | MIROC5_r1i1p1 | ✓ | |
| SMHI-RCA4_v1 | HadGEM2-ES_r1i1p1 | ✓ | ✓ |
| CCLM4-8-17_v1 | HadGEM2-ES_r1i1p1 | | ✓ |
| KNMI-RACMO22E_v1 | HadGEM2-ES_r1i1p1 | | ✓ |
| CLMcom-CCLM4-8-17_v1 | MPI-ESM-LR_r1i1p1 | ✓ | ✓ |
| MPI-CSC-REMO2009_v1 | MPI-ESM-LR_r1i1p1 | ✓ | ✓ |
| SMHI-RCA4_v1 | MPI-ESM-LR_r1i1p1 | ✓ | ✓ |
| SMHI-RCA4_v1 | NorESM1-M_r1i1p1 | ✓ | |
| SMHI-RCA4_v1 | GFDL-ESM2M_r1i1p1 | ✓ | |

*Table A3. Basic information on the historical datasets used for the different indicators*

| Indicator | Dataset | Variable | Resolution (deg.) |
|---|---|---|---|
| Droughts | E-OBS | Precipitation | 0.50 |
| Heat waves | E-OBS | Maximum temperature | 0.50 |
| Wildfires | ERA-Interim | 10-m U wind component<br>10-m V wind component<br>2-m temperature<br>2-m dew point temperature | 0.75 |
| Windstorms | ERA-Interim | 10-m U wind component<br>10-m V wind component | 0.75 |
| Heavy precipitation | E-OBS | Precipitation | 0.25 |

## 3.2 Droughts

### Indicator

Drought loading conditions were assessed using the following indicator:

**The maximum number of consecutive dry days (CDD) when precipitation is less than 1 mm.**

The largest CDD in the 30-years period was considered. This indicators was chosen because IPCC uses the consecutive dry days index as indicator for droughts:

### Methodology

As explained in section 3.1, with the CDD computed as the length of the longest dry spell period in the full 30-year daily precipitation time series. A day will be considered dry wen the daily precipitation depth is less than 1 mm.

### Limitations and uncertainty

As for the heavy precipitation and heat waves indicators, the benefit of this indicator is that it is based on direct meteorological outputs of the climate models. The mean of a large ensemble of both global and regional climate model runs were considered. Hence, the climate change signals used on this basis of the droughts' indicator are expected to be rather robust. There are, however, some limitations:

- The mean climate change signal (mean obtained from the full set of climate models) does not provide information on the uncertainty in the climate change signal. This can be easily obtained from the ensemble results and will be considered in the tier 2 and/or 3 approaches.
- Next to the number of successive days with no or little rainfall days, there are many more properties of the temporal rainfall variability that are of importance for impact analysis of droughts, such as the cumulative rainfall amounts, the temperature and evaporation amounts, the impacts on soil moisture, low river flows, etc.
- Different types of drought related impacts exist. Quantification of such impacts would require a very specific type of local impact model.

## 3.3 Heat waves

### Indicator

Heat wave loading conditions were assessed using the following indicator:

**The number of heat waves over a period of 30 years**

This indicator was chosen because number of heat waves is used as indicator by the European Environment Agency.

Based on the WMO definition, heat waves are defined as periods of more than 5 consecutive days with daily maximum temperature exceeding the mean maximum temperature of the May to September season for the control period (1971–2000) by at least 5°C (Jacob et al., 2014).

### Methodology

As explained in section 3.1, with the heatwave indicator as defined above computed from the daily maximum temperature series.

### Limitations and uncertainty

The benefit of this indicator is that it is based on direct meteorological outputs of the climate models. The mean of a large ensemble of both global and regional climate model runs were considered. Hence, the climate change signals used on this basis of the heat waves' indicator are expected to be rather robust. There are, however, some limitations:

- The mean climate change signal (mean obtained from the full set of climate models) does not provide information on the uncertainty in the climate change signal. This can be easily obtained from the ensemble results and will be considered in the tier 2 and/or 3 approaches.
- Next to the number of heat waves, the intensity and duration of the heat waves may be important as well.

- Just one potential definition of heat waves, the WHO one, was considered whereas many more definitions exist, or information on the full temporal variability of temperature values may be useful for specific types of heat wave related impacts.
- Daily temperature values were considered whereas also the maximum and minimum daily temperature values are of importance as well.
- Different types of heat wave related impacts exist. Quantification of such impacts would require a very specific type of local impact model.

## 3.4 Wildfires

### Indicator

Wildfire loading conditions were assessed using the following indicator:

**The average daily Forest Fire Danger Index (FFDI).**

The FFDI was considered as indicator for this project, using the simplified version of the formula proposed by Noble et al. (1980). This formula is frequently used and can be computed directly from meteorological variables available in the climate model outputs.

### Methodology

As explained in section 3.1, the The Forest Fire Danger Index (FFDI; Noble et al., 1980) is defined as:

$$FFDI = 2\exp(0.987logD - 0.45 + 0.0338T + 0.0234V - 0.0345H \qquad (7)$$

where $H$ is the relative humidity from 0-100%, $T$ is the air temperature in degree Celsius, $V$ is the average wind speed 10 meters above ground, in meter per second and $D$ is the drought factor in range 0-10 (Sharples et al. 2009). The drought factor has its maximum value of 10.

For the wildfires' indicator, the ERA-Interim reanalysis dataset was considered for the historical period. Because relative humidity is not available in ERA-Interim dataset, the following procedure was used to calculate relative humidity from air temperature and dew point temperature:

$$RH = \frac{e_a}{e_s} \times 100 \qquad (8)$$

in which,

$$e_a = 0.6108 \exp\left(\frac{17.27T_{dew}}{237.3 + T_{dew}}\right) \qquad (9)$$

$$e_s = 0.6108 \exp\left(\frac{17.27T_{mean}}{237.3 + T_{mean}}\right) \qquad (10)$$

where $e_a$ is the actual vapor pressure, $e_s$ is the saturation vapor pressure, $T_{mean}$ is the air temperature and $T_{dew}$ is the dew point temperature.

Wind speed, which is another variable required for windfire computation, was calculated using the U (eastward wind) and V (northward wind) wind components based on the Pythagorean Theorem.

Finally, the Forest Fire Danger Index (FFDI) as a wildfire indicator was computed following eq. 7. This was done for each day of the time series and the final index computed by averaging the FFDI for all days of the 30-year time series.

### Limitations and uncertainty

As for the heavy precipitation, heat waves and droughts indicators, the benefit of this indicator is that it is based on direct meteorological outputs of the climate models. The mean of a large ensemble of both global and regional climate model runs were considered. Hence, the climate change signals used on this basis of the wildfires' indicator are expected to be rather robust. There are, however, some limitations:

- The mean climate change signal (mean obtained from the full set of climate models) does not provide information on the uncertainty in the climate change signal. This can be easily obtained from the ensemble results and will be considered in the tier 2 and/or 3 approaches.
- The average index for all days of the 30-year period was considered, whereas specific drought seasons would be more relevant.
- Other meteorological and hydrological conditions next to relative humidty, air temperature and wind speed may play a role but were not considered such as precipitation.
- Wildfires are in different regions of Europe induced by other meteorological and hydrological conditions. Hence, different indicators may need to be considered. This will be done in the tier 2 and/or 3 approaches.

## 3.5 Windstorms

### Indicator

Windstorm loading conditions were assessed using the following indicator:

**The 99$^{th}$ percentile of daily wind speed.**

The 99$^{th}$ percentile was selected as to consider more extreme wind storms.than the European Environment Agency, which considers changes in the 98$^{th}$ percentile of daily maximum wind speed as an indicator of wind storms.

### Methodology

As explained in section 3.1, considering the windstorm indicator as defined above considering the daily wind speed time series.

### Limitations and uncertainty

As for the other indicators, except for the coastal and rivers floods' indicators, the benefit of this indicator is that it is based on direct meteorological outputs of the climate models. The mean of a large ensemble of both global and regional climate model runs were considered. Hence, the climate change signals used on this basis of the wind storms indicator are expected to be rather robust. There are, however, some limitations:

- The mean climate change signal (mean obtained from the full set of climate models) does not provide information on the uncertainty in the climate change signal. This can be easily obtained from the ensemble results and will be considered in the tier 2 and/or 3 approaches.
- Just one percentile, $99^{th}$, was considered, which corresponds to medium severity storms. Less extreme wind storms may also cause damage.
- The specific impact of extreme wind storms may depend on the types of buildings and other local conditions, which need to be considered in a more specific / detailed impact analysis, which may be applied in the tier 2 and/or 3 approaches.

## 3.6 Heavy precipitation

### Indicator

Heavy precipitation loading conditions were assessed using the following indicator:

**Daily precipitation amount with a return period of 5 years**

This indicator was chosen because most urban drainage systems are designed for return periods between 2 and 20 years.

### Methodology

As explained in section 3.1, with the heavy precipitation indicator as defined above, considering the daily precipitation time series. The return period *T* was computed in an empirical way:

$$T = \frac{n}{i} \tag{11}$$

with *T* being the return period in number of years, *n* the length of the time series (30 years in this case), and *i* the rank number of the daily precipitation intensity (*i*=1 for the highest intensity in the full 30-year time series, *i*=2 for the second highest, …).

### Limitations and uncertainty

The benefit of this indicator is that it is based on direct meteorological outputs of the climate models. The mean of a large ensemble of both global and regional climate model runs were considered. Hence, the climate change signals used on this basis of the heavy precipitation indicator are expected to be rather robust. There are, however, some limitations:

- The mean climate change signal (mean obtained from the full set of climate models) does not provide information on the uncertainty in the climate change signal. This can be easily obtained from the ensemble results and will be considered in the tier 2 and/or 3 approaches.

- Daily precipitation may not be fully representative for pluvial flooding such as flooding as a consequence of sewer surcharge. Many urban drainage systems have response times smaller than 1 day, which means that sub-daily precipitation may be more appropriate. The most relevant time scale does, however, vary from system to system. Moreover, sub-daily precipitation data are only available for a limited number of climate model runs.

- Just one selected return period was considered whereas urban drainage systems in different parts of Europe are designed for various return period, typically in the range between 2 and 20 years. The return period was empirically assessed.

- Just one season was considered whereas the heavy precipitation amounts in many places of Europe strongly vary from season to season.

- This first … mm of rainfall will be stored in the underground sewer network, hence does not contribute to the urban flooding. A threshold could be applied to the heavy precipitation intensities or the exceedance above this threshold considered but this threshold strongly depends on the specific system properties.

- For the impact analysis on pluvial flooding, an urban drainage and surface inundation model would be required. Such models are very detailed and should be considered for local impact analysis.

# 4 Normalization of loading conditions

Innovations dealing with different hazards need to be evaluated in a way that allows a direct comparison of their utility. That requires normalized loading conditions. Here, normalization is carried out by establishing the spatial distribution of the intensity of the hazard indicators. This was done at three levels: local, regional and national. At each level, different aggregation method was used, but all involved political divisions of Europe: countries, regions and local administrative units. Table A4 summarizes the geographical units used in the normalization, while further details are provided in the following subsections.

*Table A4. Summary of units at national, regional and local scale. Names of regional and local units in national languages. Source: based on European Union (2014) and Eurostat (2015, 2017).*

| NATIONAL | | | | REGIONAL | | LOCAL | |
|---|---|---|---|---|---|---|---|
| NUTS 0 | Country | Area (km²) | Population (1-1-2015) | Names of units* | No. of units | Names of units* | No. of units |
| AT | Austria | 83 879 | 8 576 261 | *Gruppen von Bezirken* | 35 | Gemeinden | 2 354 |
| BE | Belgium | 30 530 | 11 237 274 | Arrondissementen / Arrondissements*** | 44 | Gemeenten / Communes | 589 |
| BG | Bulgaria | 110 370 | 7 202 198 | Oblasti | 28 | Naseleni mesta | 4 617 |
| HR | Croatia | 56 600 | 4 225 316 | Županije | 21 | Gradovi, općine | 556 |
| CY | Cyprus | 9 251 | 847 008 | - | 1 | Demoi, koinotites | 614 |
| CZ | Czech Republic | 78 868 | 10 538 275 | Kraje | 14 | Obce | 6 253 |
| DK | Denmark | 42 923 | 5 659 715 | *Landsdele* | 11 | Sogne | 2 178 |
| EE | Estonia | 45 227 | 1 314 870 | *Maakondade rühmad* | 5 | Linn, vald | 230 |
| FI | Finland | 338 440 | 5 471 753 | Maakunnat / Landskap | 19 | Kunnat / Kommuner | 320 |
| FR | France** | 543 965 | 64 343 948 | Départements | 96 | Communes | 36 573 |
| DE | Germany | 357 367 | 81 197 537 | Kreise, kreisfreie Städte | 402 | Gemeinden | 11 426 |
| EL | Greece | 132 049 | 10 858 018 | *Omades perifereiakés enótites* | 52 | Demoi | 326 |
| HU | Hungary | 93 011 | 9 855 571 | Megyék + Budapest | 20 | Települések | 3 154 |
| IS | Iceland | 103 000 | 329 100 | *Hagskýrslusvæði* | *2* | Sveitarfélög | 74 |
| IE | Ireland | 69 797 | 4 628 949 | *Regional Authority Regions* | 8 | Electoral Districts | 3 441 |
| IT | Italy | 302 073 | 60 795 612 | Province | 110 | Comuni | 8 092 |
| LV | Latvia | 64 573 | 1 986 096 | *Statistiskie reģioni* | *6* | Republikas pilsētas, novadi | 119 |
| LI | Liechtenstein | 160 | 37 366 | - | 1 | Gemeinden | 11 |
| LT | Lithuania | 65 286 | 2 921 262 | Apskritis | 10 | Seniūnijos | 563 |
| LU | Luxembourg | 2 586 | 562 958 | - | 1 | Communes | 106 |
| MK | Macedonia | 25 436 | 2 068 864 | *Statistički regioni* | *8* | Naseleni mesta | 1 817 |
| MT | Malta | 315 | 429 344 | *Gzejjer* | *2* | Kunsilli | 68 |
| NL | Netherlands | 41 540 | 16 900 726 | *COROP-gebieden* | *40* | Gemeenten | 408 |
| NO | Norway | 323 772 | 5 166 493 | Fylker | *19* | Kommuner | 428 |
| PL | Poland | 312 679 | 38 005 614 | *Podregiony* | *72* | Gminy | 2 479 |
| PT | Portugal** | 89 103 | 9 869 783 | Entidades Intermunicipais (Comunidades Intermunicipais + Áreas Metropolitanas) | 23 | Freguesias | 4 050 |
| RO | Romania | 238 391 | 19 870 647 | Județe + Bucuresti | 42 | Comuni, municipii, orașe, sectoarele Bucureștiului | 3 186 |
| SK | Slovakia | 49 035 | 5 421 349 | Kraje | 8 | Obce | 2 927 |
| SI | Slovenia | 20 273 | 2 062 874 | *Statistične regije* | 12 | Občine | 211 |
| ES | Spain** | 498 466 | 44 154 159 | Provincias + consejos insulares | 50 | Municipios | 8 110 |
| SE | Sweden | 438 574 | 9 747 355 | Län | 21 | Kommuner | 290 |
| CH | Switzerland | 41 291 | 8 237 666 | Kantone / Cantons / Cantoni | 26 | Gemeinden / Communes / Comuni | 2 453 |
| UK | United Kingdom | 248 530 | 64 875 165 | *Upper-tier authorities or groups of lower-tier authorities (unitary authorities or districts)* | 173 | Wards (or parts thereof) | 9 499 |
| | **Total study area** | **4 857 361** | **519 399 126** | **Total no. of regional units** | **1 382** | **Total no. of local units** | **117 522** |

Notes: * names of regional and local units are given in the administrative languages of their respective countries (separated by a slash). Regional units that are statistical regions rather than actual administrative divisions are indicated in italics; ** Excludes parts of the countries that are located outside the study's domain; *** including one region split by two language communities.

## 4.1 Local level

At local level, the normalization was carried out firstly by averaging the indicators' values for every local administrative unit (LAU) in the study area. Then, an empirical probability distribution of each aggregated indicator over Europe was obtained. Hence, for an innovation applicable to a certain intensity of a natural hazard, the corresponding percentile of the normalized distribution of hazard can be calculated. For the hydrological indicators, the average was calculated from all available estimates within a given LAU without weighting. For the meteorological indicators, a weighted average based on grid cells' areas was used.

The aim of using LAUs, which equal municipalities or similar units, is to capture the lowest, local decision level. In many countries, LAUs are the most important layer of administration apart from the central government. They are responsible for a significant part of road infrastructure, waste and water management, spatial planning, housing, volunteer fire service, schools, social care or sometimes even health care and other rescue services.

The local administrative units were defined using Eurostat's two-level LAU classification (Eurostat 2015). The lowest level (LAU 2) was used for all countries, except for Greece, for which LAU 1 units had to be used due to data availability[6]. The boundaries of LAUs were obtained from a map provided by Eurostat (2017), originally developed by EuroGeographics. The precision of the boundaries' geometrical representation corresponds to a 1:1,000,000 scale map, which is sufficient for the purposes of this analysis. The administrative divisions in the map are nominally accurate as of 2013[7].

There are almost 118,000 LAU 2 units in the study area (see Table A4). They vary greatly in size: the Swedish municipality of Kiruna has an area of around 20,000 km$^2$, while more than a thousand LAUs are smaller than 1 km$^2$. By population, the German city of Berlin is the biggest LAU 2 unit with more than 3 million inhabitants, whereas some local units have less than a dozen inhabitants, according to Eurostat (2017).

## 4.2 Regional level

At regional level, the normalization was carried out firstly by averaging the indicators' values for every regional unit in the study area. Then, an empirical probability distribution of each aggregated indicator over Europe was obtained. Hence, for an innovation applicable to a certain intensity of a natural hazard, the corresponding percentile of the normalized distribution of hazard can be calculated. Additionally, the total population and gross domestic product (GDP) is calculated for regional units within that percentile, and divided by the grand total for entire the study area. This creates an empirical probability distribution corrected by taking into account the different size of regional units. For the hydrological indicators, the

[6] In some countries (Estonia, France, Germany, Lithuania, Macedonia, Spain and Switzerland) there are areas not belonging to any local administrative unit, typically forest compounds, lakes or military zones. Nonetheless, those areas have their LAU identifiers, and were therefore included in the map of LAUs. Also, in case of Ireland and United Kingdom, electoral divisions are used by Eurostat as LAU 2 units instead of administrative divisions; this is largely due to the heterogenous and complex system of local government in those countries, especially in the UK.

[7] The map was corrected by aggregating LAU units for Latvia and Slovenia, as the map showed the level of localities, which is one level down from LAU 2 classification.

average was calculated from all available estimates within a given region without weighting. For the meteorological indicators, a weighted average based on grid cells' areas was used.

Regions are important geographical, administrative, economical or cultural divisions of countries. Here, we utilize EU's *Nomenclature of Territorial Units for Statistics* (NUTS), version 2013. The NUTS regions are either administrative divisions of countries, or groupings of smaller administrative units created purely for statistical purposes. The aim of the NUTS classification is to reduce differences in the population of units of the same level. NUTS uses three levels – 1, 2 and 3. Additionally, national level is considered to be level "0". The most detailed level 3 (NUTS 3) was utilized in this study. As presented in Table A4, in 17 countries NUTS 3 indicates actual administrative units and in 13 – statistical regional units (indicated by italics). Yet, in a given country, some of the statistical units might also be actual administrative units. In the remaining 3 countries no subdivisions are distinguished at this level, as the countries are too small; in other words, the whole country constitutes a single NUTS 3 region. It should be noted that the NUTS classification was also implemented in the EU law[8] and is currently used e.g. for allocating structural funds (Eurostat 2015).

The boundaries of NUTS 3 units (2013 edition) were obtained from a map provided by Eurostat (2017), originally developed by EuroGeographics. The precision of the boundaries' geometrical representation corresponds to a 1:1,000,000 scale map, which is sufficient for the purposes of this analysis[9]. To complete the normalization process, the following statistical data at regional level were collected from Eurostat (2017)[10]:

- Resident population as of 1 January 2015 and
- GDP in current prices in euro generated in 2014.

A statistical summary of the 1382 regions is shown in Table A5. Regions vary greatly in size and wealth, with the largest and wealthiest being metropolises or their parts (Madrid, Paris, London). Meanwhile, many regions in eastern and northern Europe are sparsely populated or relatively poor.

*Table A5. Summary statistics for NUTS 3 regions in the study area. Source: based on Eurostat (2017)*

| Category | Study area total | Study area average | Largest region | | Smallest region | |
|---|---|---|---|---|---|---|
| Area (km²), 1-1-2015 | 4 857 361 | 3515 | SE332 Norrbottens län | 105 205 | UKI42 Tower Hamlets | 22 |
| Population ('000s), 1-1-2015 | 517 399 | 375.8 | ES300 Madrid | 6385.3 | CH054 Appenzell Innerrhoden | 15.9 |
| Population density per km² | 107 | X | FR101 Paris | 20 976 | IS002 Landsbyggd | 1 |
| GDP (bln euro), 2014 | 14 710 | 10.3 | FR101 Paris | 207 | EL643 Evrytania | 0.2 |
| GDP per capita ('000 euro) | 28.3 | X | UKI31 Camden and City of London | 410.3 | MK006 Pološki | 1.9 |

[8] For the official listing of all NUTS 2013 units within the EU, see European Union (2014). For a list of NUTS units of non-EU states, see Eurostat (2017).

[9] The map was modified by adding the autonomous Mount Athos to region EL527 Chalkidiki, as this entity is the only LAU unit in the EU not included in any NUTS region.

[10] Except for GDP data for for Switzerland, which are from Bundesamt für Statistik (2017). Regional GDP is not available for Iceland; GDP per capita was assumed the same in both NUTS3 regions of Iceland.

## 4.3 National level

At national level, the normalization is carried out by calculating the 95$^{th}$ percentile of the indicators' values for every country in the study area. Then, an empirical probability distribution of each aggregated indicator is obtained. Hence, for an innovation applicable to a certain intensity of a natural hazard, the corresponding percentile of the normalized distribution of hazard can be calculated. For the hydrological indicators, the 95$^{th}$ percentile was calculated from all available estimates within a given country. In case of the meteorological indicators, the data were sampled using a regular 5 km mesh of points.

The study area is composed of countries with very different sizes and territorial structures (Table A4). At the national level, mitigation of natural hazards is done by the central governments and their agencies. This layer of administration usually has the most financial means and authority to employ innovations in dealing with natural hazards, through research & development, water management, infrastructure or environmental administrations and their budgets. However, the country-wide scale of operations of those institutions also implies they will be interested mainly in innovations applicable for the majority, if not all, of their territories. Hence, the 95$^{th}$ percentile of hazard intensity is considered here, as it is a benchmark of (nearly) universal applicability of the innovation in a given country.

As for local and regional level, the boundaries of countries were obtained from a map provided by Eurostat (2017), originally developed by EuroGeographics.

# 5 Results

In this section, the distribution of hazard is analysed for the historical and climate change scenarios. In Table A6, the average and extreme values of each indicator per scenario and normalization level are presented. Each hazard is described in a separate section, together with a map depicting the normalization at regional level, followed by graphs with the distribution of hazard in Europe at all levels and scenarios.

*Table A6. Summary results of normalized loading conditions by level, indicator and scenario. The statistics are only for units for which estimates of loading conditions for given hazard were available.*

| Hazard | Indicator | Scenario | Local normalization (by percentile) | | | Regional normalization (by percentile)* | | | National normalization | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 5% | 50% | 95% | 5% | 50% | 95% | Min | Mean | Max |
| Coastal floods | Storm surge height, 100-year return period, in meters** | *hist* | 0.09 | 0.25 | 0.56 | 0.09 | 0.25 | 0.70 | 0.08 | 0.41 | 0.87 |
| | | *rcp4.5* | 0.30 | 0.55 | 1.08 | 0.12 | 0.47 | 1.11 | 0.21 | 0.65 | 1.37 |
| | | *rcp8.5* | 0.50 | 0.72 | 1.08 | 0.36 | 0.66 | 1.06 | 0.45 | 0.82 | 1.57 |
| River floods | River water level, 100-year return period, in meters** | *hist* | 0.09 | 0.26 | 1.24 | 0.15 | 0.35 | 1.11 | 0.39 | 1.43 | 2.88 |
| | | *rcp4.5* | 0.07 | 0.32 | 1.74 | 0.10 | 0.40 | 1.55 | 0.37 | 1.89 | 4.13 |
| | | *rcp8.5* | 0.07 | 0.34 | 1.93 | 0.08 | 0.43 | 1.67 | 0.41 | 1.97 | 4.79 |
| Droughts | Maximum number of consecutive days when precipitation is ≤1 mm | *hist* | 32 | 42 | 102 | 30 | 40 | 97 | 30 | 71 | 188 |
| | | *rcp4.5* | 35 | 48 | 126 | 33 | 45 | 122 | 29 | 79 | 205 |
| | | *rcp8.5* | 38 | 56 | 150 | 34 | 50 | 139 | 32 | 88 | 213 |
| Heat waves | Total number of heat waves in 30 years*** | *Hist* | 16 | 38 | 58 | 19 | 38 | 51 | 15 | 47 | 80 |
| | | *rcp4.5* | 50 | 97 | 124 | 54 | 90 | 114 | 46 | 101 | 150 |
| | | *rcp8.5* | 70 | 119 | 146 | 77 | 117 | 139 | 68 | 125 | 181 |
| Wildfires | Average daily Forest Fire Danger Index [-] | *Hist* | 0.43 | 0.52 | 0.81 | 0.40 | 0.50 | 0.77 | 0.37 | 0.63 | 1.26 |
| | | *rcp4.5* | 0.47 | 0.59 | 0.95 | 0.44 | 0.56 | 0.90 | 0.41 | 0.72 | 1.54 |
| | | *rcp8.5* | 0.49 | 0.66 | 1.13 | 0.47 | 0.62 | 1.09 | 0.46 | 0.82 | 1.93 |
| Windstorms | 99th percentile of daily wind speed [m/s] | *hist* | 4.6 | 8.5 | 12.3 | 4.7 | 8.8 | 12.1 | 4.1 | 10.7 | 16.4 |
| | | *rcp4.5* | 4.5 | 8.4 | 12.2 | 4.6 | 8.8 | 12.0 | 4.1 | 10.6 | 16.2 |
| | | *rcp8.5* | 4.5 | 8.5 | 12.3 | 4.6 | 8.9 | 12.1 | 4.1 | 10.6 | 15.9 |
| Heavy precipitation | Daily precipitation with a 5-year return period [mm] | *hist* | 28.5 | 38.0 | 69.6 | 30.4 | 38.5 | 69.1 | 33.8 | 57.5 | 117.5 |
| | | *rcp4.5* | 31.4 | 41.8 | 75.5 | 33.5 | 42.5 | 74.6 | 37.8 | 62.9 | 131.0 |
| | | *rcp8.5* | 33.5 | 45.3 | 79.8 | 36.0 | 46.0 | 80.9 | 41.3 | 68.5 | 143.5 |

Notes: * percentile of regional units, not regional population or GDP; ** above 10-year surge height (coastal) or water level (river) in the historical scenario; *** periods of more than 5 consecutive days with daily maximum temperature exceeding the mean maximum temperature of the May to September season for the control period (1971–2000) by at least 5°C.

## 5.1 Coastal floods

Out of seven hazards considered in this report, coastal floods have the smallest spatial extent. Only 30,000–50,000 km$^2$, or less than 1%, of the study area is at risk of a 1 in 100 years flood (depending on the methodology of calculating flood extents; Vousdoukas et al. 2016). Merely 5.3% (6,275) of local administrative units, 29% (394) of regions and 76% (25) of countries have access to the coastline. The indicator of coastal flood hazard, therefore, was only calculated for those units and the percentiles pertain only to them. The indicator shows the difference between 100-year and 10-year storm surges.

Overall, the values of the indicator in the historical scenario (1971–2000) are rather low, and range from 7 to 94 cm at local level. In approx. 80% of local units the value of the indicator is below 40 cm. At regional level, units with larger GDP indicate slightly higher hazard than those with large populations (Fig. A5). In Fig. A4 sharp geographic divisions are visible in the distribution of surge heights. In the Mediterrenean or Black seas, surges are mostly no larger than half a metre, therefore the flood hazard indicator does not exceed 20 cm in most of southern European countries. Only in the northern part of the Adriatic Sea, surges could be larger, with Venice being one of the endangered locations in that area. Hazard increases moving northwards, with only small surges in the Portuguese or Spanish coasts. In the French coast, the hazard indicator rises from the middle quintile by the Bay of Biscay to the top quintile in the English (La Manche) Channel. Highest surge are observed in the southern coasts of the North Sea, i.e. in Belgium, Denmark, Germany, the Netherlands and the UK. Large surges are also present in the entire Baltic Sea, especially in its southern and eastern coasts, from Germany through Poland, Lithuania, Latvia, Estonia up to Finland. Meanwhile, hazard in the middle quintile or lower can be observed in Norway, Iceland or Ireland. Those patterns are the result of the distribution of paths of extra-tropical cyclones (ETCs). They typically sweep Europe eastwards, starting with southern England or northern France and continuing through the southern North Sea into Scandinavia. Additionally, storms cause seawater to move through the Danish Straits into the Baltic Sea, filling the basin and resulting in potentially very large surges in the German and Polish coasts. Meanwhile, the Mediterrean region and far north of Europe are outside the main paths of ETCs. In southern Europe, occurrence of tropical cyclones is possible, though they only exceptionally form in the Atlantic Ocean near Europe.

It is projected that, in general, storm surges will become more intense in the future. An average 100-year surge at local or regional level will be 30–50 cm higher in 2071–2100 compared to 1971–2000. In the upper quintile, a future 100-year surge will be about 90–100 cm above 10-year surge in the historical scenario. However, there are many differences between various parts of Europe, as three distinct factors have to be considered: changes in storm patterns, sea level rise and glacial isostatic adjustment. In 5% (311, RCP 4.5) or 3% (172, RCP 8.5) local units the hazard will decrease. Those are mostly located in the Baltic Sea, where storms will become weaker as their main paths will move further north, and sea level rise will be largely offset by the upwards movement of the Earth’s crust (up to 1 cm per year). In the south of Europe, sea level rise will multiply the values of the indicator even 6-fold (RCP 4.5) and 10-fold (RCP 8.5). In the western coasts of Europe (Iberian peninsula, France, the British Isles) both sea level rise and increased storm activity will contribute to higher surges.

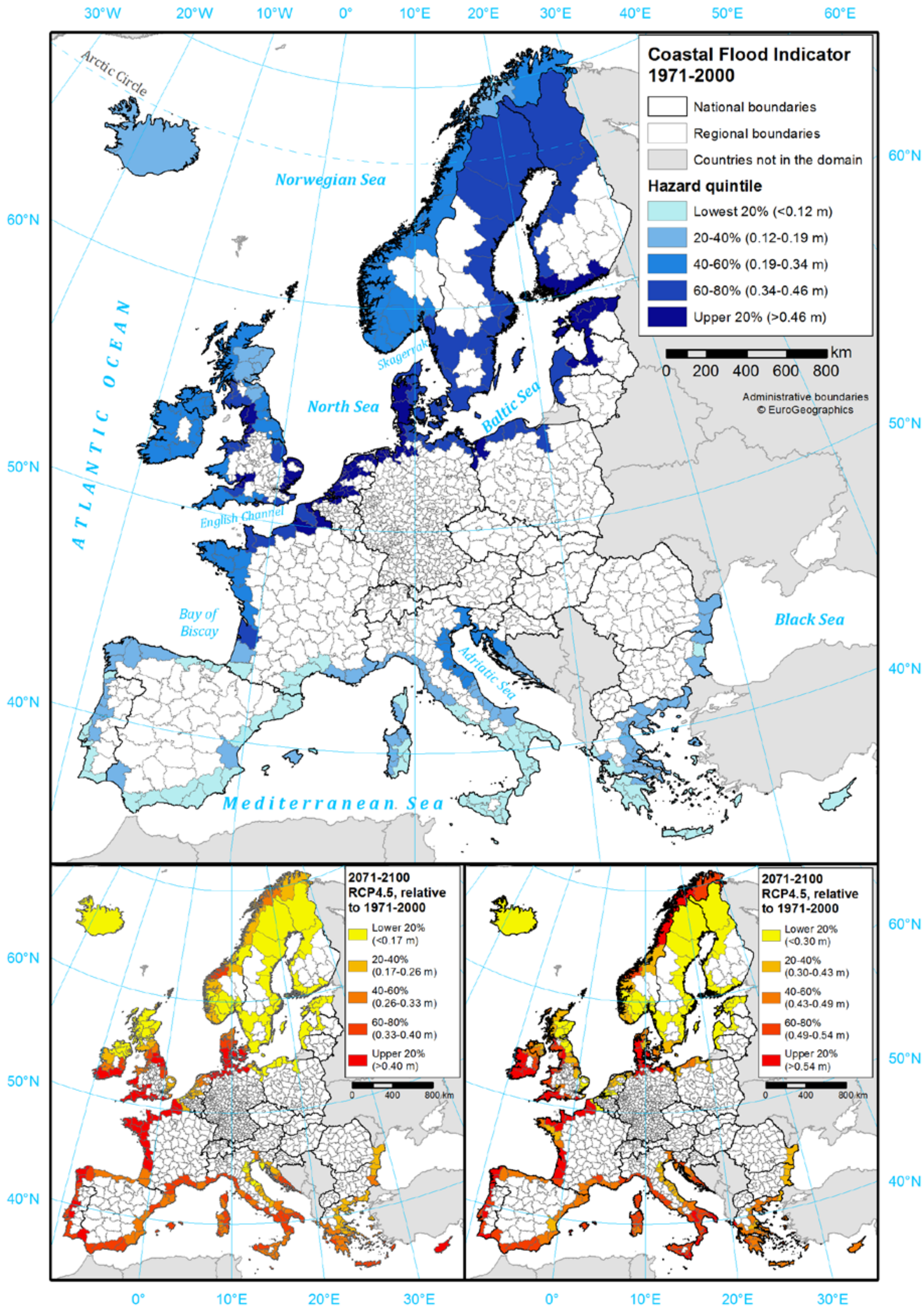


*Figure A4. Quintiles of normalized coastal flood hazard indicator at regional level for historical scenario (main map) and relative change (subtraction) between 2071–2100 and 1971–2000, in two scenarios.*

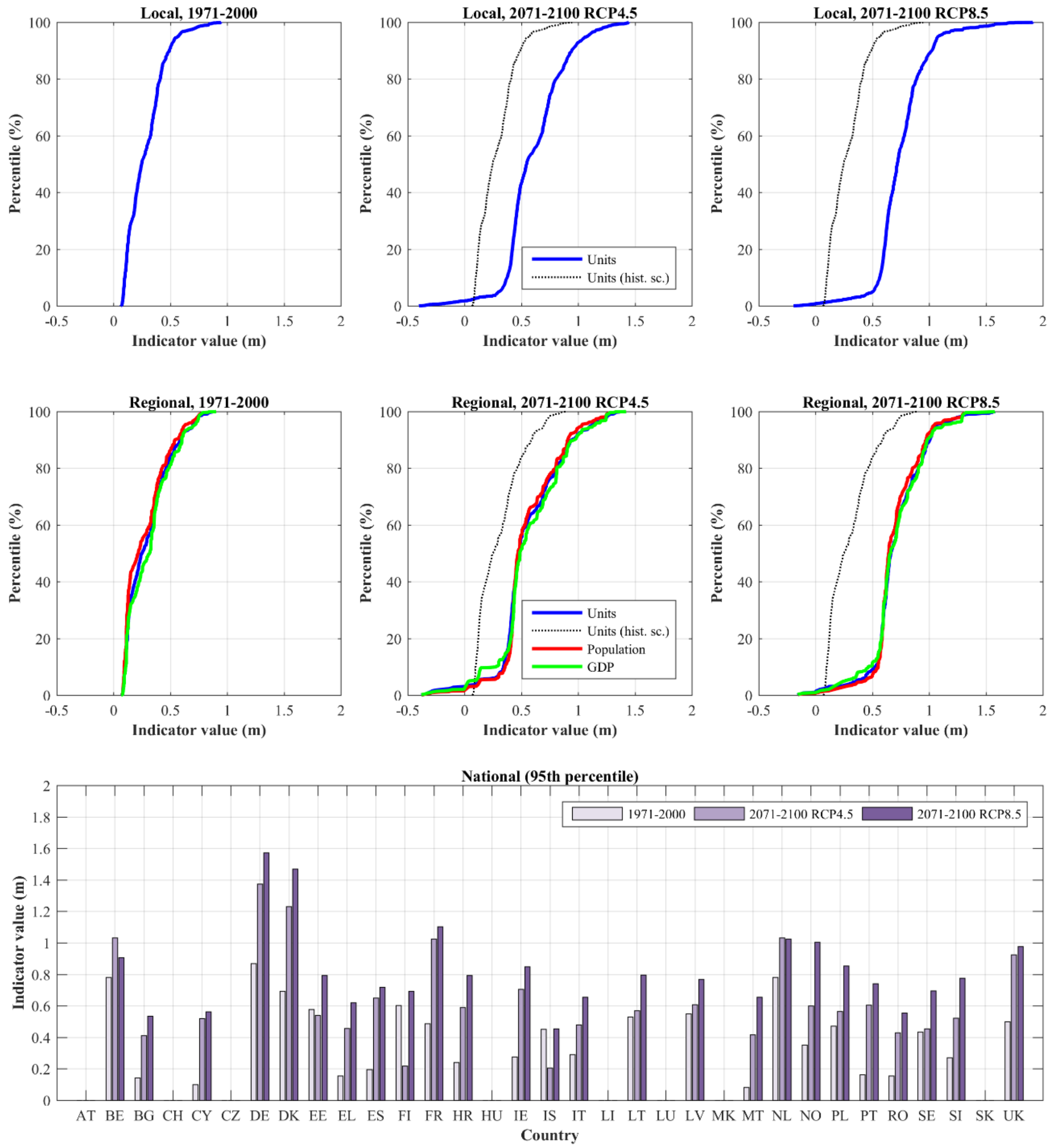


*Figure A5. Normalized coastal flood hazard indicator at local, regional and national level, by climate scenario. Histograms only for units connected to the coastline (6275 local, 394 regional). For country codes, see Table A4.*

## 5.2 River floods

River floods have a larger spatial extent than coastal floods, however it also pertains only to part of Europe. According to 100-year flood zone delimitation by Paprotny et al. (2017), the hazard is extends over 293,000 $km^2$, or 6%, of the study area. A total of 42% (49,369) of local administrative units, 97% (1,338) of regions and all countries except Malta have access to rivers with catchment area larger than 100 $km^2$. The indicator of river flood hazard, therefore, was only calculated for those units and the percentiles pertain only to them. The indicator shows the difference between 100-year and 10-year river water level.

Overall, the values of the indicator in the historical scenario (1971–2000) are diversified, which is largely caused by different size of catchments. In approx. 80% of local units the value of the indicator is below 50 cm. At regional level, units with larger GDP indicate slightly higher hazard than those with large populations (Fig. A7). In Fig. A6 the are no distinct geographic divisions in the distribution of water levels. Regions with the highest average water levels are concentrated around large rivers, as outlines of Danube, Elbe, Loire, Po, Rhine or Vistula rivers could be clearly seen. Elevated values of the indicator could be be found in more mountainous areas (Norway, Portugal, Spain, Switzerland).

It is projected that, in general, extreme river water levels will be higher in the future. An average  100-year surge at local or regional level will be about 10 cm higher in 2071–2100 compared to 1971–2000. In the upper quintile, a future 100-year water level will be about 80–90 cm above 10-year level in the historical scenario. However, the trends will vary enormously from one location to another. In about 30% (RCP 4.5) or 40% (RCP 8.5) of local units the hazard is actually projected to decrease. Negative trends will mostly occur in northern Europe due to substantially reduced snowfall, which in turn would cause less severe snowmelt. In most of other locations, including large parts central and southern Europe, more cases fo extreme rainfall are expected, resulting in higher frequency of extreme river flow occurrences. From the histograms in Fig. A7 it can be noticed that regions with larger population and GDP are slightly lower at risk of adverse changes in water levels in the future.

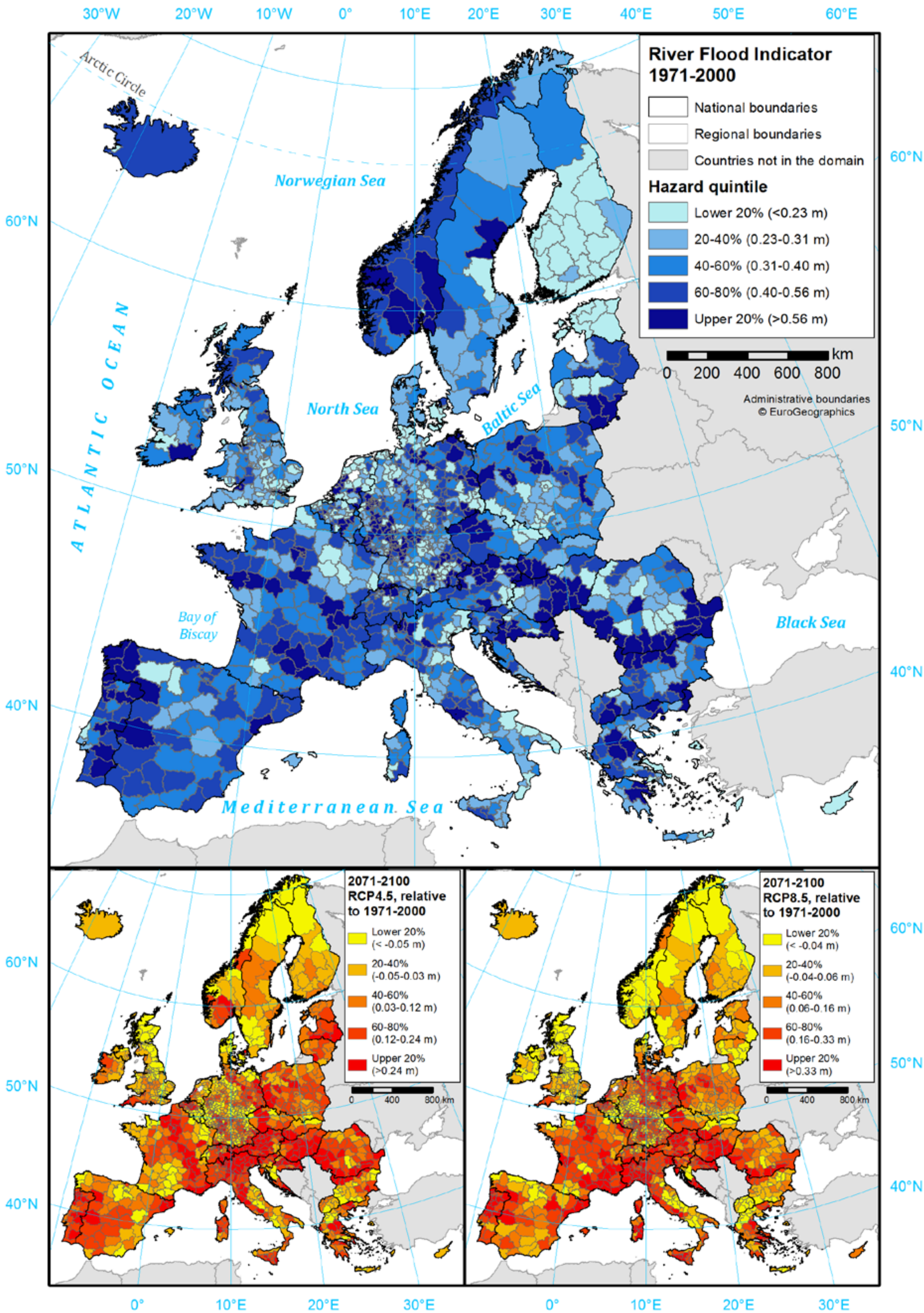


*Figure A6. Quintiles of normalized river flood hazard indicator at regional level for historical scenario (main map) and relative change (subtraction) between 2071–2100 and 1971–2000, in two scenarios.*

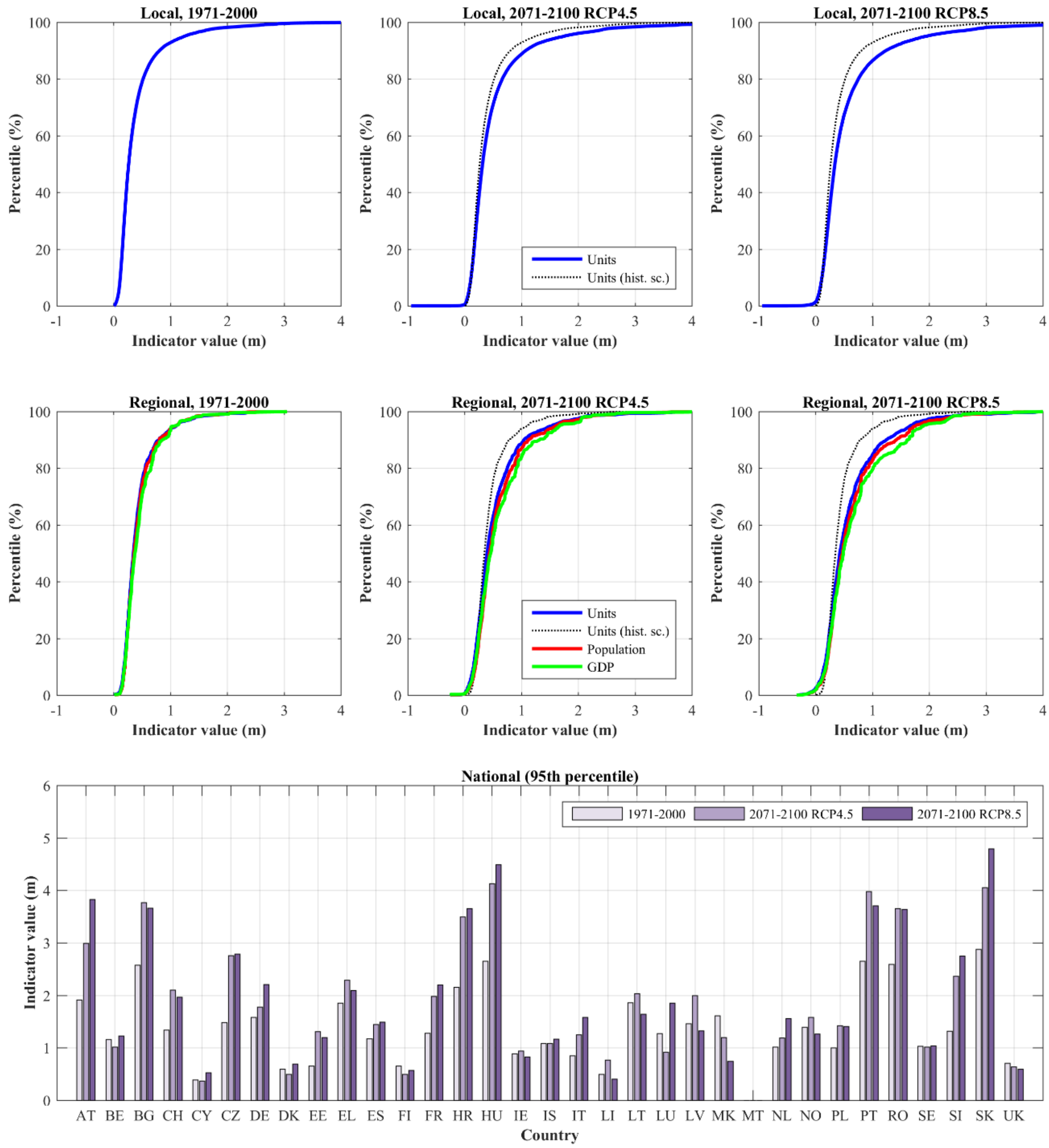


*Figure A7. Normalized river flood hazard indicator at local, regional and national level, by climate scenario. Histograms only for units for which river water level estimates were available (49,369 local, 1338 regional). For country codes, see Table A4.*

## 5.3 Droughts

The droughts’ hazard indicator based on the CDD indicator, which represents the maximum number of consecutive dry days when precipitation is less than 1 mm and shows strong regional differences. Figure A8 shows a strong north-south variation in the number of CDDs with much higher drought hazard conditions in Southern Europe. At the national level, the Southern European countries Cyprus, Spain, Portugal, Greece and Italy have the highest CDD indicator days (Figure A9). In the historical climate (1971-2000), the 5 and 95 percentiles of CDDs across Europe are 28 and 99. They are projected to increase all over Europe, with increases up to more than 8 CDDs for RCP4.5 and more than 18 CDDs for RCP8.5 (Table A6). This causes an increase of the 5 and 95 percentiles of the total number of CDDs across Europe from 28 - 99 (historical climate) to 31 – 125 (RCP4.5) and 32 – 149 (RCP8.5). The changes are strongest for the more dry countries of Southern Europe. The maximum number of CDDs at the regional level increases from 97 (historical climate) to 121 (RCP4.5) and 139 (RCP8.5). The mean number of CDDs at the regional level increases from 40 (historical climate) to 45 (RCP4.5) and 50 (RCP8.5). At the national level, the maximum number of CDDs increases from 188 (historical climate) to 205 (RCP4.5) and 213 (RCP8.5).

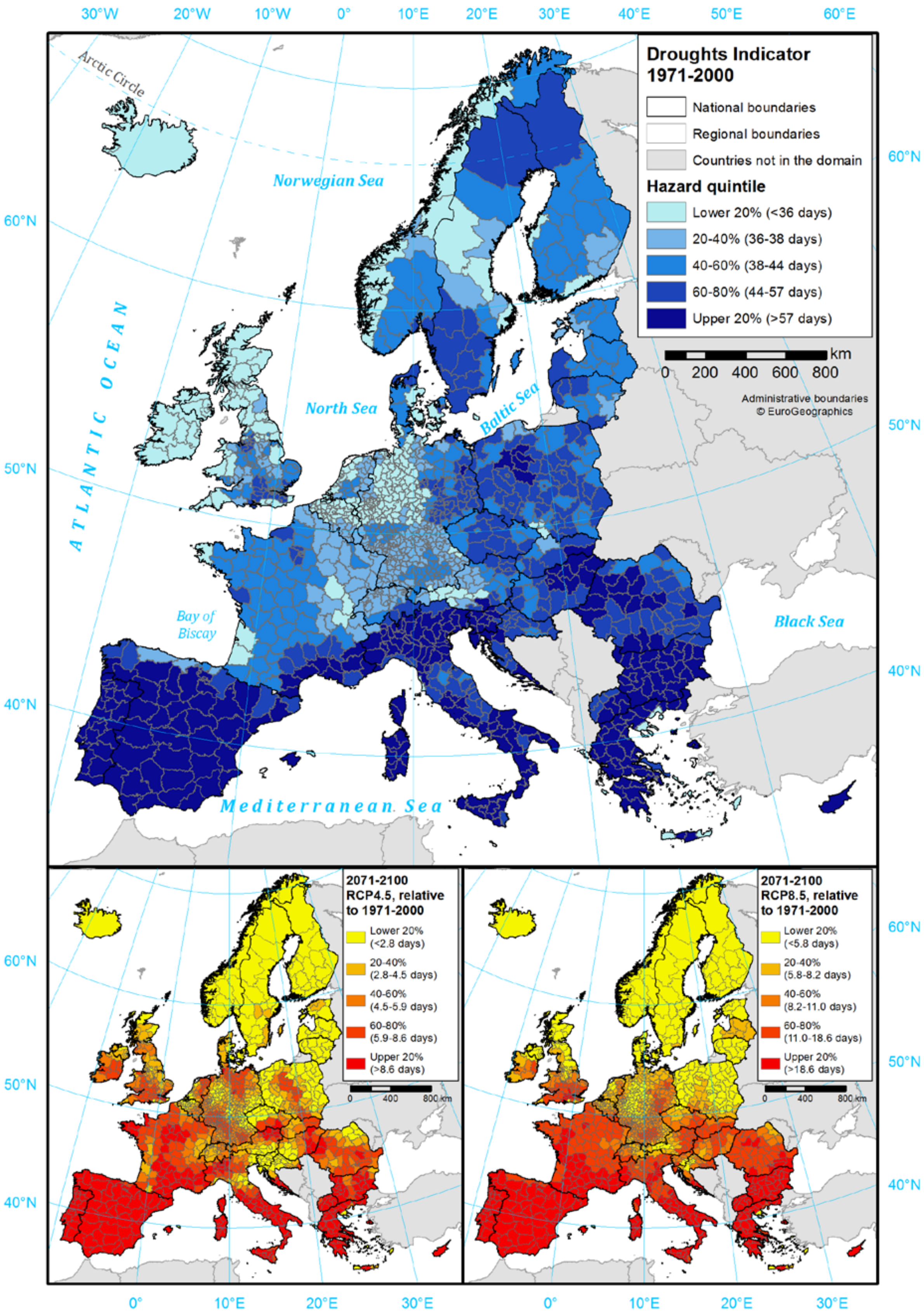


*Figure A8. Quintiles of normalized drought hazard indicator at regional level for historical scenario (main map) and relative change (subtraction) between 2071–2100 and 1971–2000, in two scenarios.*

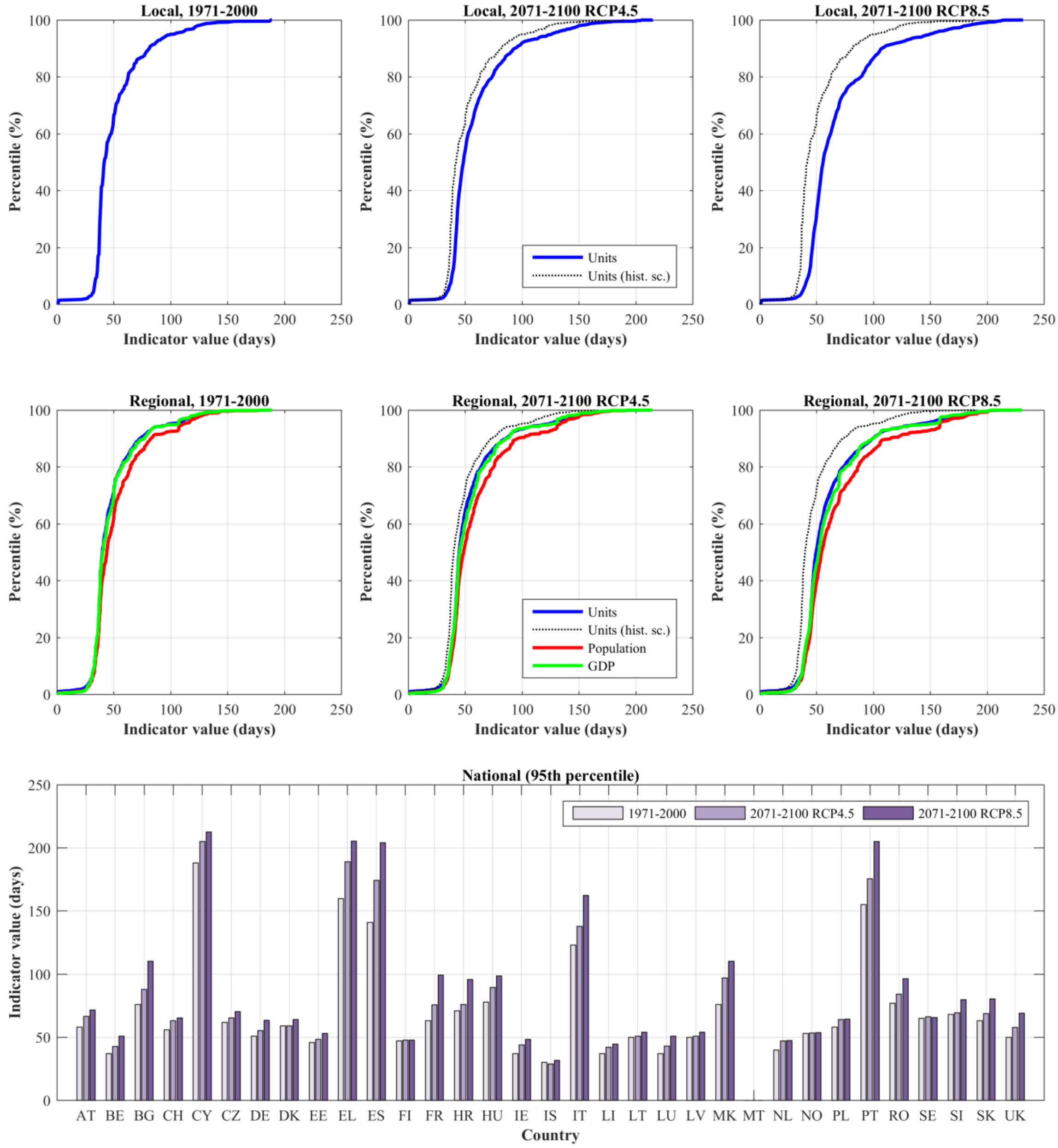


*Figure A9. Normalized drought hazard indicator at local, regional and national level, by climate scenario. Histograms only for units for which estimates were available. For country codes, see Table A4.*

## 5.4 Heat waves

The heat waves' hazard indicator is based on the total number of heat waves in 30 years. Figure A10 shows higher number of heat waves for the inland areas of Southern Europe. At the national level, Spain and Portugal have the highest number of heat waves (Figure A11). In the historical climate (1971-2000), the 5 and 95 percentiles of total number of heat waves in 30 years across Europe are 9 and 57. They are projected to increase quite strongly over entire Europe, with increases up to more than 60 heat waves in 30 years for RCP4.5 and more than 80 RCP8.5 (Table A6). This causes an increase of the 5 and 95 percentiles of the total number of local heat waves in 30 years across Europe from 9 - 57 (historical climate) to 37 – 124 (RCP4.5) and 61 – 146 (RCP8.5). The maximum number of heat waves at the regional level increases from 51 (historical climate) to 114 (RCP4.5) and 139 (RCP8.5) in 30 years. The mean number of heat waves at the regional level increases from 38 (historical climate) to 90 (RCP4.5) and 117 (RCP8.5) in 30 years. At the national level, the maximum number of heat waves increases from 80 (historical climate) to 150 (RCP4.5) and 181 (RCP8.5) in 30 years.

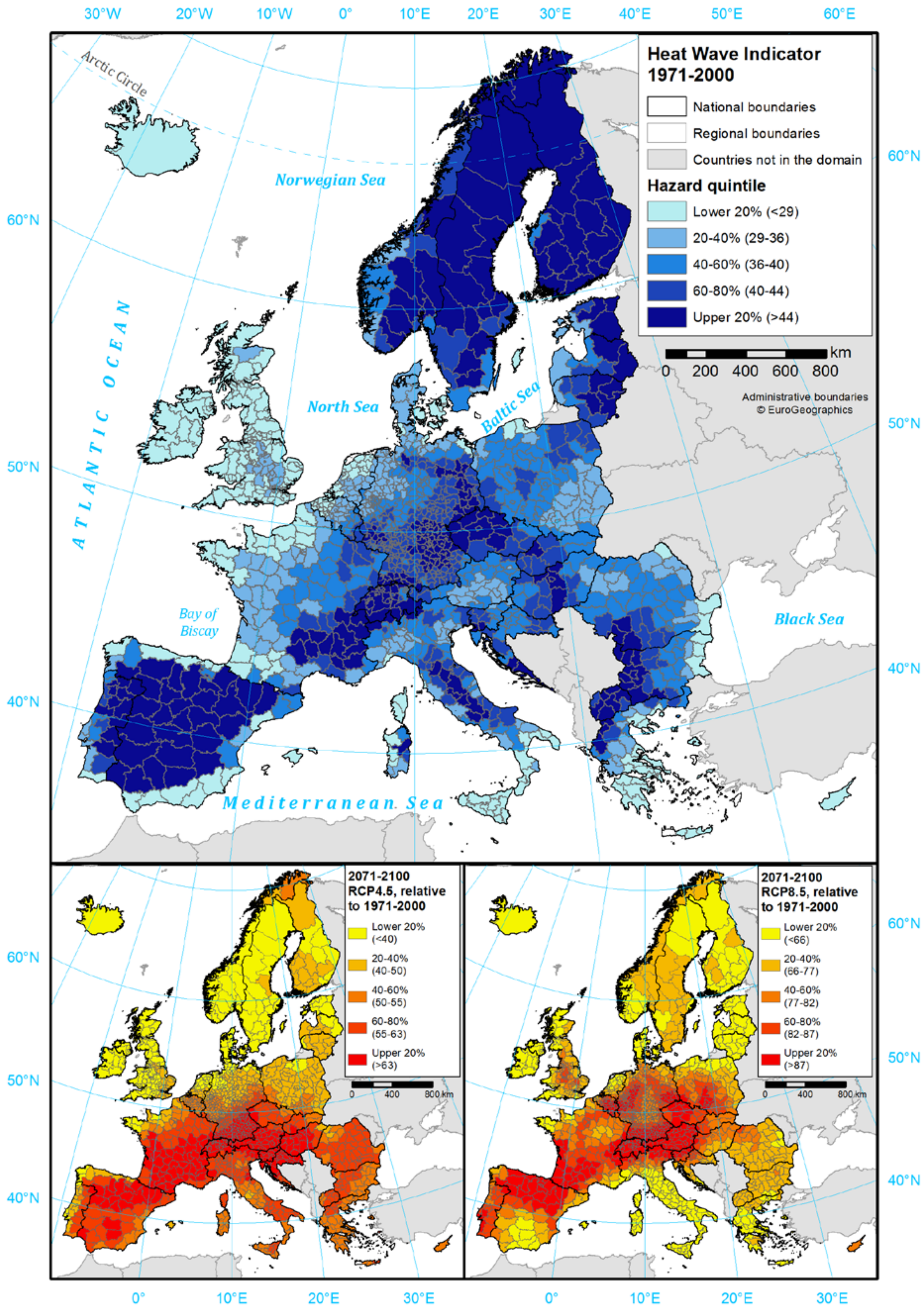


*Figure A10. Quintiles of normalized heat wave hazard indicator at regional level for historical scenario (main map) and relative change (subtraction) between 2071–2100 and 1971–2000, in two scenarios.*

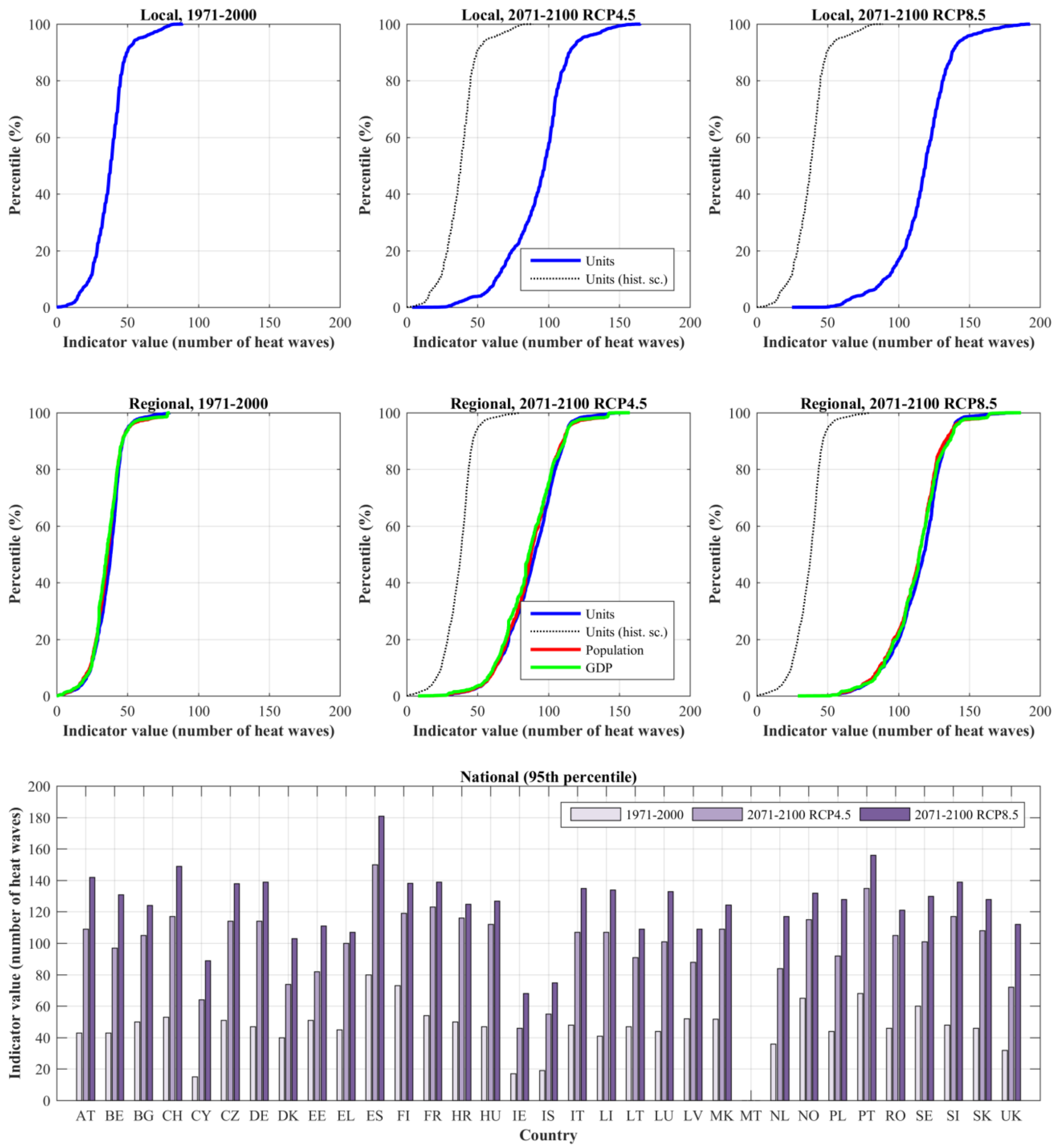


*Figure A11. Normalized heat wave hazard indicator at local, regional and national level, by climate scenario. Histograms only for units for which estimates were available. For country codes, see Table A4.*

## 5.5 Wildfires

The wild fire hazard indicator based on the Forest Fire Danger Index (FFDI) is provided for any location in Europe but with strong regional differences, as was also the case for the drought and heat wave indicators. Figure A12 shows a strong north-south variation in the FFDI with much higher wild fire hazard conditions in the drier countries of Southern Europe. At the national level, the Southern European countries Cyprus, Spain, Portugal and Greece have the highest FFDI values (Figure A13). In the historical climate (1971-2000), the 5 and 95 percentiles of the FFDI values across Europe are 0.43 and 0.81. They are projected to increase all over Europe, with increases up to more than 0.09 for RCP4.5 and more than 0.19 for RCP8.5 (Table A6). This causes an increase of the 5 and 95 percentiles of the FFDI values across Europe from 0.43 – 0.81 (historical climate) to 0.47 – 0.95 (RCP4.5) and 0.49 – 1.13 (RCP8.5). The changes are strongest for the more dry countries of Southern Europe. The maximum FFDI value at the regional level increases from 0.77 (historical climate) to 0.90 (RCP4.5) and 1.09 (RCP8.5). The mean FFDI value at the regional level increases from 0.50 (historical climate) to 0.56 (RCP4.5) and 0.62 (RCP8.5). At the national level, the maximum FFDI value increases from 1.26 (historical climate) to 1.54 (RCP4.5) and 1.93 (RCP8.5), while the mean FFDI value increases from 0.64 (historical climate) to 0.74 (RCP4.5) and 0.84 (RCP8.5).

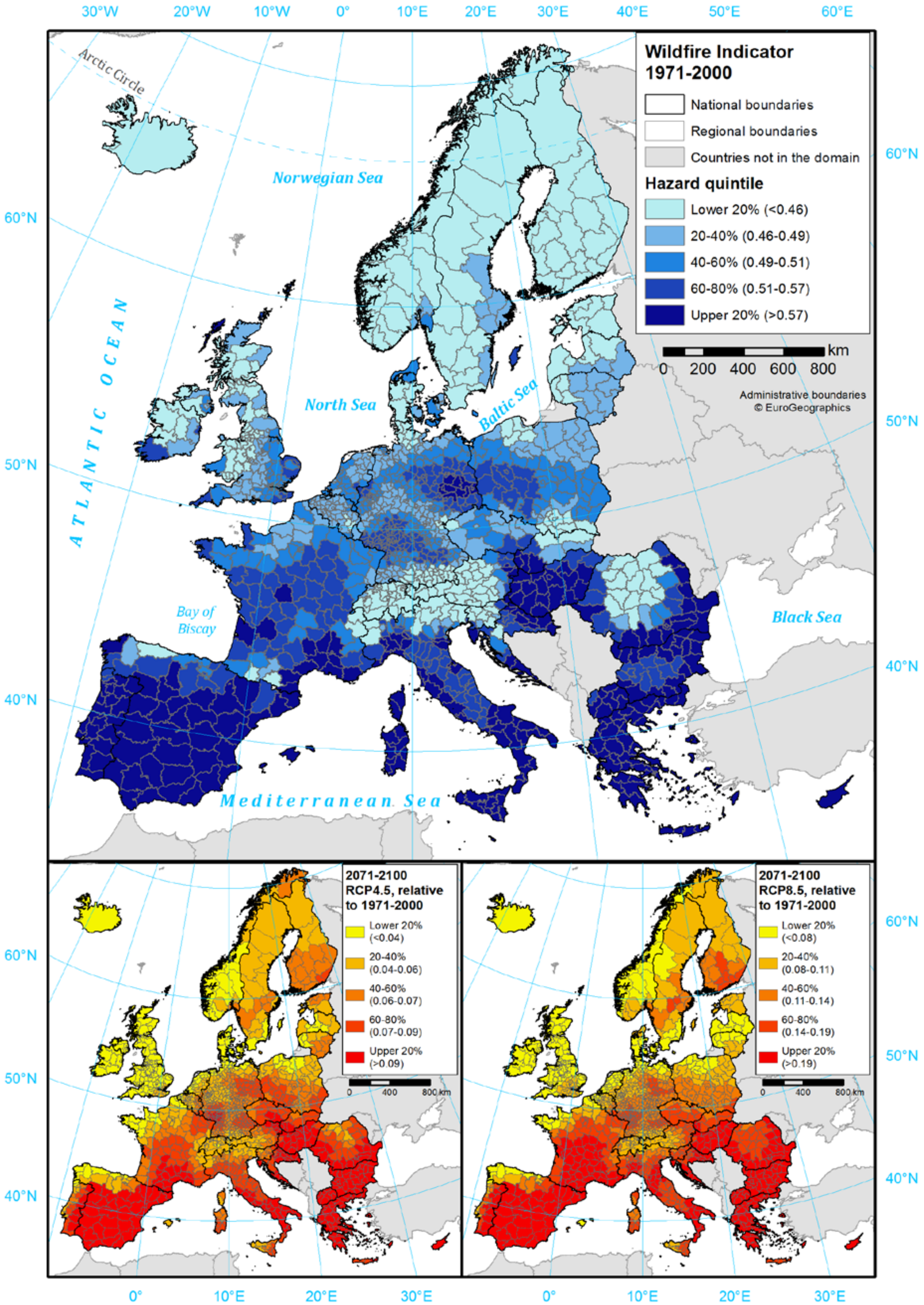


*Figure A12. Quintiles of normalized wildfire hazard indicator at regional level for historical scenario (main map) and relative change (subtraction) between 2071–2100 and 1971–2000, in two scenarios.*

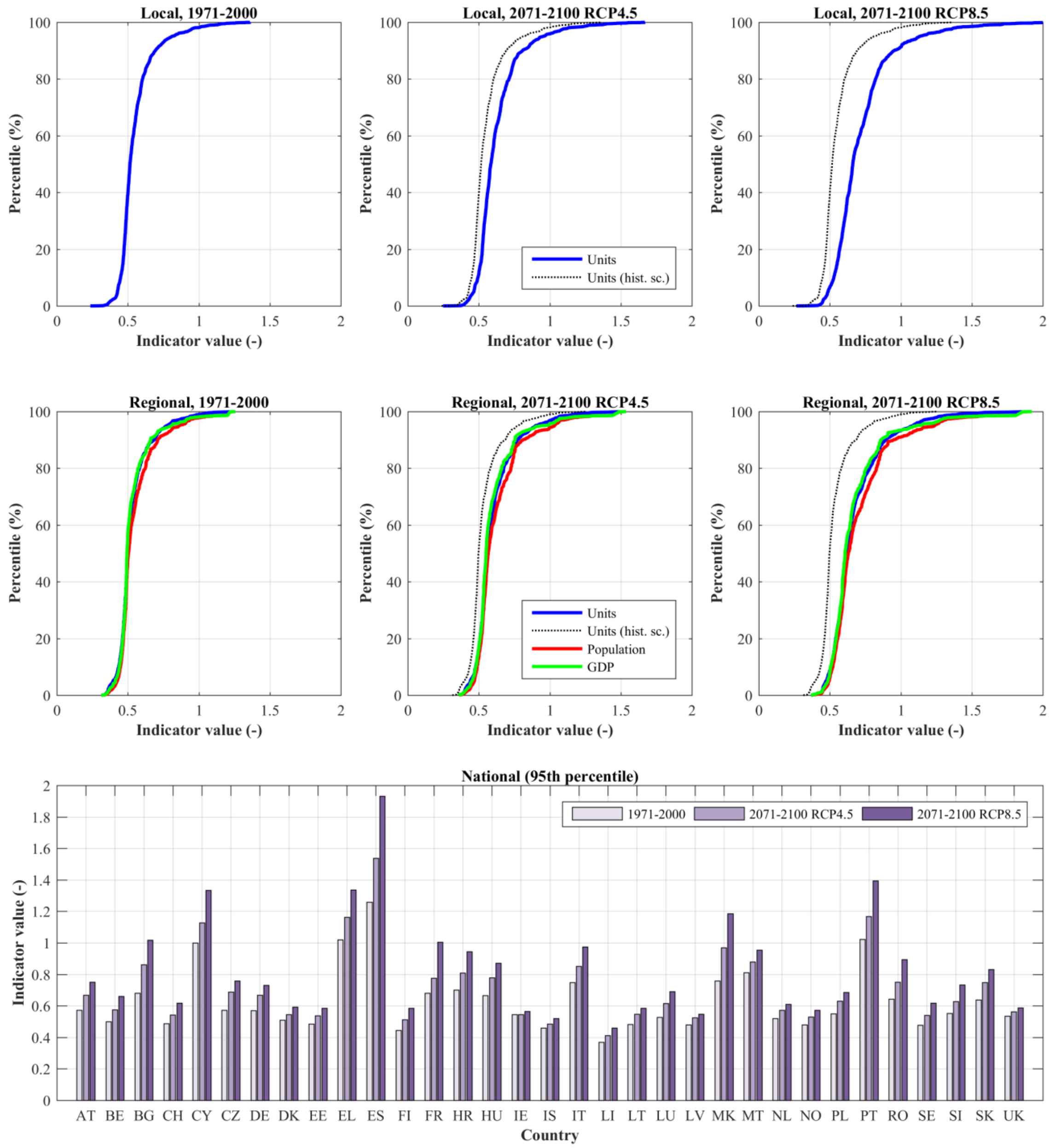


*Figure A13. Normalized wildfire hazard indicator at local, regional and national level, by climate scenario. For country codes, see Table A4.*

## 5.6 Windstorms

The wind storms' hazard indicator based on the 99th percentile of daily wind speed (in m/s) is provided for any location in Europe but with strong regional differences. There are both negative and positive changes. For the RCP4.5 scenario, the changes are primarily negative, whereas for the RCP8.5 scenario they are both positive and negative. Figure A14 shows higher changes (lower decreases for the RCP4.5 scenario and higher increases for the RCP8.5 scenario) for Iceland, the UK and the coastal areas of north-western Europe and Norway. In the historical climate (1971-2000), the 5 and 95 percentiles of the wind storms' indicator values across Europe are 4.6 and 12.3 m/s. For the RCP4.5 scenario, the 99th percentile of daily wind speed decreases to more than 0.12 m/s in comparison with the historical climatic conditions. For the RCP8.5 scenario, this percentile increases up to more than 0.10 m/s (Table A6). The 5 and 95 percentiles of the 99th percentile of daily wind speed values across Europe change from 4.6 – 12.3 m/s (historical climate) to 4.5 – 12.3 m/s (RCP4.5) and 4.5 – 12.3 (RCP8.5). Hence, the range of extreme wind speed values remains almost the same. The same applies to the values at the regional and national levels.

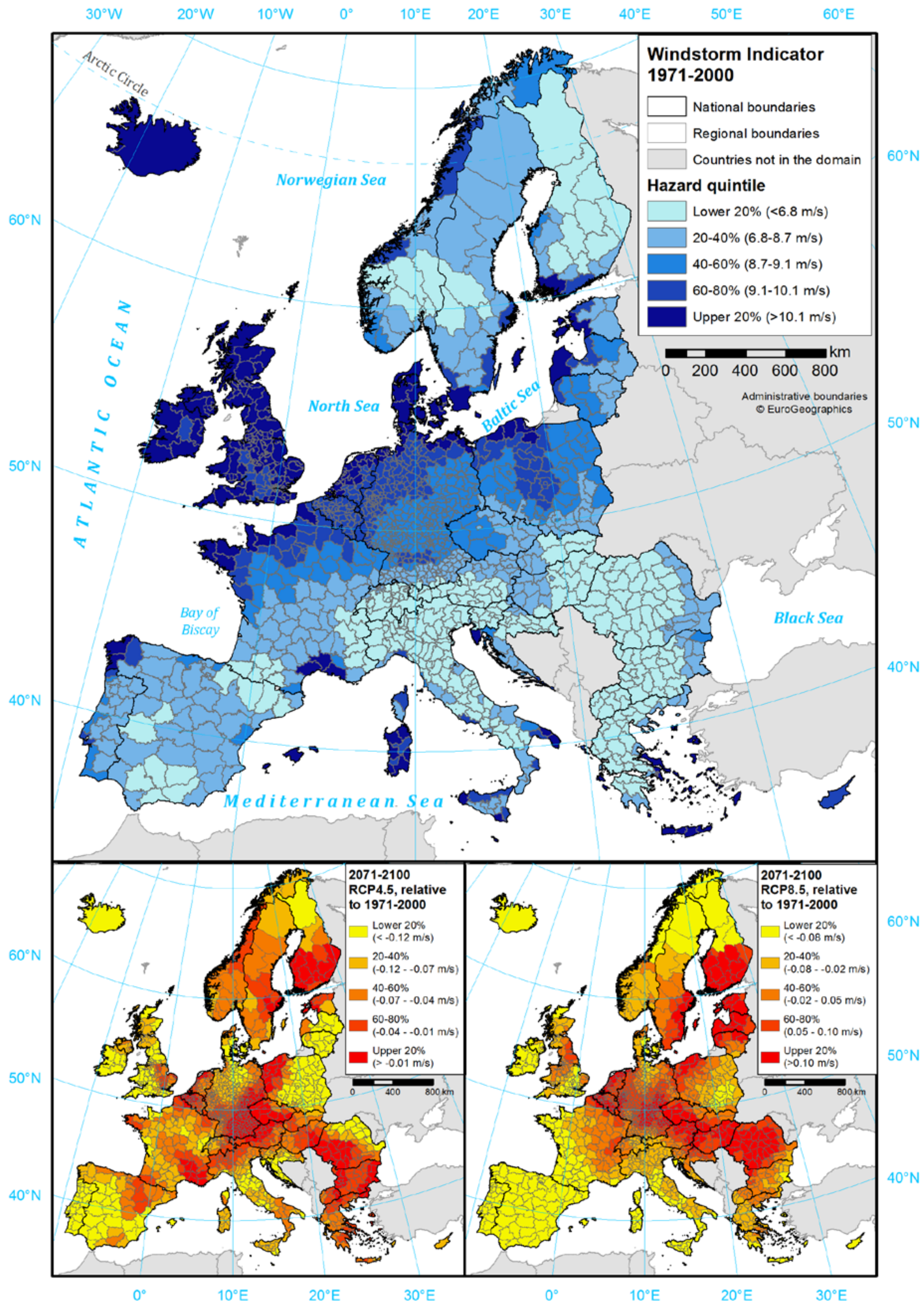


*Figure A14. Quintiles of normalized windstorm hazard indicator at regional level for historical scenario (main map) and relative change (subtraction) between 2071–2100 and 1971–2000, in two scenarios.*

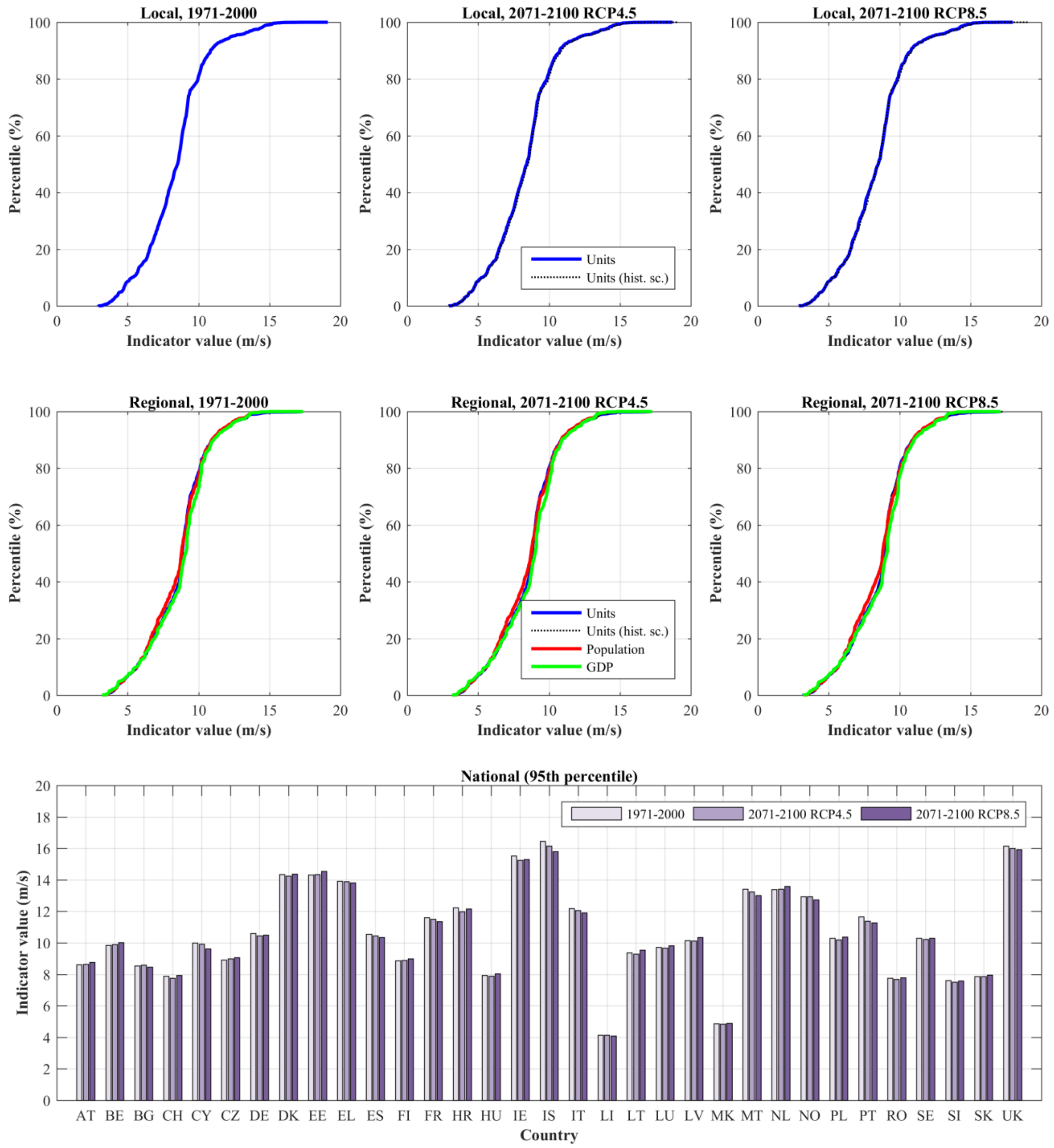


*Figure A15. Normalized windstorm hazard indicator at local, regional and national level, by climate scenario. For country codes, see Table A4.*

## 5.7 Heavy Precipitation

The heavy precipitation hazard indicator is based on the daily precipitation intensity for a return period of 5 years. This does, however, not mean that pluvial floods and other heavy precipitation induced disasters can happen at any location. The pluvial flood hazard, for instance, depends on the local conditions in terms of topography, land use and drainage system properties.

Figure A16 shows that heavy precipitation is variable across Europe with higher intensities over elevated areas such as the alps because of the orographic lifting. Also some other areas show higher precipitation extremes such as the western Norwegian Coast, due to the passage of mid-latitude cyclones directed from west to east, and regions bordering the coasts in the Mediterranean region due to coastal cyclones that transport humid air masses. At the national level, Slovenia, Switzerland and Italy show the highest intensities (Figure A17). In the historical climate (1971-2000), the 5 and 95 percentiles of local heavy precipitation intensities vary from 27.2 mm to 69.2 mm across Europe. The heavy precipitation intensities are projected to increase over entire Europe, with increases up to more than 5 mm for RCP4.5 and more than 9 mm for RCP8.5 (Table A6). This causes an increase of the 5 and 95 percentiles of local heavy precipitation intensities across Europe from 27.2 - 69.2 mm (historical climate) to 29.9 – 75.2 (RCP4.5) and 31.7 – 79.3 (RCP8.5). The maximum intensities at the regional level increase from 69.1 (historical climate) to 74.3 (RCP4.5) and 80.9 (RCP8.5). At the national level, they increase from 117.5 (historical climate) to 131.0 (RCP4.5) and 143.5 (RCP8.5).

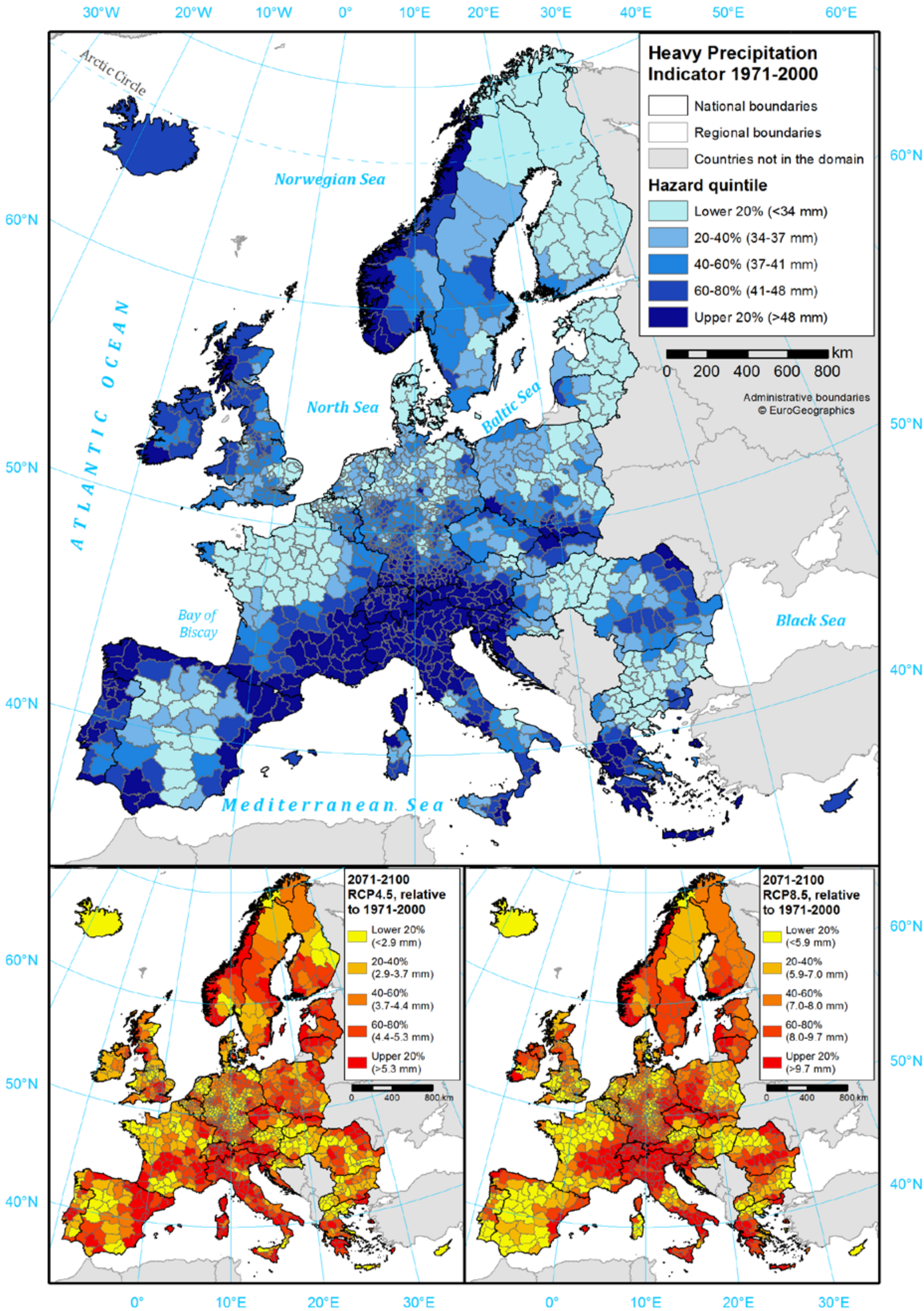


*Figure A16. Quintiles of normalized heavy precipitation hazard indicator at regional level for historical scenario (main map) and relative change (subtraction) between 2071–2100 and 1971–2000, in two scenarios.*

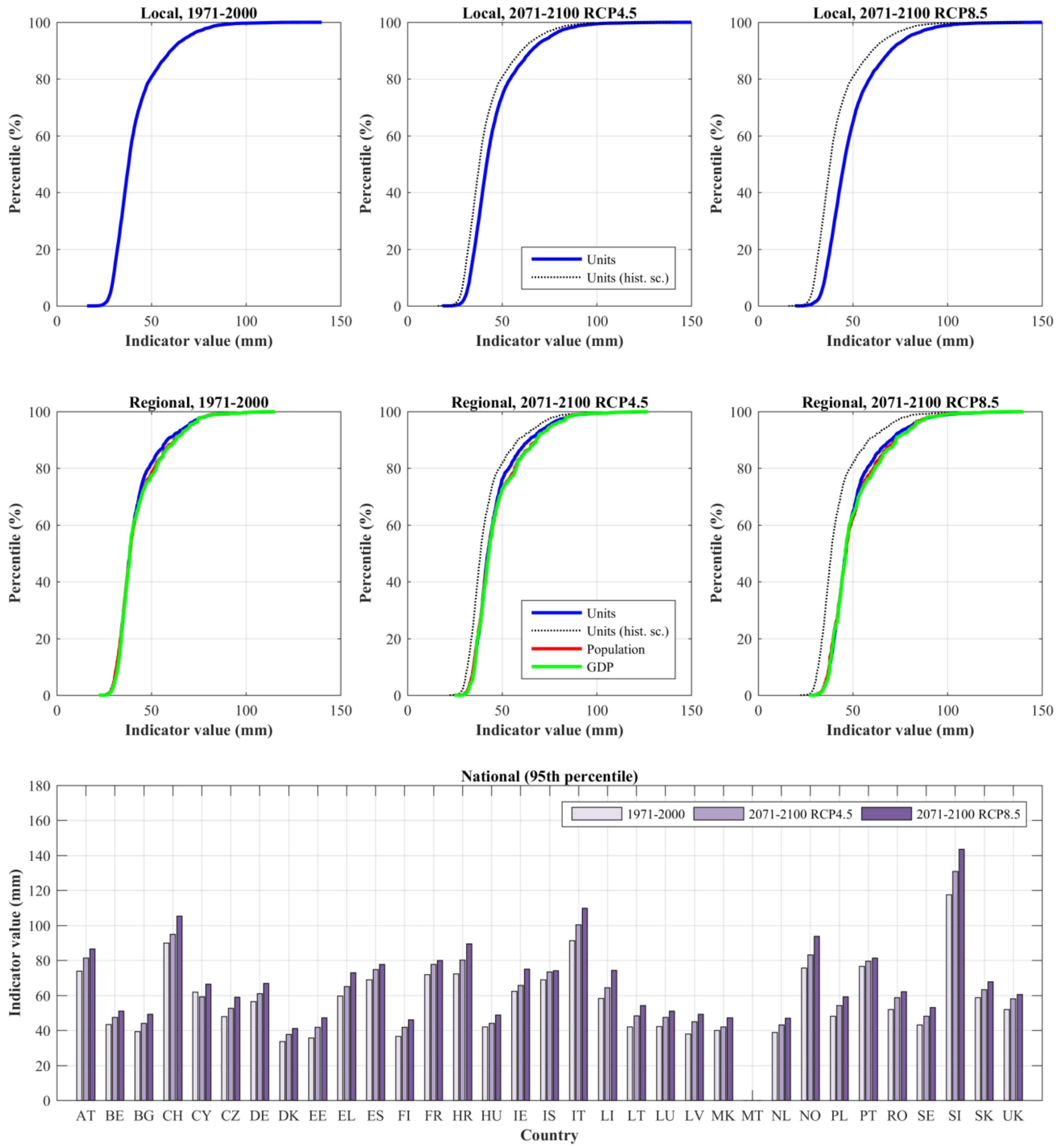


*Figure A17. Normalized heavy precipitation hazard indicator at local, regional and national level, by climate scenario. Histograms only for units for which estimates were available. For country codes, see Table A4.*

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# Appendix B.

# Integrating Testing with the Stocktaking Process

Individually, the TIF, MAF+ and PPIF each propose their own step-wise testing guidelines and activities which sometimes results in overlaps in testing and baseline information requested from the innovator. BRIGAID streamline the communication with the innovator by developing a series of questionnaires that build on one another. The development of these questionnaires will decrease the time invested by the innovator and minimize overlaps between the different work packages (i.e., WP5-8).

The three questionnaires are:

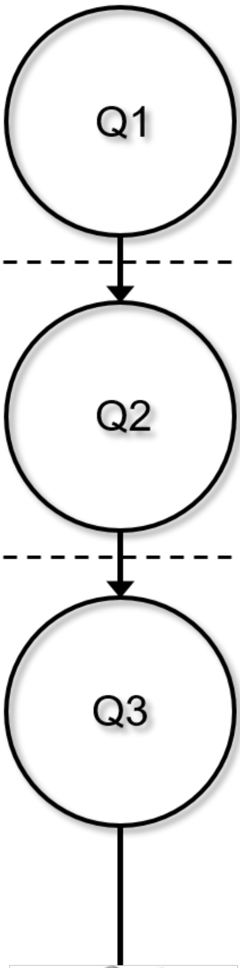
1. Innovation Description Questionnaire: to gather the minimum information needed for presenting the innovation in the ISP;

2. Selection Questionnaire: to determine whether the innovation should be included within a BRIGAID testing cycle; and

3. Desk Study Questionnaire: to lay the basis for developing a test plan (i.e., applying the TIF) and extracting information for initial steps in the application MAF+/PPIF.

Each questionnaire and its purpose are described in more detail in the flowchart provided on the following page. Generally, the questionnaires will increase in length and complexity as the innovator progresses in BRIGAID. The questions associated with the first two questionnaires have already been developed and applied, and are provided in the stocktaking reports by WP2,3,4.

The ambition of the third questionnaire (Desk Study Questionnaire) is that it will act as a "warm up" for the innovator, introducing them to the terminology of the TIF, MAF+ and PPIF and helping them to identify the baseline information needed to apply these frameworks. The Desk Study Questionnaire, which covers the preliminary steps of these three frameworks, ensures that a full scan of the innovation has been performed before laboratory or operational testing begins. This will enable the innovator to strategically plan testing – in terms of achieving technical, social and market readiness – and avoid traditional pitfalls in the development of an innovation. This questionnaire will streamline the desk study and facilitate ease-of-use and broader application of the methods developed and recommended by BRIGAID.




**Innovation Description Questionnaire:** This questionnaire is administered to obtain the minimum information needed to display the innovation on the ISP. It is designed to be an "in-take" survey (i.e., stocktaking) and is short (15 questions). It ends with an additional question asking the innovator whether they would like to participate in the BRIGAID testing process. If the innovator answers "Yes," then the innovator will be administered Q2: the Selection Questionnaire.

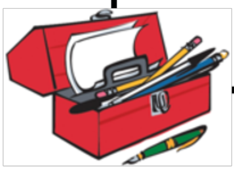
*Innovator chooses whether to continue.*

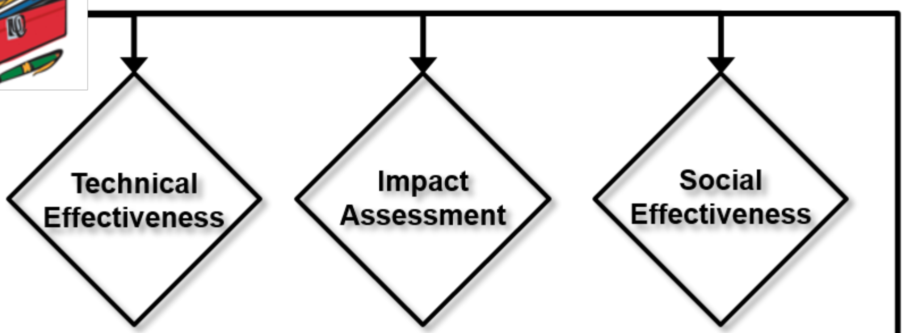
**Selection Questionnaire:** This questionnaire is administered to obtain the information needed to score the innovation in the BRIGAID stocktaking process. It contains basic questions about social, technical, and market readiness. For specific scoring criteria, please refer to the selection procedure. If the innovation achieves the minimum required score and is chosen to be tested within the testing cycle, then the innovator will be administered Q3: the Desk Study Questionnaire.

*BRIGAID chooses whether to support innovator.*

**Desk Study Questionnaire**: This questionnaire is administered as the basis for developing a test plan. It requires that the innovator clearly describes the system and intended functionality of the innovation, followed by a qualitative assessment of all KPI (social, technical, and impacts) and preliminary screening related to the activities within MAF+ and PPIF. The results of the screening questions will be used to determine whether the innovation is chosen to be included within the activities performed by WP6.

**TIF:** After completing the Desk Study Questionnaire, the innovator will be provided with testing guidelines (appropriate for the innovation category and current TRL) and access to toolboxes/activities to facilitate testing. The goal of testing is to increase the TRL of the innovation, while simultaneously evaluating its social acceptance, and its potential for market uptake (if applicable).






*BRIGAID chooses whether to support innovator.*

**MAF+/PPIF:** After completing the Desk Study Questionnaire and if the innovation meets the minimum requirements to participate in the BRIGAID market assessment activities, the innovator will be provided with toolboxes/activities to facilitate the assessment of Market Readiness.

# Appendix C. Results of the Frontrunner Workshop

This appendix summarizes the results the Frontrunner Exercise performed between August and November 2016 in the context of the activities performed (and lessons learned by) WP5.

# Objective

The goal of the frontrunner exercise was to develop and apply portions of the TIF “in real time” and to test the methodologies using real-world examples (i.e., innovations). It was also aimed at increasing the working interactions between BRIGAID partners (e.g., TUD, UOXF, KUL) in the WPs 5 and 6. The format of the frontrunner exercise was that each (stocktaking) work package leader (WP 2,3,4) initiated a series of teleconferences between the frontrunner innovators and the partners responsible for developing the social and technical portions of the TIF (and the MAF+, PPIF, etc., respectively). The majority of these conference calls took place during the month of October 2016. Some of these calls involved all partners (e.g., TUD, UOXF, Eco) simultaneously, whereas others did not. Note that the impact of the innovation(s) on different market sectors (e.g., nature, agriculture, health) was not evaluated during the frontrunner exercise; for more discussion of this point, see Section 3.

As a result of these conference calls, WP5 developed Key Performance Indicators (KPI) aimed at providing standard criteria that could be used in assessing the social and technical readiness of each innovation and that could be used to connect/match the innovation with end-users and potential investors in the Innovation Sharing Platform (ISP) under development by WP7. As they were established, the KPI were defined and provided to the innovators as a series of memos and/or worksheets. This was a process that required frequent updates/edits and was often rapidly changing over the course of the conference calls; for more discussion of this point, see Section 3.

Four innovations were chosen for the frontrunner exercise. The objective was to select one innovation from each of the climate-related hazards (i.e., floods (WP2), droughts (WP3), and extreme weather (WP4)). Ultimately, two innovations were chosen from the category extreme weather (WP4). Note that, in hindsight, it would have also been useful to also distribute the selection across different categories of innovations (e.g., structural, informational, nature-based); for more discussion of this point, see Section 3. The four innovations and a brief description of each are provided below. Additional information about the innovations and the results of the frontrunner exercise can be found in the internal reports provided by each innovator and/or respective work package leader.

- **Flip-Flap Cofferdam (FFC) (WP2)** is designed to prevent river flooding (caused by heavy precipitation) up to 1 meter in urban areas. The flood protection structure is made up of PVC sheet piles which are stored flat within a concrete bed and raised (i.e., flipped up) in the event of a flood. The FFC is designed to be operated by a team of (maximum) four (unskilled) laborers at an estimated rate of 20 m/hour. Galvanized steel pipes between each component of the FFC fasten to steel infrastructure laid within a concrete gutter and the base of the wall is sealed by a rubber gasket (in the gutter). The FFC is semi-permanent, i.e., it is stored in place, but only operated during a hazard event. When not in use it is designed to function as a boardwalk. The FFC is at a Technical Readiness Level (TRL) 4: a prototype has been built on a test stand and a static water column of 1 meter can be resisted without failure. It is estimated that the structure has a lifetime of approximately 25 years (based on the material lifetime of the PVC sheetpiles). The envisioned operational environment for the FFC is the City of Bucharest, Romania on the Danube River. *Innovator: Daniel Soiman (Spectrum Constructs Co.)*

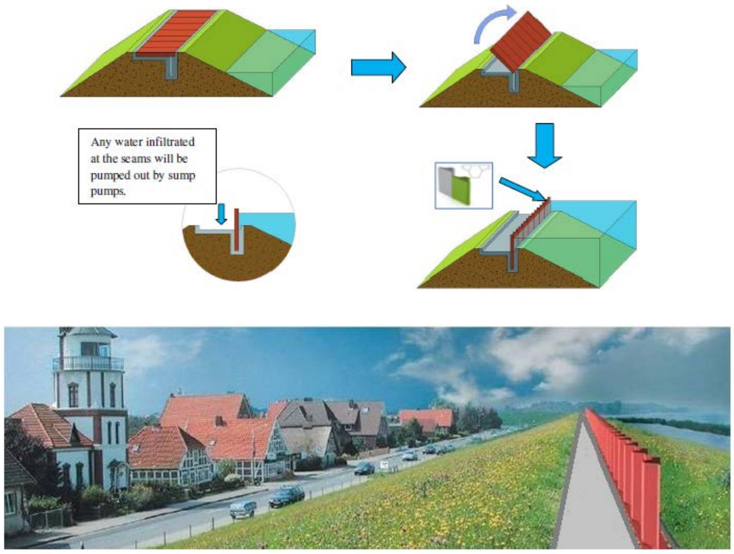



*Figure C-1. Visualization of the Flip-Flap Cofferdam.*

- **InfoDROUGHT (WP3)** (www.infosequia.es) is a web-mapping climate service for the operational monitoring of droughts and their impacts. The innovation runs continuously in real-time and provides weekly updates on the drought conditions of a region (in the form of a colored drought indicator). The core of the system includes a set of algorithms which automatically collect satellite data from the cloud, process and generate severity drought indices and portable bulletins, and feed a web-mapping service from which all the information can be interactively queried and downloaded. InfoDROUGHT is at a TRL 5: the prototype has been designed and formulated; preprocessing, processing, and communication functionalities have been successfully integrated and tested in a desktop environment. Some reliability assessments have been performed and validation of of the system is in progress. The current testing/operational environment is Spain, but the innovator would like to expand to other areas in Europe. *Innovator: Sergio Contreras (FutureWater)*

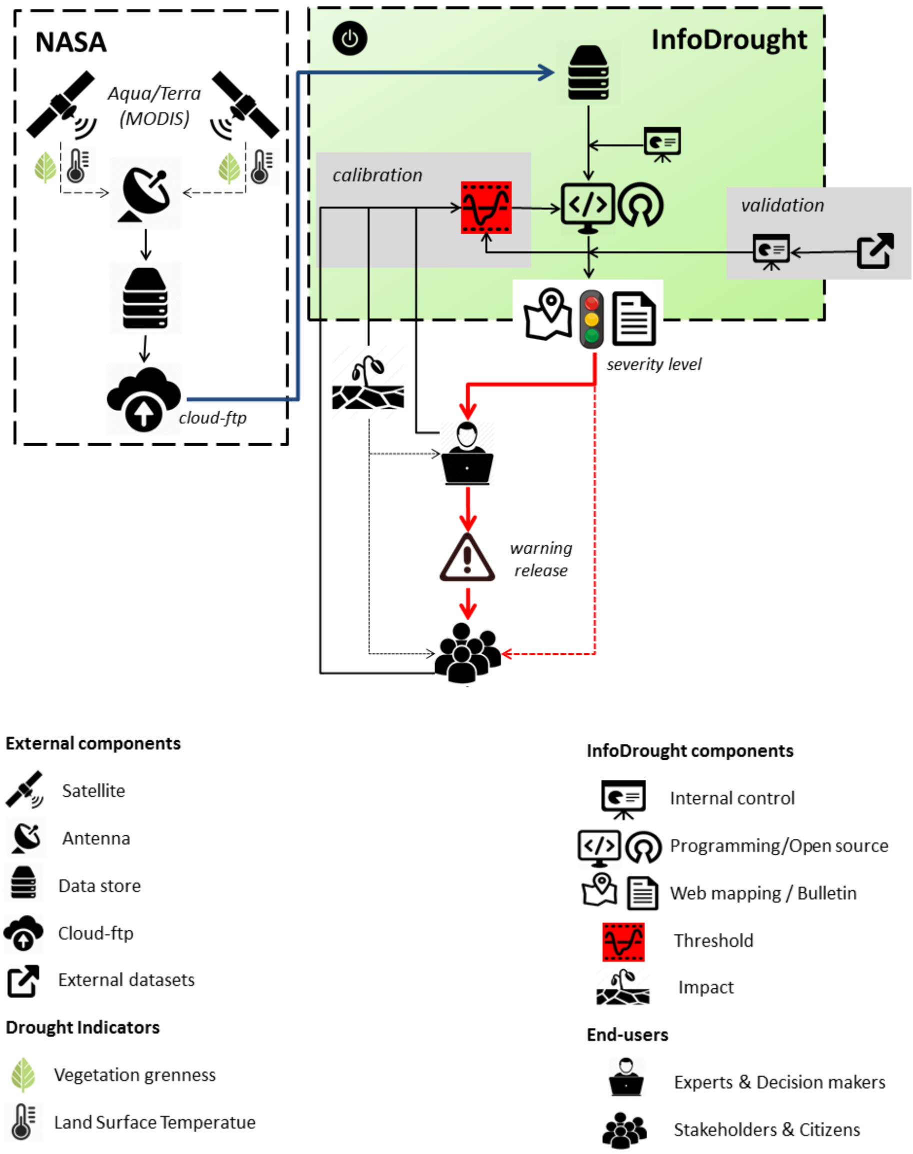



*Figure C-2. Sketch of the InfoDROUGHT monitoring system.*

- **Precipitable Water Vapor Montor (WP4)** is a new technology designed to continuously monitor precipitable water vapour (PWV) with a high horizontal resolution (at vertical elevations <1km). Because PWV is a precursor of rainfall, measurements of PWV can be integrated into meteorological models to monitor and now-cast (and predict) small-scale extreme weather events (e.g., flash/urban floods and river floods) in cities. The innovation makes use of existing low-cost single-frequency (SF) Global Navigation Satellite Systems (GNSS) receivers and antennas which collect raw PWV data. The innovation is at a TRL 6: the technology has been demonstrated in a relevant environment. The structural components (i.e., hardware) are proven (TRL 9+), but the technological components (e.g., processing of PWV data collected and integration of the PWV product with high-resolution radar in cities) have not yet been fully tested. The foreseen operational environments are dense urban cities and the innovation will be tested in Monterosso al Mare and Rotterdam. *Innovator: Eugenio Realini (GReD)*

*Figure C-3. Picture of the Precipitable Water Vapor Monitor*

- **Fire Risk Monitor Advisor (WP4)** is a decision support tool that continously monitors and assesses the risk of wildfires caused by drought conditions. The tool generates maps showing the probability of wildfire (or ignition) based on meteorological and drought indicies, landscape metrics, and vegetation loads. These maps can be accessed by forest and fire manages and used to identify windows of opportunity to apply forest management practices aimed at reducing the risk of wildfires. The Fire Risk Monitor is at a TRL 5: the innovation has been validated in a relevant environment and the pre-processing, processing, and communication functionalities have been successfully integrated and tested. Additional testing is planned to establish the reliability (and effectiveness) of the estimates for windows of opportunity. The current testing/operational environment for the innovation is Portugal. *Innovator: Francisco Castro Rego (ISA)*

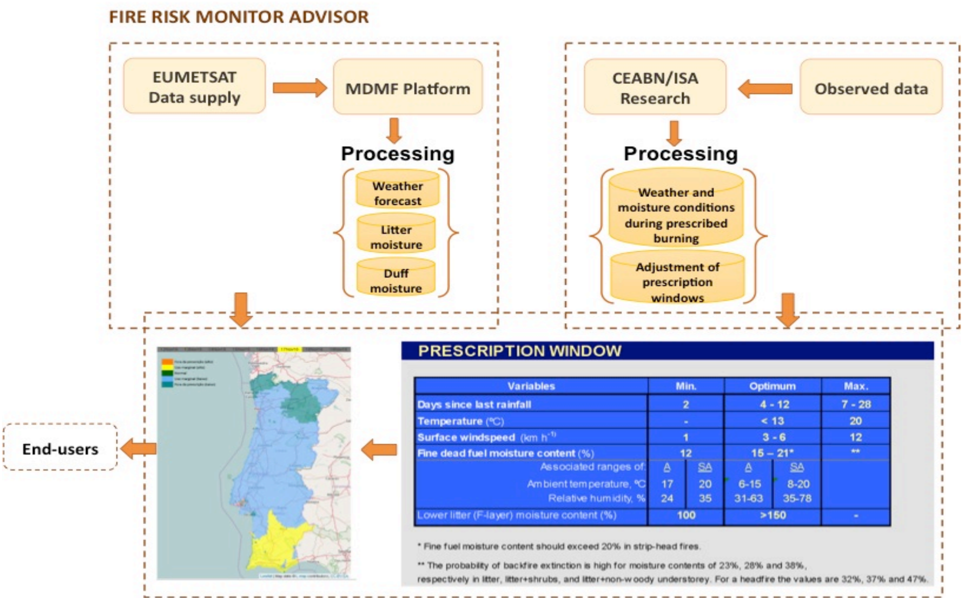



*Figure C-4. Schematic showing the process used in Fire Risk Monitor Advisor*

# Lessons Learned

The following paragraphs describe the lessons learned/key observations made during the Frontrunner Exercise. Many of these observations have already been acted upon and integrated into the initial version of the TIF (in the wake of the Leuven Workshop), whereas others are included only to advise the reader of the lessons learned.

1. *The Frontrunner Exercise highlighted the need for common terminology used within BRIGAID (and especially for reporting).*

    a. Some specific examples of terminology which need to be clearly defined (and agreed upon) include: Risk, Technical Readiness Levels, Technical Effectiveness, Reliability, Reusability, Innovation Categories (different types of innovations are considered within BRIGAID, e.g., structural, technological/informational and nature-based innovations)

2. *The Frontrunner Exercise highlighted the need to develop and clearly define Key Performance Indicators (KPI) before developing testing guidelines.*

    a. During the frontrunner exercise, we conducted a brainstorming activity to define the audience and the perspectives of the users of the Innovation Sharing Platform (ISP). Three primary groups were identified: innovators, end-users (i.e., clients), and investors. It became clear that a “common langauge” would be needed in order to connect innovators with end-users and potential investors since these groups are accessing the platform with different goals in mind. For this reason, we decided that it was important to define KPI prior to developing the testing guidelines. The KPI should be applicable to all innovations allowing for the matching of an innovation to end-users or investors or comparison between innovations (in the Innovation Sharing Platform).

    b. The KPI must be clearly (and fully) defined to avoid confusion. The KPI should be used to justify the need for specific tests to be performed and drive the development of testing guidelines.

3. *The Frontrunner Exercise highlighted that within the technical portion of the TIF, testing guidelines will need to be different for different categories of innovations.*

    a. While the KPI will be the same across all categories of innovations (in order to allow for comparison with a uniform format for the back-end of the ISP), the methods for quantifying the KPI will differ across different categories of innovations. For example, testing the reliability of a stuctural innovation (e.g., a flood barrier) will be very different from that of a technological innovation (e.g., a flood warning system). Similarly, technical effectiveness will be measured differently for an innovation that reduces hazards versus an innovation that reduces vulnerability. For this reason, it will be necessary to develop specific testing guidelines for different categories of innovations. To our knowledge, this only applies to the technical portion of the framework, but we may later find that it is also relevant for the impact analyses as well.

    b. It is important to note that during the frontrunner exercise only one of the innovations was structural in nature, whereas the other three can be categorized as informational/technological. None of the chosen innovations were nature-based, limiting any potential "testing" of the TIF for this type of innovation. In future cycles, it will particularly be important to to select innovations that not only come from the different work packages (i.e., are associated with the different hazards), but also span the range of potential categories of innovations. For a list of categories and to see examples of climate adaptation options, refer to the IPCC report by Noble et al. (2014).

4. *The Frontrunner Exercise highlighted that clear guidelines need to be developed for testing which include references to literature and/or technical reports to help the innovator navigate their way through the TIF.*

5. *The Frontrunner Exercise highlighted that we should utilize the TRL scale to guide development of innovations and "stage-gate" the development process.*

   a. The goal of BRIGAID is to bridge the "Valley of Death" that often occurs between the development of an innovation prototype and its uptake into the market. There is an existing scale to describe the process of innovation development (from a technical readiness standpoint), but it neglects to incorporate social acceptance or market readiness into its definitions. As a result of the frontrunner exercise, it became clear that it would be useful to base testing guidelines on this existing (and widely accepted) scale for describing technical readiness, but also incorporates guidelines for social and impact analysis into the scale. There is already literature describing the limitatations of the scale (a summary can be found in a separate report on the TIF, forthcoming) and a key point is that the TRL scale in its current form is too granular. For this reason, we suggest dividing testing into three phases: TRL 1-3, TRL 4-5, TRL 6-8. In each of these phases, different levels of (technical) testing can take place (e.g., desk study, qualitative and quantitative testing in a laboratory environment, quantitative testing using operational boundary conditions) and analyses of social acceptance (and market readiness) can be performed.

   b. During the Frontrunner Exercise, we discussed the idea of evaluating social "readiness," but decided instead on a concept of "stage-gating" where specific criteria (i.e., KPI for social acceptance) are analysed and/or checked before the innovator can move to the next TRL. In this way, an innovator proceeds along the TRL scale (is guided through development) without missing critical checkpoints for social acceptance and market readiness. A discussion of the benefits of using the TRL scale to guide innovation can be found in the report by EARTO (2014) to the EU.

6. *The Frontrunner Exercise highlighted the need to develop the TIF in a way that requires less "hands on" contact with the innovators.*

   a. It became clear during the frontrunner process that the TIF needs to be academically rigorous, yet simple enough to be applied (at least initially) by someone with no technical background in the subject area (i.e., social sciences, engineering, ecology). This is because (1) not every innovator can be assisted with the development of a testplan or testing, and (2) our objective is that the TIF has application beyond the project. We propose that after the initial framework has been developed (in report form), effort be put into developing a "tool" or "toolbox" that can be applied with limited guidance. This toolbox could be in the form of an excel workbook (with macros), a fillable pdf, or an internet-based toolbox. An initial step towards this type of interactive toolbox is the development of testing guidelines that are associated with the TRL scale (see observation #6 below).

7. *The Frontrunner Exercise highlighted that it would be beneficial to move towards a series of questionairres that build off of one another and guide the innovator through the testing phases instead of a single long questionaire and multiple phone calls.*

    a. We propose that BRIGAID develops a series of questionaires (to reduce stress of the innovator) and that the questions also reflect the TRL of the innovation. For example, an innovator who is at a TRL 4 should not be concerned with questions requiring the calculation of reliability with the boundary conditions in the operational environment, but instead should conduct a desk study based on the design characteristics of his/her innovation (see Appendix B). We believe that this would reduce frustration of the innovator (over the length of the survey) and reduce confusion. These questionaires (in the long term) can be integrated into the toolbox.

    b. We also noticed a number of overlaps between WP5 and WP6 especially with regard to social and market analyses. A series of questionaires would help reduce these overlaps by allowing the answers from one questionaire to feed the next.

# Appendix D.

# Detailed Guidelines and Examples for Technical Testing

For an engineered/built environment innovation, technical readiness is best achieved through engineering calculations and testing for the operational environment of the innovation. The following sections describe testing of an engineered/ built innovation. A temporary flood barrier, or TFB, will be used as a running example throughout the remainder of this section to demonstrate the application of the testing guidelines. The example is discussed in separate text boxes within each section.

## Desk Study, TRL 1-3

This desk study consists of a qualitative analysis of the innovation in which its functionality, and Performance Indicators (PI) are analyzed. This qualitative assessment may be guided by the innovation questionnaires (see Appendix B) and must be completed prior to entering the BRIGAID testing framework. The following steps have been proposed during the Desk Study, (i.e., testing protocol):

A.1: Describe the intended functionality of the innovation;

A.2: Qualitatively assess the intended technical effectiveness;

A.3: Qualitatively assess the intended reusability;

A.4: Qualtiatively assess the intended reliability;

A.5: Qualitatively assess the expected exploitability;

A.6: Identify all possible failure modes of the innovation and generate a fault tree;

A.7: Identify a testing facility where the governing failure modes can be tested;

A.8: Determine whether to proceed to the next phase of testing.

These steps are described in further detail below.

#### Step A.1. Describe the system and intended functionality of the innovation

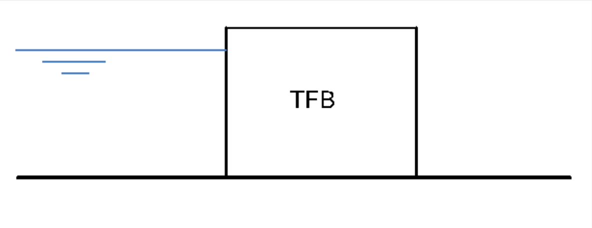
Describe the intended system and functionality of the innovation as specifically as possible; at a minimum the following topics need to be addressed: (i) hazard type, (ii) intended risk reduction capacity, and (iii) operation of the innovation (i.e., how it works). Considering the hazard type, the design criteria corresponding to the intended risk reduction capacity should be identified (see the running example for further explanation). For example, for the hazards considered in BRIGAID, design criteria could be:

- For flooding: a water level/wave height or flow velocity to be resisted;
- For droughts: a volume of water to be stored or a volume of evaporation to be reduced;
- For extreme weather: a volume of water to be stored temporarily or fire intensity that can be resisted.

To describe the intended system and functionality, techniques such as flow charts, sketches, drawings, photos and other material can be used for further clarification.

**Step A.1: System and Functionality Description of a Temporary Flood Barrier (TFB)**

A TFB is designed to temporarily retain water levels to prevent flooding of the area behind the TFB. The barrier is placed prior to arrival of an urban, river or coastal flood and is removed (completely) after the flood has passed. The barrier is used in areas where a permanent flood barrier is not preferred due to, for example, public resistance against barriers that block the view of the river or coast. We will consider water-filled tubes as an example of a TFB. These types of barrier typically consist of one or more flexible tubes that obtain their stability through their self-weight when filled with water. (A typical cross section is shown in Figure 1). The tubes are made of canvas material.



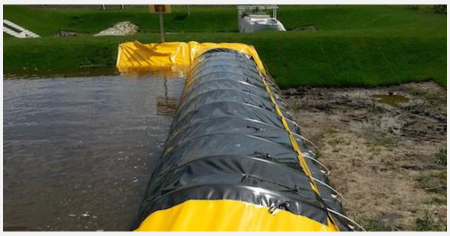



*Figure 1 Schematic cross section of a Temporary Flood Barrier (left) and an example TFB (right) (source: www.tubebarrier.com)*

Water-filled tubes are designed to reduce risk of flooding by retaining water. The risk reduction capacity of a water-filled TFB is expressed as a water level, wave height and/or flow velocity that the structure is able to resist. In this example, the design criteria of the water-filled tube are a water level of about 0.6 meter and small waves of up to 0.2 meter acting perpendicular to the structure.

Successful operation of the water-filled tube requires completion of the following steps before the flood arrives: (1) transport to implementation location; (2) implementation/installation on site; (3) anchoring to the subsoil; and (4) filling with water.

### Step A.2. Qualitatively assess the intended technical effectiveness

Describe the **technical effectiveness** of the innovation based on the description of the system and its functionality. As explained, technical effectiveness is a metric to evaluate the intended functionality of the innovation when used to reduce climate-related risks. Also describe the design criteria that can be derived from the hazard and intended functionality.

### Step A.3. Qualitatively assess the intended reusability

During this step, describe the **reusability** (i.e., the permanent, semi-permanent, or temporary nature) of the innovation. Depending on the nature of the innovation, also estimate the percent of the innovation needed to be repaired / replaced after each operation and the expected lifetime of the innovation (determined by the lifetime of its structural and/or material components). In addition, provide a clear description of the inspection and maintenance requirements to fulfill its function during the anticipated lifetime. Finally, if the innovation is a temporary structure, provide additional information about the storage requirements (e.g., space needed, type of storage location) when the innovation is not in use.

### Step A.4. Qualitatively assess the intended reliability

Depending on the intended reusability (i.e., permanent, semi-permanent or temporary) of the innovation, qualitatively assess the **reliability** of the innovation during operation. Take into account the following general failure modes in the assessment (if applicable):

1. *Implementation Failure*: failure to implement the innovation due to, e.g., human error during implementation, insufficient lead-time for installation or external factors inhibiting correct installation of the innovation. This category only applies to temporary and semi-permanent innovations (not to permanent innovations);

2. *Structural Failure*: failure of the innovation to fulfill its intended function due to, e.g., foundation failure, structural component failure, failure to resist physical loads during operation.

Note that *implementation failure* is only relevant for innovations that are of semi-permanent or temporary nature. Implementation failure can occur due to *implementation errors* or *insufficient time. Implementation errors* can have different causes ranging from human error to power outages. In general, for innovations where implementation failure is relevant (i.e., for semi-permanent or temporary innovation), operators are required to implement the innovation. Successful implementation depends on the performance of the operators involved. *Insufficient time* can occur when the implementation procedure takes longer than the available warning time before operation of the innovation. The operational environment determines the available warning time.

#### Step A.5: Qualitatively assess the expected exploitability;

To assess the expected exploitability, the potential size of the European market for the innovation should be determined by comparing the intended risk reduction capacity to the loading conditions throughout Europe for the considered hazard. After the potential market is determined, the actual exploitability is determined with:

- a description of the innovation's modularity: the degree to which the components of an innovation can be separated and refitted for a specific location;

- a description of the availability and cost of the material components at the specified locations within Europe: the degree to which the material components are easily obtained and their costs. Material cost may be dependent on location (in which case the innovator should report the maximum cost for the foreseen market(s)).

The combination of the modularity of the innovation and the availability and cost of the materia components of the innovation determine the exploitability in all regions of the potential market previously determined.

#### Step A.6: Identify all possible failure modes for the innovation and generate a fault tree

The qualitative analysis of reliability may be done by identifying possible failure modes for both implementation and/or structural failure (if relevant) and ranking these according to their impact on the reliability of the innovation. Methods typically used for this purpose are failure mode and effect analyses (FMEA) or failure mode effect and criticality analyses (FMECA). In these analyses, failure modes are described and ranked according to their severity, potential causes and potential impacts on the considered innovation. The ranking of failure modes is used to gain insight in the dominant failure modes of the considered innovation and how likely these are to occur.

Use the system and functionality description to perform a qualitative assessment to identify all possible sub failure modes for both implementation (if relevant) and structural failure. Standard methods used to identify failure modes are FMEA or FMECA (see Chapter 5). First, construct a fault tree for the innovation taking in to account the identified sub failure modes:

- Sub failure modes for implementation failure should include all possible events that may lead to failure *before* operation (e.g., human errors or logistical issues) and should also consider possible (environmental) events that may affect successful implementation that are outside the control of the operator (e.g., a power outage).

- Sub failure modes for structural failure should include all possible structural failures that would lead to failure *during* operation of the innovation. An example of a fault tree analysis is provided for the example TFB in the text box below.

Now, to proceed to the following step, list the two most governing failure modes for implementation (if relevant) and structural failure based on a ranking of all sub failure modes. The (likelihood of the) governing failure modes will be tested in the following steps. Simple tests with a proof of concept (or prototype) in a laboratory environment can be used to gain insight in the governing failure modes.

**Steps A.2-5: Qualitative Description of Technical PI for a TFB**

*Technical effectiveness (A.2)*:

The technical effectiveness of the water-filled tube is expressed by its capacity to reduce flood risk. At this point, the risk reduction capacity is expressed as a water level, wave height and/or flow velocity that the structure is able to resist. The water filled tubes are designed to withstand 0.58 meter of water. The water filled TFB is also designed to withstand small waves of up to 0.2 meter perpendicular to the structure. The tubes are not intended to be placed in flowing water, so no (lateral) flow velocities are considered.

*Reusability (A.3)*:

By definition a TFB is not a permanent innovation because it requires implementation prior to the arrival of a flood. A TFB can be either semi-permanent, if some components of the innovation (e.g., the foundation) are installed permanently at the intended location, or temporary, if the whole innovation has to be implemented prior to the flood.

In this example, the water-filled tubes are temporary structures that do not have any components implemented permanently at the implementation location. It is estimated that after each use minor repairs (< 10%) may be required; such repairs could include patching a rip in the canvas material or refilling tubes with water.

The technical lifetime of the water-filled tubes depend on the canvas material; in this case, assuming this is some kind of plastic/vinyl material, a technical lifetime of 10 years is estimated. To reach the maximum lifetime, the water-filled tubes should be stored in a cool, dry location. Each water-filled tube (estimated storage required per meter of tube). The tubes should be filled semi-annually to test check for leaks/tears in the material.

**Steps A.2-5: Qualitative Description of Technical PI for a TFB (cont.)**

*Reliability (A.4)*:

Water-filled tubes are implemented prior to arrival of a flood. To assess the reliability of the innovation, both implementation and structural failure are qualitatively assessed:

Implementation failure could occur due to logistical issues during transport of the innovation to the location, (human) errors during implementation/installation, or failure of the necessary equipment required to install and fill the barrier. Considering water-filled tubes, logistical issues can occur due to the unfamiliarity with the location where the tubes are implemented (e.g., if the location cannot be easily accessed or the subsoil is uneven). However, the implementation/installation and filling of the tubes is fairly easy as no real complex operations are required; therefore it is expected that the implementation can be directed by emergency personnel who have received training. Filling of the tube is dependent on the presence and correct functioning of certain equipment (e.g., a pump to fill the tube with water). The lead-time needed for implementation of the tubes prior to a flood will be dependent on the capacity of the pump. Taking this in to account, we find the following ranking of implementation failure modes: 1) failure due to operator error and 2) failure due to insufficient time.

Structural failure could occur due to instability of the tube (e.g., due to sliding or turning over), ruptures of the material, or seepage/leakage of water under the tube. The stability of the structure depends highly on the subsoil upon which it is placed (i.e., operational environment). For example, placement on clay/peat material can result in horizontal sliding because of insufficient friction. In comparison, placement on sand can result in significant seepage/leakage under the tube. Considering that these structures are gravity structures, structural failure modes that are most likely to occur are: 1) sliding failure, 2) rotational failure and 3) failure due to seepage.

*Exploitability (A.5)*:

Water filled tubes can be applied anywhere in Europe where flood levels do not exceed 0.58 meter and waves do not exceed 0.2 meter. To determine the potential market size this should be compared to the boundary conditions throughout Europe (see Chapter 2).

Water filled tubes are very modular, they consist of separate tubes of a finite length (aprooximately 8 meters) that can be connected. Variable lengths van be applied depending on the location where the innovation is required. The tubes are made of canvas material that is available at upholstery stores.

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## Step A.6: Identifying Failure Modes of a TFB

Using the description of the system and operation procedure for the water-filled tubes described in the Desk Study, the following failure modes for implementation and structural failure have been identified and ranked according to their likelihood to occur (the ranking is based on expert judgment):

- Implementation Failure Modes:
  - Insufficient time: failure to implement the tubes due to insufficient time for transport and implementation/installation of the tube at the operational site
  - Equipment failure: forgetting to bring the necessary equipment for implementation or failure of the equipment (e.g., pump breakdown)
  - Obstruction: the tubes cannot be implemented due to obstructions on site (e.g., cars or trees)
  - Human error: failure to implement the tubes correctly due to human error
- Structural failure Modes:
  - Overflowing/overtopping: water overflowing the tube
  - Instability: rotational instability (toppling over), horizontal instability (sliding) or vertical instability (settlements)
  - Seepage/leakage/piping: seepage flow under the tube may cause a leakage and/or backwards erosion and ultimately failure due to instability
  - Structural failure: ruptures of the canvas/vinyl material due to insufficient bending resistance or stiffness of the materials used, or due to impact loads (e.g., debris)

Note that only failure modes that will lead to failure of the water retaining function of the TFB have been taken in to account. These failure modes are included in the following fault tree for the water-filled tube barrier:

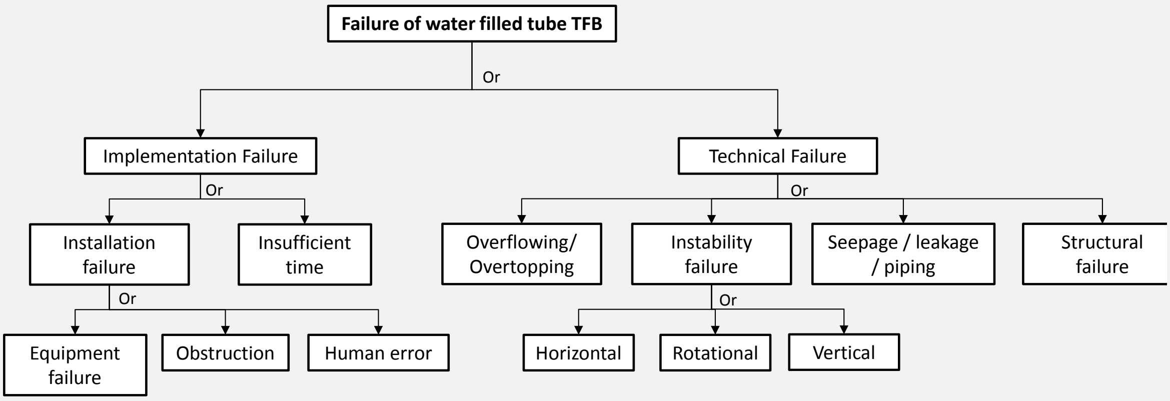


*Figure 2 Fault tree example of a water filled tube (TFB)*

Considering (the likelihood of) all failure modes (both implementation and technical), the following governing failure modes are expected: 1) human error, 2) insufficient time, 3 instability due to rotation or 4) instability due to sliding.

### Step A.7: Identify a testing facility where (most of) these failure modes can be tested

Identify and secure a testing facility where the structural failure modes identified in Step B.1 can be tested. Note: it is possible that not all failure modes can be tested for all conditions imaginable. In this case, either a secondary testing facility may be required to fully test the innovation or the innovation will only tested for the conditions that are able to be tested in the facility available and the end-user will be advised that additional testing may be necessary.

#### Step A.7: Identifying at Test Facility for a TFB

Test facilities where water-filled tubes can be tested are the facilities of Floodproof Holland in Delft, the Netherlands, or the planned testing polder Floodproof Romania.

- At Floodproof Holland in Delft, water levels up to 1 meter and low flow velocities can be simulated for testing.
- At Floodproof Romania (under construction), water levels up to 1.5 meters can be simulated for testing.

*Figure 3 Testing at Floodproof Holland (source: www.proeftuinendelft.nl)*

### Step A.8 Determine whether you can proceed to the next phase

To proceed to Laboratory Testing (TRL 4-5), the preceding steps must be completed, a report containing the results of the desk study made and a prototype must be available for testing in a laboratory environment.

# Laboratory Testing, TRL 4-5

The goal of Laboratory testing is to optimize the performance of the innovation when subject to the design criteria. Preliminary calculations are used to quantify each technical PI taking into account the design criteria from the Desk Study. The following steps have been proposed for Laboratory Testing (i.e., testing protocol):

B.1: Evaluate technical effectiveness under design criteria;

B.2: Evaluate the reliability of the innovation under design criteria

- for implementation failure, test the vulnerability of the innovation to operation errors (if applicable);
- for structural failure, test the stability of the innovation during operation;

B.3: Check that the reusability holds under the design criteria;

B.4: Check that the exploitability holds under the design criteria

B.5: Determine whether to proceed to the next phase of testing.

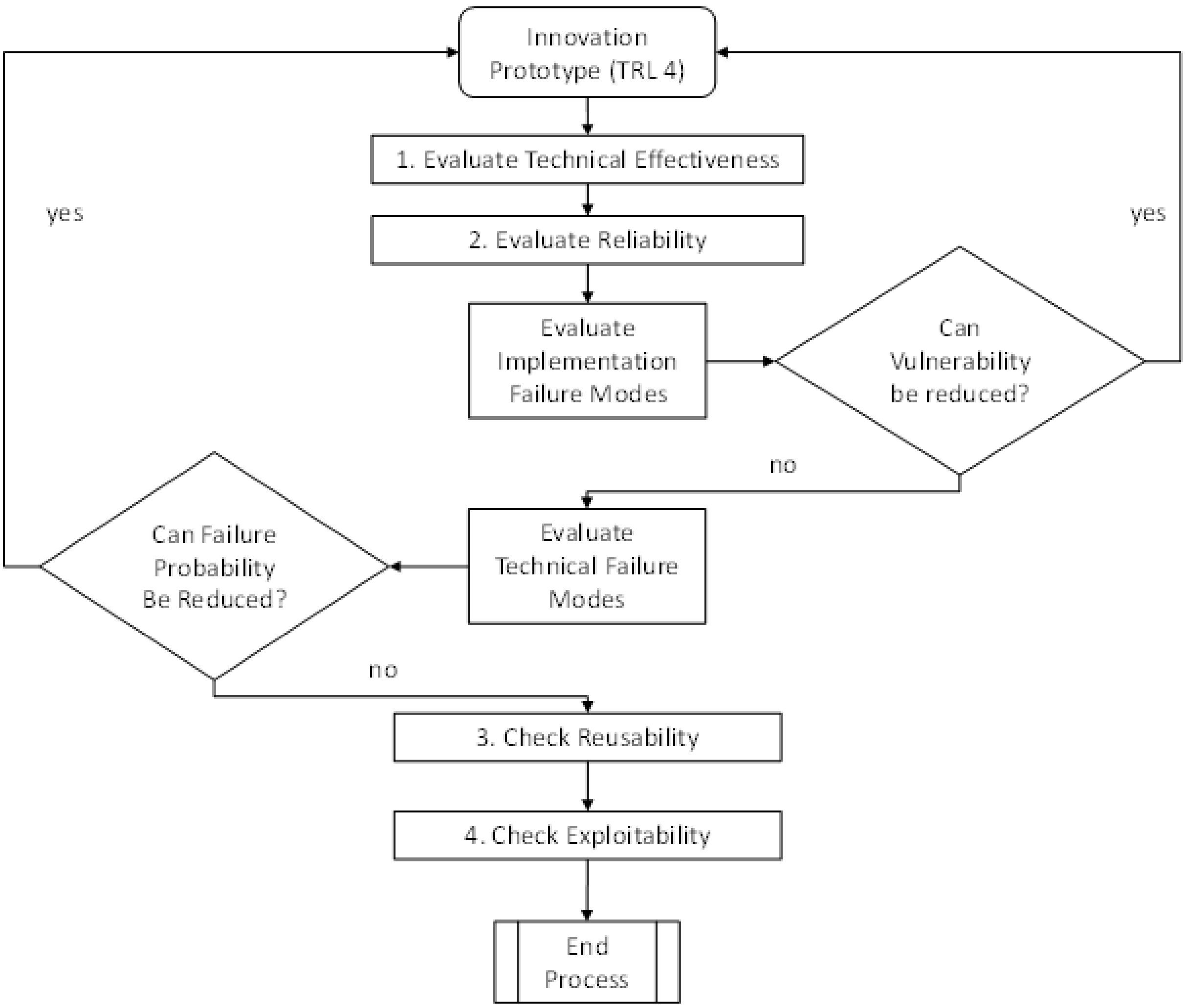

*Figure 4 Overview of laboratory testing for an engineered/built (structural) innovation.*

These steps are described in further detail below.

#### Step B.1: Evaluate technical effectiveness under design criteria

Conduct an engineering-based study to evaluate the technical effectiveness of the prototype, considering the governing structural failure modes. Calculations must be provided to check whether the innovation can withstand the design criteria defined in the Desk Study for the governing structural failure modes. For these failure modes, a safety factor must be provided.

Safety factors reflect how much stronger the system is than the minimum required for the intended load. These are calculated by dividing the resistance of an innovation by the loads (defined by the design criteria): equation 1 contains an example calculation for sliding failure of a TFB. The safety factor should be higher than one for a system to be considered stable. Innovations with safety factors higher than one contain a margin of safety for the considered structural failure mode. This margin reflects the (required) reliability of the innovation. End-users can require a certain margin of safety for (the structural failure modes of) an innovation, depending on the intended operational environment.

**Step B.1: Evaluating Technical Effectiveness of a TFB under design criteria**

As stated before, water-filled tubes can be seen as small gravity structures which obtain their stability through self-weight (W [kN/m]). The loads on the structure consist of the horizontal water pressure ($F_{w;h}$ [kN/m]) and upward water pressure ($F_{w;v}$ [kN/m]).

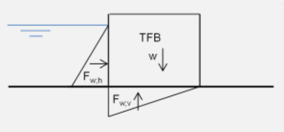


*Figure 5: Typical loads on a schematized temporary water-retaining structure consisting of layers of sand bags.*

As previously identified, these structures are subject to the following failure modes: overflow/overtopping, rotation instability, horizontal sliding, seepage and structural failure (Figure 6). The stability is largely influenced by the weight and the development of upward water pressure under the structure, which depends on the subsoil, loading time and connection between the structure and the subsoil (Lendering et al. 2015).

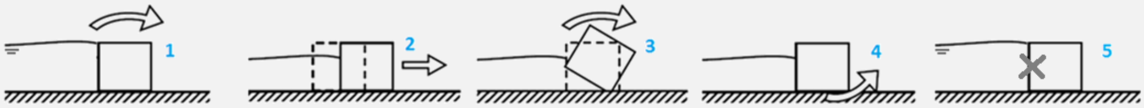


*Figure 6 Typical structural failure mechanisms of temporary water retaining structures: Overflow (1), Sliding (2), Rotation (3), Seepage (4) and (5) Structural failure* (Boon 2007)

For complete Laboratory Testing, all failure modes need to be quantitatively evaluated. Explanations for how these can be calculated can be found in (Boon 2007; Lendering et al. 2013). In this example, we will demonstrate how safety factors are calculated for the sliding failure mechanism. Sliding is often governing for these structures and occurs when the horizontal force on the structure exceeds the friction force between the structure and the subsoil due to self-weight (Boon 2007):

$$Fs_{sliding} = \frac{f \cdot (W - F_{w;v})}{F_{w;h}} > 1 \, [-] \qquad [1]$$

where $Fs_{sliding}$ is the safety factor for sliding and stability is obtained when $Fs_{sliding} > 1$ [-].

**Step B.1: Evaluating Technical Effectiveness of a TFB under design criteria (cont.)**

The horizontal force ($F_{w;v}$) is the result of the design loads, which (in this example) are a water level of 0.58 meter and a wave height of 0.2 meter. The resulting horizontal water pressure should be calculated, after which it is compared to the friction force between the structure and the subsoil, resulting from the self-weight (W) and friction coefficient of the subsoil (f [-]). In this calculation, we neglect the upward water pressure under the structure due to the temporary nature of the load and the construction on impermeable layers. To validate this assumption, tests in a Laboratory Environment will be performed to show whether the calculated safety factors are realistic for the governing failure mode. These tests will also determine whether sliding is indeed the governing failure mode. The input data is given in the following table.

*Table 1 Example calculation of safety factor for sliding of temporary flood barrier*

| Variable | Parameter | Equation | Value | Unit |
|---|---|---|---|---|
| Ø | Friction angle of subsoil (clay) | - | 22.5 | ° |
| $y_W$ | Volumetric weight water | | 10 | kN/m$^2$ |
| *f* | Friction coefficient between structure and subsoil | tan(Ø) | 0.4 | - |
| H | Water level inside structure | - | 0.6 | m |
| L | Length of structure | - | 1.0 | m |
| B | Width of structure | - | 0.7 | m |
| V | Volume of structure | $B \cdot H_r \cdot L$ | 0.42 | m$^3$ |
| $F_{w;v}$ | Upward water pressure | | 0 | kN/m |
| W | Weight of structure | $V \cdot y_w$ | 4.2 | kN/m |
| $H_w$ | Water level | | 0.58 | m |
| $F_{w;h}$ | Horizontal force | $0{,}5 \cdot y_w \cdot H_r^2$ | 1.25 | kN/m |
| FS | Safety factor | $W \cdot f / F_{w;h}$ | 1.0 | - |

The estimated factor of safety for sliding is 1.0. For the remaining structural failure modes, the following safety factors are calculated for installation of the water filled tube on clay subsoil:

| Structural failure mode | Safety factor |
|---|---|
| Overflow | 1.5 |
| Sliding | 1.0 |
| Rotating | 1.5 |
| Vertical stability | 1.5 |
| Piping | N/A for clay subsoil |

*Table 2 Safety factors for structural failure mode of water filled tubes (fictive example)*

**Step B.2a Test the structural reliability of the innovation under the design criteria**

Test the innovation in the chosen laboratory environment for the design criteria corresponding to the intended functionality of the innovation. During these tests, insight can be gained into the likelihood of each structural failure mode (by evaluating if and when they occur) when the innovation is subjected to the hazard loads. Depending on the considered (type of) innovation, specific guidelines are available for testing. In the running example of a TFB, guidelines developed by the USACE are used (Wibowo & Ward 2016). After testing, evaluate/validate the safety factors calculated in Step 3 to determine whether these were realistic and/or whether the prototype should be adjusted.

As explained, safety factors reflect how much stronger the system is than the minimum required for the intended load, the margin above one reflects the reliability/ robustness of the innovation for the considered structural failure mode. For innovations with a safety factor close to one, failure under design criteria is (very) likely. If this is confirmed by laboratory testing, an innovator might want to:

- reduce the design criteria (and corresponding loads);
- adjust the considered innovation to make it more robust.

Similarly, for innovations with large safety factors (e.g., 2.0 and higher), innovators might want to:

- increase the design criteria (and corresponding loads);
- adjust the considered innovation to make it less robust (and more effective).

Either way, the safety factors calculated in step B.1 should be validated during this step before continuing to the next step.

**Step B.2a: Testing the Reliability of a TFB under design criteria**

The design criteria of the water-filled tubes were determined in the Desk Study: a water level of 0.5 meters and a wave height of 0.2 meters. In the preceding step, safety factors for every structural failure mode were calculated. During this step we will test for structural failure of the water-filled tubes. We will use the standard testing protocol (Wibowo & Ward 2016) shown in the table below for these tests. Depending on the intended functionality, hydrostatic (i.e., water levels), hydrodynamic (i.e., waves or flow), overflow, or impact loads may be relevant:

*Table 3 Example Testing Protocol for Laboratory Testing (Wibowo and Ward, 2016)*

| Test | Pool/Test Conditions | Repair Allowed |
|---|---|---|
| Hydrostatic (water level) | 33%H, 24 hour<br>66%H, 24 hour<br>95%H, 24 hour | After 24 hour test<br>After 24 hour test<br>After 24 hour test w/ water level lowered to 66% |
| Hydrodynamic (waves) | 66%H, Low-wave, 7 hour<br>66%H, Med-wave, 3 x 10min<br>66%H, High-wave, 3 x 10min<br>80%H, Low-wave, 7 hour<br>80%H, Med-wave, 3 x 10min<br>80%H, High-wave, 3 x 10min | After finish of 7 hour<br>After finish of 66% H, high-wave test<br>After finish of 7 hour<br>After finish of 80% H, high-wave test |
| Overflow | 2.5 cm overflow, 1 hour | Major repair or rebuild |
| Impact loads | 0.3 m log, 8 km/hour<br>0.4 m log, 8 km/hour | Removal of all material |

**Step B.2a: Testing the Reliability of a TFB under design criteria (cont.)**

In our example, only hydrostatic (a water level of 0.58 meter) and hydrodynamic (waves up to 0.2 meter) are tested. Using the testing protocol, we are able to test for every structural failure mode:

- Instability: rotational, horizontal and vertical instability is tested during hydrostatic, hydrodynamic and impact load tests. These tests are performed by raising the water level until the maximum retaining height and assessing whether instability occurs. If no instability occurs after 24 hours, the testing is considered successful.
- Seepage/leakage/piping: Measure the amount of seepage flow under the water-filled tube during hydrostatic tests and record the occurrence of piping (if any). (Conduct these tests using different subsoils when possible).
- Overtopping/overflowing: Allow the structure to overtop/overflow to test its stability. Note that for water-filled tubes, overflowing may be allowed (and can be part of the intended functionality of the innovation) as long as the barrier is not breached (i.e., move or topple over). In this phase, testing for overtopping/overflow is considered successful if no breaching occurs during overtopping/overflow.
- Structural failure: Measure whether elements of the water-filled tube fail when subject to the design criteria for a certain duration; or when subjected to impact loads (e.g., debris).

Testing is considered successful if no failure has occurred after 24 hours. For all failure modes, the water levels, wave loads, and subsoil applied during the tests should be documented. The testing results are compared to the safety factors calculated during Step 3.

Based on the calculations in Step 3, sliding failure will be governing (the safety factor for sliding is the lowest). Hydrostatic tests are performed on clay according to the protocol shown in Table 3. The following results were documented:

- No failure at 33% of water level (0.165meter) after 24 hours.
- No failure at 66% of water level (0.33meter) after 24 hours.
- Failure at 95% of water level (0.55 meter) after 12 hours due to horizontal sliding.

The laboratory test showed that sliding is indeed the governing failure mode and that the barrier fails at a water level lower than 0.58 meter. This does not correspond to the computed safety factors in Step 3, which predicted failure at water levels exceeding 0.58 meter. The tests have shown that the technical reliability at 0.5 meter is not guaranteed. To continue, the innovator may consider to reduce the design criteria (i.e., description of the intended functionality) to a water level below 0.55 meter or to adjust the prototype to increase sliding stability. Stability can be increased by increasing the stability of self-weight of the structure. An increase of the width of the structure to 0.9 meter is proposed. This will increase the safety factor to 1.3.

*Figure 7: Example testing of a 'porta dam' using to the USACE guidelines for testing* (Wibowo & Ward 2016)

### Step B.4b: Test the vulnerability of the innovation to implementation errors

For all sub failure modes identified within "implementation failure" in Step 2, evaluate the vulnerability of the innovation to these failure modes. It is useful to examine how vulnerable the innovation is to implementation failure, for example to evaluate what happens when some components are incorrectly placed. Vulnerability should be evaluated by the innovator (i.e., not inexperienced/outside people). If the innovation is deemed "too vulnerable" due to these errors (or the probability of construction error is recognized as too high in this process), changes should be made to the prototype at this point (and not a later TRL). Such changes could be to the structural design of the prototype or to the operation and maintenance protocols for the innovation (e.g., requiring additional training for emergency personnel or higher skill level to reduce probability of implementation error).

Subject the innovation to the hazard loads determined by the design criteria, but with construction errors intentionally in place. Assess whether the innovation fails under these conditions and whether the prototype can be adjusted to mitigate these failures (i.e., reduce vulnerability) (and return to TRL 4). If not, consider these failure modes as part of implementation failures during Operational Testing in Section 5.2.

**Laboratory Testing, Step B.4b: Testing the Vulnerability of a TFB for Implementation Errors**

Errors during implementation of a water filled tube include insufficient filling or insufficient anchoring of the water-filled tube (or no installation of anchors). The vulnerability of the tube to failure caused by these errors is tested by simulating these circumstances in the laboratory environment and repeating the tests performed under Step 4a.

Suppose we only fill the water-filled tube with 75% of the total volume of water required or forget to install the required anchors. During testing it is likely that the barrier will fail at lower water levels than 0.55 meter, because insufficient friction due to self-weight or anchors is present. Changing the operational protocol in such a way that a check of the required volume of water in the tube will help reduce vulnerability for this type of errors.

### Step B.3: Check that the reusability holds under the design criteria

For temporary or semi-permanent innovations, evaluate whether the estimated re-usability holds for the design criteria identified in the Desk Study. For this purpose, determine the percent of reusable material after each operation (during testing of technical reliability) and determine whether the prototype can be adjusted to improve the re-usability of the innovation.

Further, evaluate the expected technical (or climate) lifetime of the innovation based on a decomposition of all materials used and their manufacturers lifetime. If the estimated re-usability (i.e., percentage of material to be replaced after each operation and the lifetime) holds, move to Operational Testing. Otherwise choose whether to adjust the innovation prototype (and return to TRL 4).

### Step B.4: Check that the expoitabiltiy holds under the design criteria

Evaluate whether the exploitability estimated during the Desk Study (Table 5-1) holds under the design criteria, specifically the intended risk reduction capacity. If not, update the exploitability according to the new design criteria. If satisfied with the current design of the innovation, proceed to Operational Testing (TRL 6).

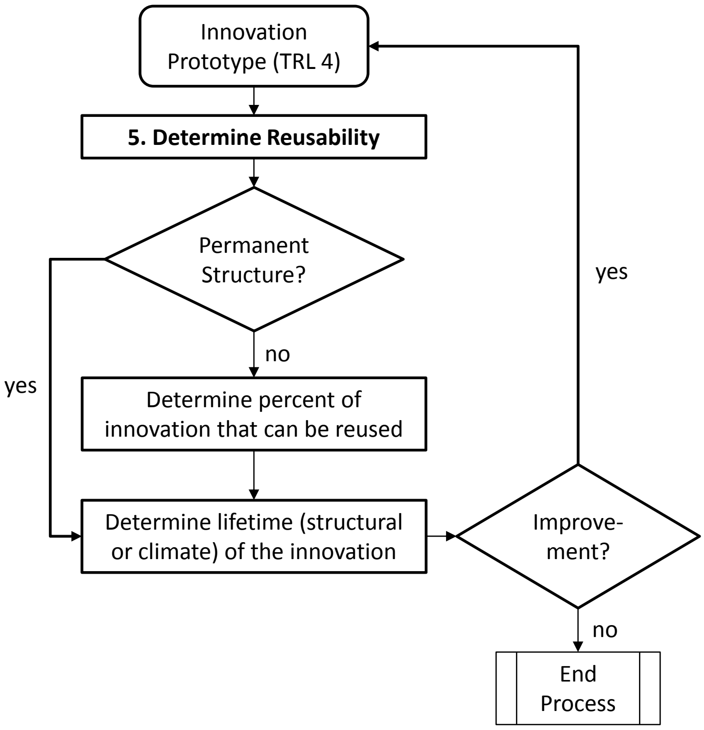


*Figure 8 Evaluating the reusability of an engineered/built (structural) innovation.*

**Laboratory Testing, Step B.3/B.4: Check that the reusability and exploitability holds under the design criteria**

The reusability is assessed after each test performed in Step 4 by documenting the required repairs to damages (if any) of the water-filled tubes and evaluating what percent of the barrier should be repaired after each use. See, for example, Wibowo and Ward (2016) where temporary flood barriers were tested to their design criteria over varying duration after which they calculated how much percent of the structure needed to be repaired/replaced after each use. Considering the lifetime, water filled tube consists of a canvas / vinyl material that has a technical lifetime of 10 years in a water environment.

The exploitability needs to be updated to account for the updated design criteria. The potential market size will be reduced due to lower water levels that can be resisted by the innovation (0.5 meter versus 0.58 meter. The remaining modularity and material properties remain the same as assessed in the Desk Study.

**Step B.5: Determine if you can proceed to the next phase**

To proceed to Operational Testing (TRL 6-8), the preceding steps must be completed, i.e., a fault tree has been generated, the technical effectiveness has been checked (and safety factors calculated), the reliability tested (both structural failure and vulnerability to implementation errors), and the reusability (re-)quantified.

## Operational Testing, TRL 6-8

This phase consists of quantitatively analyzing the technical PI in an operational environment and/or during real events. In this phase, detailed assessment / engineering is required. First, the innovator needs to define the requirements and boundary conditions for the (intended) operational environment of the innovation These may be (slightly) different than the design criteria defined in the desk study and test in Laboratory Testing. For example, the design criteria of a temporary flood barrier can be to withstand water levels up to 0.58 meter, while at envisioned operational environment the water levels will at maximum reach 0.5 meter. All technical PI will be (re-) tested for operational conditions. The following steps should be undertaken for Operational Testing (i.e., testing protocol):

C.1: Define requirements/boundary conditions for the intended operational environment (also see climate conditions provided by Work Package 5.1);

C.2: Evaluate the technical effectiveness of the innovation for operational conditions;

C.3: Evaluate reliability for operational conditions

- Evaluate the probability of implementation failure
- Evaluate the probability of structural failure
- Solve the fault tree and evaluate the probability of failure of the innovation

C.4: Check that the reusability established still holds for operational conditions;

C.5: Check that the exploitability established still holds for operational conditions;

C.6: Determine if you can proceed to the next phase.

These steps are described in further detail below.

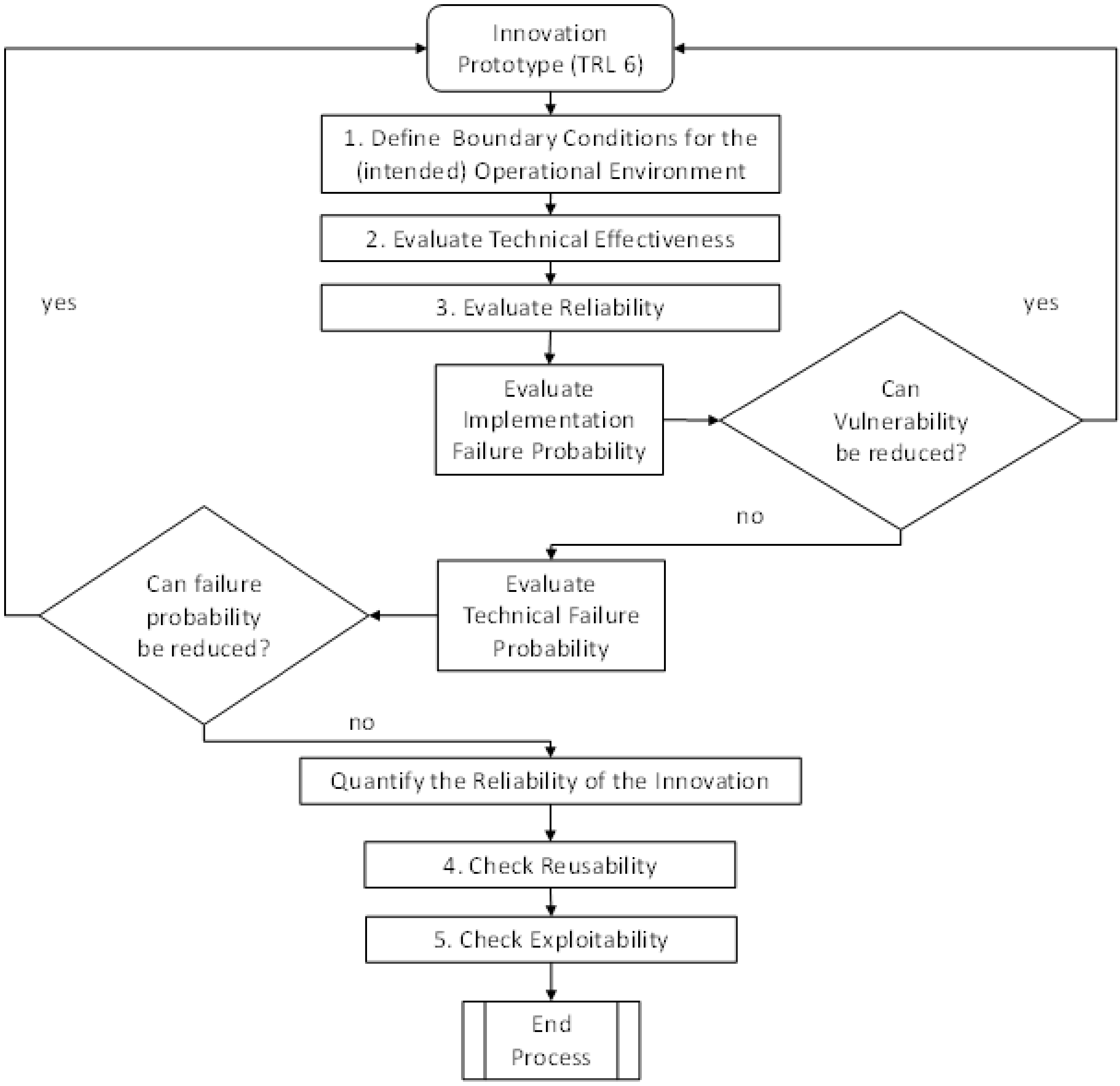


*Figure 9 Overview of operational testing for an engineered/built (structural) innovation.*

**Step C.1: Define requirements/boundary conditions for the intended operational environment**

To establish the updated design criteria, the boundary conditions and requirements of the (intended) operational environment need to be identified and quantified. For engineered/built environment innovations, the hazard loads that correspond to the (intended) functionality of the innovation need to be described. Examples of loads corresponding to each hazard are shown in Figure 4.3 below; the relevant loads for the innovation are used in quantification of each technical PI. When identifying the relevant loads for the innovation, take into account the intended lifetime of the innovation and how these loads may change due to climate change during the intended lifetime.

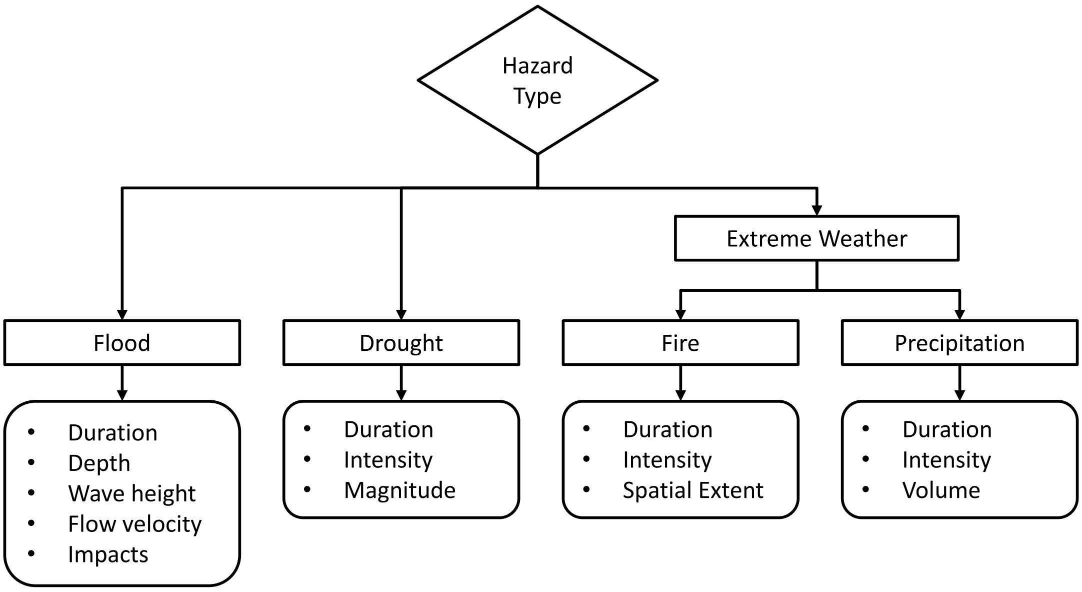


*Figure 10 Establishing physical boundary conditions for testing of structural/built environment innovations based on hazard type (minimum requirements).*

Besides the hazard loads, other boundary conditions and requirements relevant for the considered innovation when operated need to be identified. These might include (depending on your innovation type):

- geotechnical information of the location where the innovation is used (e.g., the subsoil);
- the time available for implementation (if relevant);
- the number and type of operators (e.g., experienced or inexperienced) involved during implementation / installation (if relevant).

These requirements are used in the following steps.

**Operational Testing, Step C.1: Establishing Boundary Conditions/Requirements for the (intended) Operational Environment of a TFB**

The water-filled tubes will be implemented at a location along a riverfront where the following hydraulic loads are present: a water level of 0.5 meter, waves of 0.25 meter, and a flow velocity in longitudinal direction of 0.3 m/s. The tubes will be placed on asphalt. The warning time (i.e., time for implementation) is 12 hours and the tube will be implemented by water board employees assisted by inexperienced volunteers. Furthermore, the water board expects a maximum failure probability of the tube barrier of 1/100 per use.

**Step C.2: Evaluate the technical effectiveness of the innovation for operational conditions**

During this step, detailed testing of the innovation is expected to check whether it can withstand the hazard loads when operated in operational conditions (derived in Step C.1). Testing should cover all structural failure modes identified during Laboratory Testing and will result in updated safety factors for these failure modes.

**Operational Testing, Step C.2: Evaluating the Technical Effectiveness of a TFB for the Operational Environment**

The calculations made in Step 3 of laboratory testing are repeated for the conditions determined by the operational environment. Note that in the example, the wave height has increased and the innovation is also subject to longitudinal flow with a velocity of 0.3 m/s. Furthermore, the subsoil changed from clay to asphalt. This requires recalculating the safety factors for these conditions. These safety factors will be re-evaluated in the following steps, similarly to what was done I Laboratory Testing.

### Step C.3: Evaluate reliability of the innovation for operational conditions

During operational testing, the innovator must consider both implementation and structural failure modes when evaluating reliability. This step includes evaluating the probability of implementation failure (step C.3a), quantifying the probability structural failure (step C.3b) and solving the fault tree (step C.3c). The section describes guidelines for evaluating the probability of implementation failure probabilistically. These guidelines have been developed specifically for temporary flood barriers. Other detailed (non-probabilistic) assessment methods can also be used for different types of innovations with the same goals in mind.

#### Step C.3a: Evaluate the probability of implementation failure

The following section explains a model for quantifying the probability of implementation errors (of temporary flood barriers) depending on the complexity of the implementation procedure and the performance level of the operators1 involved. Furthermore, a method is proposed to evaluate if failure due to insufficient time will occur by comparing the time required for implementation with the available warning time. This method was developed specifically for temporary flood barriers, however, these guidelines can also be used to evaluate the (probability of) implementation failure for other types of innovations.

Implementation failure can occur due to implementation errors or insufficient time. In reliability assessments, human error probabilities are often dominant compared to other sub failure modes. For simplicity, at this point we assume that human error probabilities are dominant for the probability of implementation errors for the innovations considered within BRIGAID. To quantify the probability of implementation errors, a methodology (Lendering et al. 2015) to quantify the probability of errors for detecting and placing emergency measures for flood prevention is used. In this paper, Rasmussen's model for (Rasmussen 1983) classification of human behaviour is used to estimate generic error rates that can be applied to specific human task performances. This model distinguishes between three levels of behaviour: Knowledge-based, Rule-based and Skill-based behaviour (Rasmussen 1983):

- **Knowledge-based** performance is the most cognitively demanding level; at this level there are no pre-planned actions which can be called upon because of the novelty of the situation. Protocols are unavailable and the assessor is required to analyse the unfamiliar situation, develop alternative (conceptual) plans and choose the plan which is considered to be the best alternative (Rasmussen 1983). Error rates vary between 1/2 and 1/200 per task.

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[1] Construction errors can be minimized by providing better operation and maintenance guidelines, better training for operators, or adjusting the prototype to mitigate these failures. See Phase I Step 4.

- **Rule-based** performance is the next cognitive level; this level involves responding to a familiar problem according to standardized rules and protocols. The rule to be applied is selected from previous successful experiences or from predefined protocols (Rasmussen 1983). The error rates vary between 1/100 and 1/2,000 per task.

- **Skill-based** performance is the least cognitively demanding level; at this level the calling conditions occur so often that knowledge retrieval and action are virtually automatic. Normally, skill based performance occurs without conscious attention or control (Rasmussen 1983).The error rates vary between 1/200 and 1/20,000 per task.

The relation between common error rates and three performance levels is shown in the following figure:

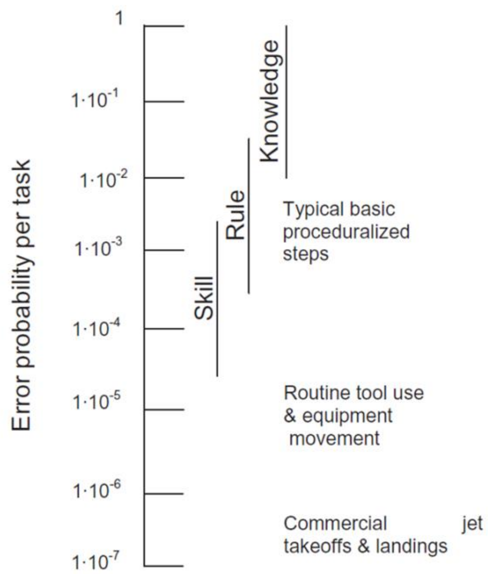



*Figure 11: Human error probabilities and performance levels by Watson and Collins* (Bea 2010)

The standard error rates per task are used to estimate the probability of implementation errors for every operation of the innovation (shown in Figure 11). The estimated probabilities depend on the expected performance level of the operators involved (Knowledge-, Rule- or Skill based) and the presence of (clear) protocols.

Now evaluate the estimated probability of implementation errors by having the innovation implemented by the operators involved and documenting whether or not errors during implementation occur. This will give insight in whether or not the assumed error probabilities are realistic. During these tests, also check whether or not all possible implementation failures are included in the fault tree derived in Laboratory testing and update the fault tree if necessary.

To estimate the probability of *insufficient time,* the innovator needs to evaluate if the available warning time is sufficient to implement the innovation. For this purpose, it is necessary to simulate the implementation procedure and document the amount of man-hours[2] needed for

[2] The time required is documented in man-hours, because more having more operators available will reduce implementation time but the amount of man-hours per meter will remain the same.

implementation of the innovation. The innovator should perform multiple tests to generate a distribution (+/-) of the time required ($T_r$) for implementation and compute the probability of insufficient time using Monte Carlo simulation, taking in to account the distribution of the available warning time ($T_a$). The following equation describes the limit state function:

$$Z = T_a - T_r \qquad [2]$$

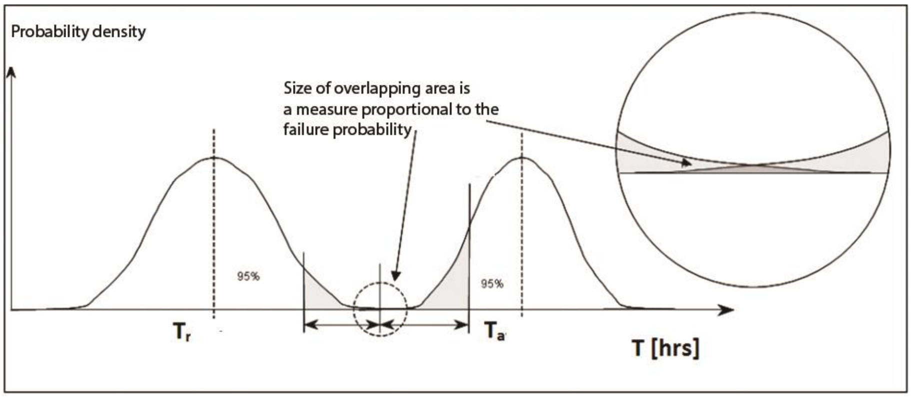



*Figure 12 Probability density of the required time ($T_r$) versus the available time ($T_a$)* (Lendering et al. 2015)

Frieser uses a similar method to determine the probability of complete evacuation of people within the available time (Frieser 2004). Note that aside from the operator performance level, the operating conditions (e.g., daytime/nighttime and different weather conditions) may influence the implementation of the innovation. Tests performed during operational testing must correspond to the conditions of the operational environment for the results to be realistic and useful for an end-user. Therefore, testing with different operators (e.g., experienced and less experiences) and under different circumstances (e.g., daytime, nighttime and/or with bad weather) will be useful for end-users.

### Operational Testing, Step C.3a: Evaluating the probability of implementation failure of a TFB for operational conditions

*Implementation errors:* As stated in Step 1, the water-filled tubes will be implemented by waterboard employees and volunteers. The water board employees are expected to have knowledge and experience with flood mitigation measures, however, specific knowledge about the implementation of the tube barriers is not expected. Volunteers are not expected to have any experience with flood mitigation measures or tube barriers. This assessment would suggest that both operators operate at a Knowledge-based level, with failure probabilities per task of 1/2 to 1/200 per use (volunteers operating at a higher failure probability and waterboard employees lower). We assess that the probability of errors during implementation is about 1/100 per use (since implementation of the water-filled tube barrier is fairly easy as described previously).

The maximum failure probability per use defined in Step 1 sets a boundary for the performance level of the operators involved in implementation of the tube barrier. Considering the expected performance level of the volunteers, it is very likely that the required maximum failure probability of 1/100 per use is not reached. To reduce the failure probability, the volunteers need to at least perform at a Rule-based level, which requires operating according to procedural steps. A protocol that explains each step should be made and tested to evaluate if the maximum failure probability is reached.

*Insufficient time:* During operational testing of the barrier the following was documented (fictive example):

- The required time for transport to site is 2 hours.
- The required time for placement is 1 hours.
- The required time for pumping is 2 hours

The total time required is on average 5 hours. We assume a normal distribution with standard deviation of 1 hour. We also assume the available time to have a normal distribution with mean 10 hours and a standard deviation of 1.5 hours. The probability of having insufficient time is calculated with Monte Carlo simulation: $P(Z,0) = P(T_a - T_r < 0) = 1/375$ per use.

### Step C.3b Evaluate the probability of structural failure for operational conditions

(re) Test the innovation in an operational environment for the updated design criteria of the innovation. After testing, evaluate/validate the safety factors calculated in Step 2 to determine if these were realistic and whether the prototype needs to be adjusted to improve on these failure modes. If the tests do not correspond to the safety factors determined in Step 3, re-calculate these until the results of the tests and the calculations match.

After matching the safety factors to those of the tests, quantify the (conditional) probability of structural failure (i.e., the probability of failure given the design water level). Several methods are available for this purpose. We will discuss a Level III probabilistic approach, using Monte Carlo simulations.

*Level III probabilistic approach:* this approach requires the derivation of a probability distribution function of every parameter used when calculating safety factors for all failure mechanisms. Monte Carlo simulation is then used to estimate the probability that the safety factors is below 1.0, which is the probability of the considered failure mode.

**Operational Testing, Step C.3b: Evaluating the probability of structural failure of a TFB for operational conditions**

First, the tests performed in Step 4a of Laboratory Testing are repeated for the updated design criteria (e.g., the boundary conditions in the (intended) operational environment), requirements and boundary conditions of the operational environment and the safety factors calculated in Step 2 of Operational Testing are checked/updated. The following table contains the input of the Monte Carlo simulation. Note that, compared to Laboratory Testing, the width of the structure is increased to 0.9 meter, resulting in a factor of safety of 1.3.

*Table 4: Input data for structural failure probabilistic calculations*

| Variable | Parameter | Distribution | Equation | Value | Unit |
|---|---|---|---|---|---|
| Ø | Friction angle of subsoil (clay) | Normal | - | μ = 22.5<br>σ = 2 | ° |
| $y_w$ | Volumetric weight water | Deterministic | | 10 | kN/m$^2$ |
| H | Water level inside structure | Normal | - | μ = 0.6<br>σ = 0.05 | m |
| L | Length of structure | Deterministic | - | 1.0 | m |
| B | Width of structure | Deterministic | - | 0.9 | m |
| *f* | friction coefficient | | tan(*Ø)* | | - |
| V | Volume of structure | - | $B \cdot H_r \cdot L$ | 0.42 | m$^3$ |
| $F_{w;v}$ | Upward water pressure | - | | 0 | kN/m |
| W | Weight of structure | - | $V \cdot y_w$ | 4.2 | kN/m |
| $H_w$ | Water level | - | | 0.58 | m |
| $F_{w;h}$ | Horizontal force | - | $0{,}5 \cdot y_w \cdot H_r^2$ | 1.25 | kN/m |
| FS | Safety factor | - | $W \cdot f / F_{w;h}$ | 1.0 | - |
| Pf | Probability of failure (conditional on $H_w$) | - | | | 1/50 |

The estimated probability of structural failure, for a given water level of 0.58 meter, is 1/50 per event.

***Step C.3c:*** **Solve the fault tree and evaluate the probability of failure of the innovation**

Quantify the probability of failure of the innovation for every operation by solving the fault tree generated during Laboratory Testing. For simplicity, at this point, we assume all failure modes to be independent. The implementation and structural failure modes are combined with an "OR" gate, which requires using the following rule for calculating the failure probability of the TFB:

$$P_{f;sys} = 1-(1-P_{f';1}) \cdot (1-P_{f;2}) \qquad [3]$$

Note that the guidelines explained in the example are specifically developed for temporary flood barriers. As mentioned before, other detailed assessment methods may be used if these satisfy the main goals of operational testing.

**Operational Testing, Step C.3c: Solving the fault tree to evaluate the probability of failure of the innovation**

The probability of failure of the water-filled tube is found by solving the fault tree constructed during Laboratory Testing. For this purpose, the implementation and structural failure modes have been quantified. The results are included below:

- Implementation failure probability (determined by probability of human error) is estimated at by solving equation 3 for the probability of implementation errors (1/100 per use) and probability of insufficient time (1/375 per use): the resulting probability is 1/80 per use;
- Structural failure probability (determined by probability of sliding failure) is 1/50 per use.

Assuming that implementation and structural failure are independent, the probability of failure ($P_f$) is found with the following equation:

$P_f = 1\text{-}(1\text{-}P_{f'implementation})\cdot(1\text{-}P_{f;technical}) = 1/31$ *per event*

The failure probability is higher than what is required by the water board (i.e., 1/100 per event). Either the implementation or structural failure probability needs to be reduced for the water filled tubes to comply with the safety standard. Either wat, adjustments to the water-filled tubes have to be made.

### Step C.4: Check that the reusability still holds for operational conditions

After each operational test, check that the findings regarding reusability made during Laboratory Testing still hold for the updated design criteria. If so, provide an operation and maintenance strategy for the innovation that guarantees the technical effectiveness for each operation during the assumed lifetime of the innovation; include a plan for repair of the innovation after each hazard event (if necessary). Also, show how the technical effectiveness is influenced by changes of hazard loads during the intended lifetime of the structure (e.g., due to climate change).

### Step C.5: Check that the exploitability still holds for operational conditions

Evaluate whether the exploitability estimated during updated during laboratory testing still holds under the operational conditions, specifically the intended risk reduction capacity. If not, update the exploitability according to the new design criteria. If satisfied with the current design of the innovation, proceed to Operational Testing (TRL 6).

**Operational Testing, Step C.4/C.5: Checking reusability and exploitability still hold for operational conditions**

Repeat the tests done during Step 5 of Laboratory testing taking in to account the updated design criteria, requirements and boundary conditions determined by the operational environment.

### Step C.5: Determine if you can proceed to the next phase.

To proceed, the prototype must comply with the requirements of the (intended) operational environment, the technical effectiveness must be (re-) evaluated when subject to the operational conditions, the reliability (both implementation and technical) must be quantified, and the reusability checked under operational conditions. Operational Testing results in the conclusion that the innovation can fulfill its intended function within the updated operating conditions. This represents a major step up in a technology's demonstrated technical readiness.

Note that successful demonstration of an innovation for one operational environment does not automatically mean that the innovation can be applied to any operational environment. If another operational environment is considered, an assessment must be made to investigate if the boundary conditions and requirements of the new operational environment are comparable, or if the innovation needs to be re-evaluated for that environment. Examples of differences between operational environments can be changing the materials used or subjecting the innovation to more extreme boundary conditions (e.g., higher water levels).

The next step of technical testing would be to implement the innovation (TRL9+) and to determine the risk reduction (and reliability) of the entire operational system (including any measures that are already in place). An example of such a system is the combination of existing permanent dikes with the implementation of innovative temporary flood barriers. System effects, such as increasing lengths or implementing multiple innovations, cannot be ignored when evaluating the risk reduction of an entire operational system. This evaluation is beyond the scope of BRIGAID.

# Appendix E. Detailed Guidelines and Examples for Impacts Assessment

The following sections provide background information for the Impact Assessment Guidelines in the core document and prvoide some relevant examples for each sector. It is still a draft version and will be further elaborated and fine-tuned during the coming months.

## E.1. Energy

### Impact of Climate Change on energy sector

The energy sector is exposed to a number of factors, referred as well  as risks. One of them is climate change risk which is caused by  global warming and weather anomalies. The effects of these changes cause: concentration of greenhouse gases in the atmosphere, global temperature increases, more and forces of all types of extreme weather, melting the world's ice. All changes are progressing faster and faster becoming a serious economic problem.

The energy sector is both a major contributor to climate change and a sector, that climate change will disrupt. The energy sector is the largest contributor to global GHG emissions. In 2010, 33% of direct emissions came from energy production. In recent years the long term trend of gradual decarbonisation of energy has reversed. From 2000 to 2010, the growth in energy sector emissions outpaced the growth on overall emissions by around 1% per year. This was due to increasing share of coal in the energy mix. From annual emissions of 30 gigatonnes (Gt) of carbon dioxide in 2010 projections indicates that without implementation of policies to constrains emissions, emissions associated with fossil fuel use, covering energy supply sector, energy use in transport, industry and buildings would contribute 55-70 GtCO2, per year by 2050. Over the coming decades, the energy sector will be affected by global warming on multiple level. The stakes are high: without mitigation polices, the global average temperature is likely to rise by 2,6 – 4,8 C by 2100 from pre-industrial level. (Key Findings AR5; IPPC 2014).

On other hand the energy sector covering energy services and resources is increasingly affected by climate change factors. There are three major climate trends which are relevant to the energy sector: 1) increasing air and water temperatures, 2) decreasing water availability in some regions and seasons, 3) increasing intensity and frequency of storm events, flooding and seal level rise. For example thermoelectric power generation facilities are at risk from decreasing water availability and increasing ambient air and water temperatures, which reduce the efficiency of cooling, increase the likelihood of exceeding water thermal intake or effluent limits that protect local ecology, as well increase the risk partial or full shutdowns of generation facilities.  Energy infrastructure located along the rivers and coast are at risk of rivers flooding, sea level rise, increasing intensity of storms, storms surge and flooding potentially disrupting electricity generation as well other energy facility operations.

Energy sector is and will be affected by climate impacts on multiple ways. Table given below summarizes potential impacts on the energy sector (Climate Impacts on Energy Systems, World Bank, 2011).

*Table E1.1 Energy Sector Vulnerability to Climate Change*

| Item | Relevant Climate Impact | Impacts on the Energy Sector |
|---|---|---|
| **Climate Change Impact on Resource Endowment** | | |
| Hydropower | Runoff / quantity / season flows / extreme events / erosion / siltation | Reduced firm energy<br>Increased variability<br>Increased uncertainty |
| Wind power | Wind field characteristic / changes in density / wind speed | Increased uncertainty |
| Biofuels | Crop responses to climate change / crop yield | Increased uncertainty<br>Increased frequency of extreme events |
| Solar power | Atmospheric transmissivity / water content / cloudiness | Positive and negative impacts |
| Wave and tidal energy | Ocean climate / wind field characteristic | Increased uncertainty<br>Increased frequency of extreme events |
| **Climate Change Impacts on Energy Supply** | | |
| Hydropower | Water availability and seasonality / water resource variability / increased uncertainty of expected energy output | Impact on the grid / Might overload transmission capacity / extreme events<br>Increased uncertainty |
| Wind power | Alternation in wind speed / increased uncertainty of energy output / short life span reduces with climate change | Increased uncertainty on energy output |
| Biofuels | Reduced transformation efficiency / high temperature reduced thermal generation efficiency | Reduced energy generated,<br>Increased uncertainty |
| Solar power | Reduced solar cell efficiency / solar cell efficiency reduced by higher temperatures | Reduced energy generated,<br>Increased uncertainty |
| Thermal power plants | Generation cycle efficiency / cooling water availability / reduced efficiency / increased water needs during heat waves | Reduced energy generated,<br>Increased uncertainty |
| Oil and gas | Vulnerable to extreme events / cyclones, floods, erosion and siltation | Reduced energy generated,<br>Increased uncertainty |
| **Impacts on Transmission, distribution and transfer** | | |
| Transmission, distribution and transfer | Increased frequency of extreme events / sea level rise / wind and ice / landslides and flooding / coastal erosion / sea level rise | Increased vulnerability of existing assets |

| | | |
|---|---|---|
| **Impacts on design and operations** | | |
| Siting infrastructure | Sea level rise/ flooding from sea level rising / coastal erosion/ water availability / permafrost melting | Increased vulnerability of existing assets<br>Increased demand for new (good) locations |
| Down time and system bottlenecks | Extreme weather events / impacts on isolated infrastructure / energy system not fully operational when community required it the most | Increased vulnerability<br>Reduce reliability<br>Increased social pressure for better performance |
| Energy trade | Increased vulnerabilities to extreme events / cold spells and heat waves / increased stress on transmission, distribution and transfer infrastructure | Increased uncertainty<br>Increased peak demand on energy system |
| **Impacts on energy demand** | | |
| Energy use | Increase demand for indoor cooling / reduced growth in demand for heating increased energy use for indoor cooling | Increased demand and peak demand taxing transmission and distribution systems |
| **Other impacts** | | |
| Cross-Sector impacts | Competition for water resources / completion of adequate siting location / conflicts in water allocation during stressed weather condition / potential completion between energy and non-energy crops for land and water resources | Increased vulnerability and uncertainty<br>Increased costs |

Following the (Key Findings AR5; IPPC 2014), the table below presents the climate change impact and adaptations issues in relation to the following segments of energy system: Power Stations, Pipelines, Power Lines, Renewables, Nuclear.

*Table E1.2 Climate change impact in relation to chosen segments of energy system.*

| Energy system segments | Impacts and adaptation issues |
|---|---|
| **Power Station** | Thermal power plant will be affected by the decreasing efficiency of thermal conversion as a result of rising ambient temperatures. Reduced water for cooling and increasing water temperatures could lead to reduced power operations or temporary shutdowns. |
| **Pipelines** | Energy transport infrastructure is a risk, with oil and gas pipelines in coastal areas affected by rising sea levels and those in cold climes by thawing permafrost. May require new land zoning codes and risk-based design and construction standards and structural upgrades to infrastructure. |
| **Power lines** | Extreme weather events, especially strong wind, heave wet snow could damage power lines. Standards can be amended to implement appropriate |

| | |
|---|---|
| | adaptation measures, including re-routing lines away from high-risk areas. |
| **Renewables** | Changes in regional weather patterns threaten to impact the hydrologic cycle that underpins hydropower. An increase in cloudiness in some regions would affect solar technologies, while an increase in the number of severity of storms could damage equipment. |
| **Nuclear** | Lack of water and extreme weather events may threaten nuclear plants by disrupting the functional of critical equipment and processes. |

## Assessing the impact of innovation on energy sector

The assessment of innovative projects should be subjected to initial qualification (pre-selection). The innovations to be assessed should be important for the energy sector, both in view of the reduction of negative impact on the climate change on energy sector and lowered emissions from the energy sector.

The analysis of innovation in the context of the energy sector involves answering to the question if the implementation will result in:

1. mitigation of negative impacts or their elimination and hence, the protection of the energy system,
2. reduction of green houses emission,
3. reduction of demand for energy,

We should determine if the innovation is applicable to the energy sector and if its implementation will substantially influence the reduction of energy consumption, improvement of energy-efficiency and reduction of GHG emissions.

The assumed approach to the conduction of the assessment includes:

- simplified CF (carbon footprint) analysis – this indicator compared with expected GHG emission or emission reductions during the expected lifetime of the innovation will give an answer if given innovation is capable to offset its construction and application impact to climate
- Analysis of the energy consumption, that directly impacts the energy system

**Key Performance Indicators** for the Energy Sector are:

- $CO_2$ Footprint of the preparation and construction of the innovation
- Energy demand of operation (after implementation), energy consumption indicator
- Energy efficiency indicators

$CO_2$ Footprint - Methodology of Calculation of $CO_2$ carbon footprint will comply to the principle of Greenhouse Gas Protocol and ISO/TS 14067:2013 specifies principles, requirements and guidelines for the quantification and communication of the carbon footprint of a product (CFP), based on International Standards on life cycle assessment (ISO 14040 and ISO 14044) for quantification and on environmental labels and declarations (ISO 14020, ISO 14024 and ISO 14025) for communication.

# E.2. Forestry

## Climate Change and Forestry Sector

Forestry is a very important and profitable sector to the majority of European countries. A very large number of companies depend directly or indirectly from the forestry sector and creates employment for thousands of Europeans. The statistics from the Western and Eastern Europe are very clear, showing a massive number of 3.2 million of employments, 164 millions of USD of GDP and 223 million USD of exports (FAO, 2014). Climate change will have significant impacts in this sector particularly on the productivity potential and on the risks increase.

The impact of a climate event on forestry depends highly on the geographical region where it is located as well as on the type of climate event. For instance, if in the southern Europe the inherent risks are related mainly with wildfire, for the European northern and mountainous regions, windstorms become a serious problem. Pests and diseases are spread all over Europe and the impact on their increase or decrease due to climate change is not that well studied, however there are some studies that point for an increase of this risk.

The impact on forestry will also depend on the severity and duration of the event together with the exposure, vulnerability and resilience of the forestry sector components.

Forestry sector components on which the innovation impacts should be assessed are:

- The capacity maintenance for:
    - *wood production* (includes timber and biomass);
    - *non-wood production* (includes cork, fruits, honey, mushrooms, pastures, game and fishing);
    - *protection* (includes forest areas for protection of coastal line, desertification, river basin and biodiversity);
    - *risk* of forest damage/losses (it includes creating more vulnerability to natural hazards like wind, wildfire and pests and diseases);
- *monetized effects* (tangible and intangible losses)

The dimensions to be evaluated on each forestry component are:

- What is the area and tree species (in case of wood production) or product (in case of non-wood production) affected by the innovation?
- The impact is direct or indirect?
- The impact is Positive, Negative or Neutral?
- The impact is permanent or temporary?
- It has effects on short, medium or long term?

- Does your innovation affects the vulnerability of the forest to any of these risks (wildfire/windstorm/pests and diseases)?

Which is the temporal scale of the impact? during construction, exploitation or after.

## Assessing the impact of climate innovations on Forestry

As mentioned before, the impact of innovations will be carried out in 3 stages namely desk study, testing in a laboratory environment, and testing in an operational environment.

### *Desk study*

If a location has been decided upon, use (general) information about e.g. specifics of area, type of forestry (pine stand, cork production), etc. to describe the potential impact.

### *Testing in a laboratory environment*

On this stage, all the questions should be answered with the help of a forest expert and with the creation of some simulations/scenarios. It is expected that the innovators will collect relevant information to fill in the questionnaire in a quantitative way whenever it is possible.

### *Testing in an Operational Environment, TRL 6-8*

When testing in an Operational Environment it is expected that the innovators can assess impacts in the field with more detail, doing some field test to monitor on a smaller scale the different impacts of their innovation. The description should be both quantitative and qualitative and should be performed with the help of experts.

## Measuring of economic impacts in Forestry

Not all the losses in the forestry sector can be quantified since they don’t have a price in the market. These are called the intangible losses. However, the losses of several other components from the forestry sector can be quantified since they have a price in the market (tangible losses).

The literature about this subject is vast, and considering the impacts in different geographical areas in Europe, is important that this measurement is done with the help of an expert that can use more accurate equations for the type of particular losses. The following equations are two examples that can help to quantify the monetized effects from the innovations.

For the wood production in a mature stand we can quantify the monetize losses of mature timber using the formula suggested by Rodríguez y Silva *et al.*, (2012)

$$S = [P*V - P1*V1] + P*V\,[(r^{(R-e)} - 1)/(i^{(R-e)})]$$

Where:

S = Value lost in €/ha
P = Price of the timber (€/$m^3$)
V = Volume of the timber ($m^3$)
$P_1$ = Price of the affected timber with commercial use (€/$m^3$)
$V_1$ = Volume of the affected timber with commercial use ($m^3$)
r = is the compound annual interest rate and depends on species growth rate: fast growth (1.06), medium growth (1.04), slow growth (1.025) and very slow growth (1.015)

i = is the annual silvicultural cost factor that depends on species growth rate: fast growth (1.27), medium growth (1.1) slow growth (1.1) and very slow growth (0.93)

R = Rotation age
e = Estimated stand age

To quantify the losses from the hunting activity we propose the equation developed by Zamora *et al.,* 2010

$$L = V*[((1+0.06)n - 1)/(0.06*(1+0.06)n] + S$$

Where

L = is the resource loss (€/ha),
V = is the annual income given the carrying capacity of the site (€/ha),
n = is the estimated number of years until recovery (vegetation resilience)
S = is the reproductive stock (€/ha)

**Box E2-1 Example of Impact Assessment on the forestry sector by the Innovation "prescribed burning (PB) has a management tool to prevent wildfires".**

Maritime pine stands are one of the forest types most affected by wildfires. The use of the prescribed burning technique in this type of forest as a fire preventive tool, has been quite successful since by reducing fuel loads, contributes to a decrease in wildfire intensity consequently diminishing the damages and losses in the area.

However, the use of this technique can result in some dead trees especially if they are more fragile due to diseases or pests.

Our example is the use of this burning technique in a Pine stand of 20 years old with a density of 1000 trees/hectare, with a dense shrub understory leading to high wildfire risk.

Photos source: www.bombeiros.pt

| Sector | KPI | **Description of Impact compared to current situation** (direct/indirect; temporarily/permanent; short/long term) | Score |
|---|---|---|---|
| Forestry | Wood Production | Although some small or fragile trees can die, prescribed burning in a very short term can seem negative due to direct impact, however that is very temporary and in a medium term it will have direct benefits increasing the healthiness of the stand and creating clearings (like a forest thinning). An average of 7% of trees can die as a result of PB and that is a permanent impact. | + |
| | Non-wood production | It has a negative direct, short term and temporary effect on the shrubs but it is very short since the Mediterranean vegetation will recover in time. It can have benefits for honey flowering and game management in a medium term. | + |
| | protection | The impact on soil protection can be negative if the fire is too intense and if eliminates all the vegetation which can promote erosion. Impact is very short and temporary, and if the technique is well applied the impacts are minimum. | - |
| | risks | The use of prescribed burning as a management technique will help to diminish the risk of wildfires; as it can kill trees that are fragile it has a positive effect in reducing the risk of pests and diseases. However, some other tree bugs can appear, affecting trees particularly 3 years after the prescribed burning. | ++ |
| | Monetized effects | We will consider that 1ha has 1000 trees and 70 trees may die. See details bellow. | |

| | | | |
|---|---|---|---|
| * | Current situation forms the Reference Situation | - | worse than reference situation |
| ++ | much better than reference situation/current situation | -- | much worse than reference situation |
| + | better than reference situation | +/- 0/+ 0/- | impact (better or worse than reference situation) depends on local situation |
| 0 | no impact (comparable to reference situation) | --/++ | potential huge impact (better or worse), however, this depends on local situation |

**Box2-2 Example of the Economic Impact Assessment on the forestry sector by the use of prescribed burning has a management tool to prevent wildfires.**

Our example is the use of this burning technique in a Pine stand of 20 years old with a density of 1000 trees/hectare.

It will damage 70 trees (7% of the trees/ha), 50 of them with a global volume of 2.25 $m^3$ and 20 with a global volume of 0.314 $m^3$

Note: For a Pine tree, 1 ton = 0.74 $m^3$ (CentroPinus (2002)*)

We will consider that Maritime Pine is a medium growth species, the commercial price of timber (diameter < 14 cm) is 32 €/ton in the factory (2015 prices). When the wood is burned, it can be used for biomass and the price in the factory is 27€/ton. (APFC, 2015)*

For the wood production in a mature stand we can quantify the monetize losses of mature timber using the formula suggested by Rodríguez y Silva *et al.*, (2012)

$$S = [P*V - P1*V1] + P*V\,[(r^{(R-e)} - 1)/(i^{(R-e)})]$$

Where:

S = Value lost in €/ha
P = Price of the timber (€/$m^3$) = 43 €/$m^3$
V = Volume of the timber ($m^3$) = 2,564 $m^3$
$P_1$ = Price of the affected timber with commercial use (€/$m^3$) = 36€/$m^3$
$V_1$ = Volume of the affected timber with commercial use ($m^3$) = 2,564 $m^3$
r = is the compound annual interest rate and depends on species growth rate: fast growth (1.06), medium growth (1.04), slow growth (1.025) and very slow growth (1.015)
R = Rotation age = 50 years
e = Estimated stand age = 20 years
I = is the annual silvicultural cost factor that depends on species growth rate: fast growth (1.27), medium growth (1.1) slow growth (1.1) and very slow growth (0.93)

$$S = [43*2{,}564 - 36*2{,}564] + 43*2{,}564\,[(1.04^{(50-20)} - 1)/(1.1^{(50-20)})]$$

S = 19,78 €

The loss executing prescribed fire in 1 ha was of 19,78 €.

*References


APFC (2015) Boletim informativo da Associação dos Produtores Florestais do Concelho de Coruche e Limítrofes. Informação 24 (in Portuguese). http://www.apfc.pt/xms/files/Boletins/FI24_Maio2015_web.pdf

CentroPinus (2002) PinusPress11. (in Portuguese). http://www.centropinus.org/img/pinuspress/pdf/pinus_press11.pdf

# E.3. Nature/Ecology &Environment

## Impact of Climate Change on ecosystems and biodiversity

The IPCC 4th Assessment Report (AR4; IPCC 2007) concluded that climate change will have significant impacts on many aspects of biological diversity, on ecosystems, species, genetic diversity within species, and on ecological interactions. This will result in negative consequences for the many benefits  and services that humans derive from biodiversity, and subsequently for human well-being. However the links between climate change and biodiversity flow both ways. Biodiversity, through the ecosystem services it supports, makes an important contribution to both climate change mitigation and adaptation. Moreover, where species and ecosystems are well protected, natural adaptation may take place, as long as the rate of climate change is not too rapid and the scale of change is not too great (Campbell et al. 2009). Protecting and restoring ecosystems can thus help us to reduce the extent of climate change and to cope with its impacts (http://ec.europa.eu/environment/nature/climatechange).

Therefore, the EU states that healthy ecosystems must lie at the center of any adaptation policy and can help mitigate climate change impacts, for example, by absorbing excess flood water or buffering against coastal erosion or extreme weather events. Moreover, forests, peatlands and other habitats are major carbon sinks. Protecting them can also help to limit atmospheric greenhouse gas concentrations and mitigate further global warming. In order to make an ecosystem climate proof, it is important to reduce all kind of pressures that cause the fragmentation, degradation, over-exploitation and pollution of ecosystems, and to search for ways to make ecosystems more robust by reconnecting natural areas. The underlying principle of green infrastructure is that the same area of land can frequently offer multiple benefits if its ecosystems are healthy. Biodiversity climate adaptation tools, such as flyways, buffer zones, corridors and stepping stones, enhance the coherence and interconnectivity in Europe (http://climate-adapt.eea.europa.eu).

## Impact of adaptation innovations on the environment (including nature and biodiversity)

Physical implementation of innovative adaptation (i.e. risk-reduction) measures may have a direct or indirect impact (positive or negative) on the environment, including nature and biodiversity.

The European Union (EU) is committed to protecting Europe’s natural capital and rich biodiversity, and has implemented a.o. the Habitats Directive (Council Directive 92/43/EEC of 21 M<ay 1992 on the conservation of natural habitats and of wild fauna and flora) and the Bird Directive (Directive 2009/147/EC on the conservation of wild birds) to protect habitats as well as species. Across Europe extensive areas are designated as EU Natura 2000 sites. Natura 2000 is an EU-wide network of nature protection areas established under the Habitats Directive and Birds Directive. The aim of the network is to ensure the long-term survival of Europe’s most valuable and threatened species and habitats. It is comprised of Special Areas of Conservation (SAC) designated by Member States under the Habitats Directive and Birds Directive. Water quality is protected by EU’s Water Framework Directive. Furthermore, on a national scale areas are designated as nature area, nature reserve, national park, or protected landscape.

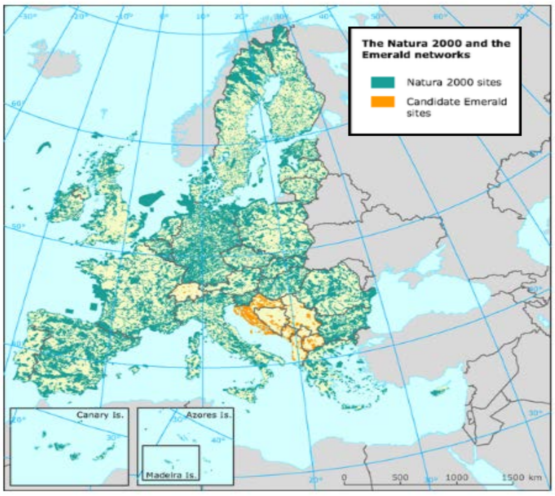



*Figure E3.1 Nature 2000 sites in Europe (see* http://natura2000.eea.europa.eu/#).

The Convention on Biological Diversity (CBD) (which has as objectives the conservation of biodiversity, the sustainable use of its components, and the fair and equitable sharing of the use from the genetic resources) requires that appropriate arrangements are established to ensure that environmental consequences of policies, plans and programs that are likely to have significant adverse impacts on biological diversity are taken into account, and whenever possible to allow public participation on those processes (article 14).

### *Environmental Impact Assessment*

Environmental Impact Assessment (EIA) is a procedure that ensures that the environmental implications of decisions (regarding the implementation of measures) are taken into account before the decisions are made. Environmental impact assessments for individual projects can be undertaken on the basis of the EU's Directive on Environmental Impact Assessment (EIA Directive 2011/92/EU), and for public plans and programs on EU's Directive on Strategic Environmental Assessment (SEA Directive Environmental Assessment 2001/42/EC). The common principle of both Directives is to ensure that plans, programs and projects likely to have significant effects on the environment are made subject to an environmental impact assessment, prior to their approval or authorization. Consultation with the public is a key feature of environmental assessment. An Environmental Impact Assessment normally requires a substantial amount of detailed information on several topics, supplied and analyzed by experts. Information on EU's laws on Environmental Impact Assessment of public and projects and of public plans and programs together with other related information can be found on www.ec.europa.eu/environment/eia.

Although for smaller projects, or for projects were no significant effects on the environment are foreseen, such an extensive assessment may not be obliged by EU legislation, an *ex-ante* identification of potential impacts may improve or speed up implementation of the innovative measures, help to find funding, or hinder or prevent implementation in case of foreseen (minor) negative impacts. Insight in the potential impacts (positive or negative) may also result in adjustments in the design in order to reduce or even prevent foreseen negative impacts, or increase co-benefits.

### *Location specific*

Due to its physical geography and the long history of cultural development, Europe harbors a broad variety in ecosystems (e.g. *Cropland and grassland*, *Woodland and forest*, *Heathland and shrub*, *Sparsely vegetated land*, *Wetlands*, *Rivers and lakes*, *Marine*, *Urban*, *Mountains*, *Islands, see http://biodiversity.europa.eu/topics/ecosystems-and-habitats/grasslands)*.

The impact of the physical implementation of an innovative measure is thus **site-specific**. Testing in a lab or constructed/artificial test-site will probably not lead to a profound insight in the potential co-benefits and trade-offs for nature/ecology, but may lead to some information about the impact on the environment (e.g. about contamination).

Because of the diversity and complexity of ecosystems, scientist and knowledge institutes have often specialized in part of the system. Therefore, ecologists investigating the impact of human interventions on the ecosystems often work in teams of specialists.

Nevertheless, the Desk Study may result in some initial/general/qualitative insight in the potential impact of an innovative measure on nature and ecology, and the environment, needed to bring the innovation to a next level. Furthermore, it forms an indication if further investigation (by experts) is needed, or if an EIA is required.

### *Ecosystem Services*

As pointed out by the Millennium Ecosystem Assessment (MEA, 2005), nature offers besides its intrinsic value, a broad range of benefits for human beings (ecosystem services) (Figure 6.X). This relationship between biodiversity and ecosystem services, is important for human well-being (Partidario & Gomes, 2013)). Recently a lot of attention is drawn to methods to value these ecosystem services, e.g. The Economics of Ecosystem and Biodiversity (TEEB, 2010, see www.teebweb.org), which enables insight in the co-benefits or trade-offs of different measures and to compare their co-benefits and trade-offs.

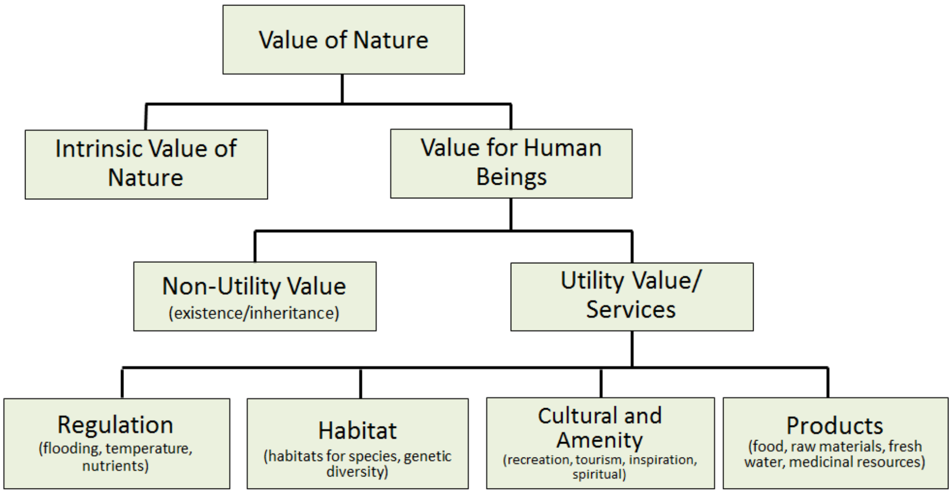



*Figure E3.2 Value of Nature for human beings (based on MEA, 2005).*

## Assessing the impact of climate innovation on Nature and the Environment

The following section provides relevant questions and gives guidelines for evaluating impacts as the detail of testing increases. Figure E.3.3 illustrates the initial impact assessment on nature and the environment (Desk Study, TRL 1-3). It is assumed that this initial assessment can be done based on a detailed description of the innovation (in the questionnaire).

**Key Performance Indicators** for Nature/Ecology are:

- Quality and Quantity of Habitats (the natural environment in which a species or group of species lives),

- Natura 2000 (or otherwise protected) species like Birds, Vegetation, Fish, Mamals, Other animals,
- Quality and Quantity of Soil Fauna, and
- Monetized effects.

**Key Performance Indicators** for the Environment are:

- Surface Water Quality and Quantity,
- Ground Water Quality and Quantity,
- Sea Water Quality,
- Soil Quality,
- Air Quality,
- Landscape Quality, and
- Monetized effects.

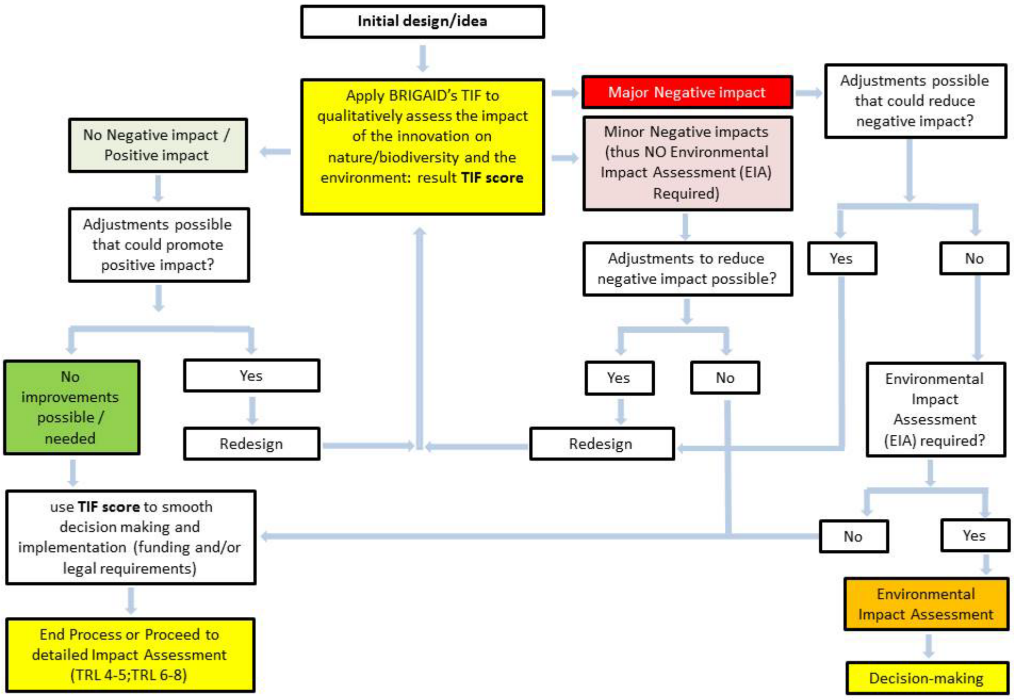



*Figure E3.3 Initial impact assessment (Desk Study, TRL 1-3) of foreseen impacts of innovation on nature and the environment.*

### *Desk Study, TRL 1-3*

Helpful questions to give a score to the KPI's on nature and the environment:

- What type of habitat is present on the foreseen location (e.g. *Cropland and grassland*, *Woodland and forest*, *Heathland and shrub*, *Sparsely vegetated land*, *Wetlands*, *Rivers and lakes*, *Marine*, *Urban*, *Mountains*, *Islands*)?
- Does the innovation reduce or change the present areal of this habitat?
- Is the foreseen location protected, or does it have a special status?
- Does the innovation affect protected species (birds, vegetation, fish, mamals or other animals)?
- Does the innovation affect the soil flora and fauna present?

  Use (general) information about e.g. protection status of the area, habitats present, etc. to describe the potential impact. Such general information is available on e.g. *http://natura2000.eea.europa.eu/#*

- Does the innovation produce pollutants (including excessive nutrients) that affect the quality of the surface water (e.g. eutrofication), ground water, sea water, the chemical soil quality, or the air quality?
- Does the innovation buffer or streamline extreme discharges?
- Does the innovation affect drainage patterns/capacity (e.g. buffer or streamline extreme discharges)?
- Does the innovation increase the water retention capacity at the foreseen location (or at connected locations)?
- Does the innovation improve the quality of the landscape? (e.g. by restoring nature, or conservation of cultural elements)

### *Testing in a Laboratory Environment, TRL 4-5*

If the impact of this innovative adaptation measure on nature/ecology or the environment be tested in the laboratory environment, then design (with the help of experts) a suitable test set-up, and collect relevant information to fill in the impact assessment framework in a quantitative way (where possible).

### *Testing in an Operational Environment, TRL 6-8*

If the innovative measure will be implemented on a given location, then it will be possible to assess the impact in more detail, and also to assess (partly quantitative) the effect on the services provided by the impacted ecosystems. Collect information site specific about protection status of the area, and about the habitats present (= reference situation), etc. to describe the potential impact (with the help of experts).

Information can be found on e.g.:
*http://natura2000.eea.europa.eu/#* (to get an impression of the protection status and the habitats present)
*http://biodiversity.europa.eu/maes* (for mapping and valuating the services of the ecosystems).
For example, a discussion with local experts and stakeholders of this (preliminary) score derived from literature, maps and other sources, and subsequently to assign a score together (Delphi-method) would form a valuable next step in the *ex-ante* assessment. Furthermore, the engagement of stakeholders is crucial for the implementation of innovations.

If possible, analyze the physical impact of the innovative measure (by experts) (*ex-post* assessment).

To get insight in the mid and long-term impact monitoring (by experts) is recommended.

## Nature Based Solution

A special type of innovative adaptation measures (with an increasing interest of e.g. the European Commission) are Nature-based Solutions. Nature-based Solutions (NbS) deliberately use ecosystems and the services they provide to address societal challenges such as climate change or natural disasters. IUCN (2016) defines NbS as: “Actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits.”

Nature-based Solutions can often be used in conjunction with other types of interventions.

**Box E3-1: Example of Impact Assessment of a Wide Green Dike (Hybrid Solution) on Nature, the Environment, and Agriculture (in Box E3-2 a picture is included)**

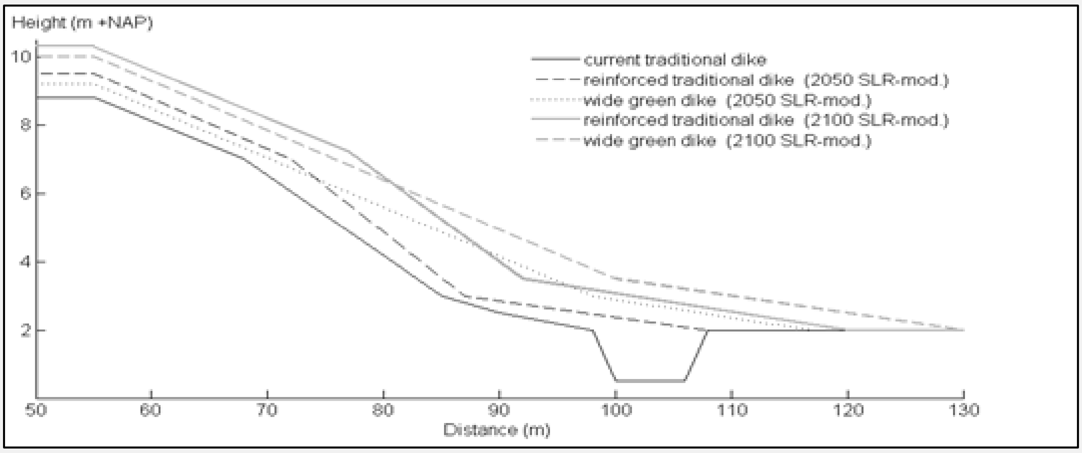
In the Netherlands most coastal dikes along the Wadden Sea have a seaward slope of 1:4 and a stone or asphalt revetment along the dike toe (even when salt marshes are present). A Wide Green Dike (as present along the German Wadden Sea coast), on the other hand, has a grass-covered gently sloped seaward face, that merges smoothly into the adjacent salt marshes. As part of the Wadden Sea Delta program, the potential costs and benefits of just such a 'Wide Green Dike', were compared to the 'Traditional Dike' (Van Loon-Steensma & Schelfhout, 2017*).*

| | KPI | Impact of Innovative Measures compared to current situation | Score |
|---|---|---|---|
| Nature/Ecology | Quality and Quantity Habitats | A Wide Green Dike provides no valuable grass or herb vegetation, but it does offer more space for grass vegetation and forbs than an asphalt-covered dike. Constructing a Wide Green Dike along the Dutch Dollard would lead to a loss of an additional 11 ha of salt marsh compared to a Traditional Dike. | - |
| | Natura 2000 (or otherwise protected) species | | |
| | - Birds | No substantial impact on feeding, breeding and refuge area. However, the mining of clay from the adjacent salt marshes could affect the bird feeding, breeding and refuge area. | 0 |
| | - Vegetation | The natural marsh vegetation from the higher salt-marsh zones would probably grow in the lower zone of the dike, which merges into the adjacent salt marsh. However, construction of a Wide Green Dike would negatively affect the present salt-marsh vegetation. | - |
| | - Fish | Unknown. | |
| | - Seals | No difference, as seals normally do not use the zone close to the dike. | 0 |
| | - Other animals | unknown. | |
| | Quality and Quantity Soil Fauna | better, because no asphalt present | + |
| Total Score (T) | | | **-1** |
| Environment | Surface Water Quality and Quantity | not foreseen | 0 |
| | Ground Water Quality and Quantity | no | 0 |
| | Sea Water Quality | no | 0 |
| | Soil Quality | no asphalt on seaward face | + |
| | Air Quality | no | 0 |
| | Landscape Quality | The Wide Green Dike blends in better with the Wadden Sea landscape. | ++ |
| Total Score (T) | | | **+3** |
| Agriculture | Area for sustainable agricultural production | Potentially more grazing area for sheep. | + |
| | Agricultural production | No difference. | 0 |
| | Monetized effects | Unknown. | |
| Total Score (T) | | | +1 |

| | | | |
|---|---|---|---|
| * | Current situation forms the Reference Situation | - | worse than reference situation |
| ++ | much better than reference situation/current situation | -- | much worse than reference situation |
| + | better than reference situation | +/- 0/+ 0/- | impact (better or worse than reference situation) depends on local situation |
| 0 | no impact (comparable to reference situation) | --/++ | potential huge impact (better or worse), however, this depends on local situation |

**Box E3-2Example of the calculated impact of Wide Green Dikes on salt-marsh habitat**

The extra space needed for a Wide Green Dike compared with a Traditional Dike can be calculated based on the required dike profile (Van Loon-Steensma and Schelfhout, 2017). This extra space will come on the account of the adjacent salt marsh. A Wide Green Dike has thus a larger areal footprint, and would overlap more of the Natura 2000 area than a Traditional Dike. Although construction of a Wide Green Dike would certainly disturb the present salt-marsh vegetation, the lower zone of the dike, which merges into the adjacent salt marsh, would probably be settled by species from the higher salt-marsh zones within a few years. This zone is covered by asphalt for a Traditional Dike. A detailed survey of the present salt-marsh vegetation and of the grass cover of the dike, and monitoring of the changes, would provide more insight in the impact on biodiversity on the mid- and long-term.



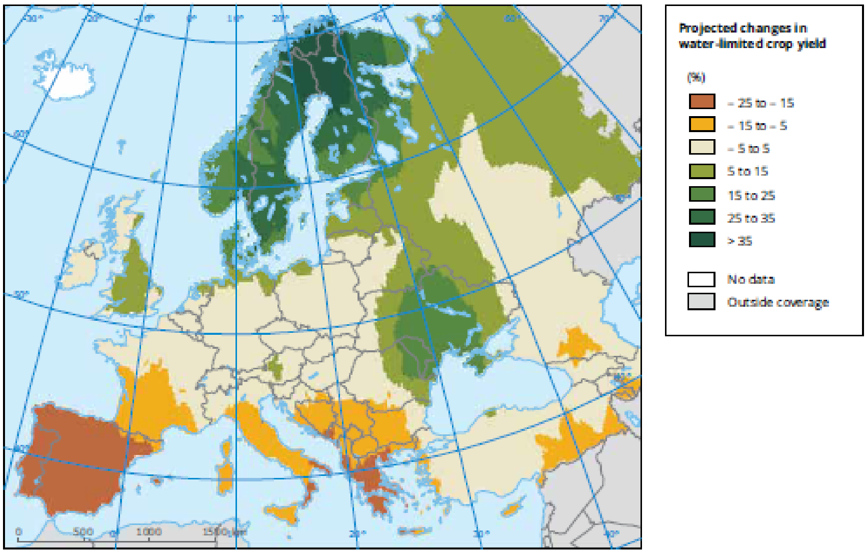
# E.4. Agriculture

## Impact of Climate Change on Agricultural Production

Facing an ongoing growing world population and increasing living and consumption standards worldwide, there is a massive challenge to produce more food and biomass in a sustainable way.  As described in EEA (2016), the cultivation of crops, their productivity and their quality are directly dependent on different climatic factors, like temperature, precipitation patterns and water availability. It is thus foreseen that climate change will strongly affect agricultural production. Livestock (another very important part of European agricultural systems) are affected by climate change as well. Directly through changes in temperature and humidity affecting animal performance and indirectly through effects on feed production and availability, as well as through livestock disease prevalence (Olesen and Bindi, 2002; Gauly et al., 2013).

Climate related risks to agricultural production are associated with the loss of cultivatable land, shorter growing seasons, uncertainty about what and when to plant, and the availability of water. By 2100, it is estimated (UNFCCC, 2007) that net crop revenues in Africa could fall by 90%, millions in Asia could be at risk from hunger, while independent research efforts in Europe show that climate change will exacerbate regional economic inequalities within the EU (EEA, 2008; Stern, 2007).

It is generally accepted that the productivity of crops will increase in northern Europe owing to a lengthened growing season and an extension of the frost-free period. In southern Europe, climate change is likely to negatively affect the productivity of crops and their suitability in certain regions, primarily as a result of extreme heat events and an overall expected reduction in precipitation and water availability (Iglesias et al., 2010) (see Figure 6.ZZ). Year-to-year variability in yields is generally expected to increase throughout Europe, owing to extreme climatic events and other factors, including pests and diseases (Ferrise et al., 2011; Kristensen et al., 2011; Trnka et al., 2014).




**Note:** The map shows the mean relative changes in water-limited crop yield simulated by the ClimateCrop model for the 2050s compared with the period 1961–1990 for 12 different climate model projections under the A1B emissions scenario. The simulation assumes that the irrigated area remains constant, and the results combine the response of the key crops wheat, maize and soybean, weighted by their current distribution.

*Figure E4.1 Projected changes in water-limited crop yield (source: EEA, 2017)*

The need to identify the impacts of climate change on agriculture (higher $CO_2$ levels, warmer temperatures, variations in precipitation, increase in weather extreme intensity and frequency, changes in the spatial distribution of crop pests and diseases; Tubiello et al., 2007) is heightened by the fact that these changes are expected to impact global food reserves, thereby leading to acute food shortages. Moreover, the increase in weather extremes can lead to a dramatic increase in food prices and to changes in the trade balance between countries (Lobell et al., 2008)

Next to be affected by climate change, agricultural production is also a major contributor to greenhouse-gas emissions. Therefore, the EU needs not only to produce more food and to adapt its food-production system to cope with climate change, but also to reduce its greenhouse-gas emissions from agriculture.

Measures and actions to mitigate the anthropogenic forcing of the climate system, include strategies to reduce greenhouse gas sources and emissions or to enhance greenhouse gas sinks (IPCC, 2007a). A major source of greenhouse gas (GHG) emissions, agriculture is also a huge 'sink' for sequestrating carbon, which could offset GHG emissions by capturing and storing carbon in agricultural soils (OECD, 2010).

Innovative measures in agriculture could help mitigate or even prevent the damages done by climate change (droughts, variations in temperature, floods, extreme weather). Any measures taken would, of course, be region specific because not all regions suffer the same problems. Lab testing or man-made test sites may prove useful for initial insights, however replicating all the conditions of an actual site might be quite difficult and might not provide accurate information since crop growth models integrate climatic, meteorological, soil properties and crop-physiology variables in order to limit prediction errors (Soussana et al., 2010).

## Assessing the impact of climate innovations on Agricultural production

Some adaptation innovations are targeting agricultural production. However, climate adaptation innovations targeting other climate risks (i.e. flooding) may affect agricultural production as well.

### *Desk Study, TRL 1-3*

Helpful questions to give a score to the KPI's on agricultural production:

- What type of agriculture is present on the foreseen location?
- Does the innovation reduce or change the present agricultural area?
- Does the innovation increase local conditions for agricultural production?
- Does the innovation favour the harvesting?
- Does the innovation affect water availability during dry periods (e.g. irrigation, water retention)?
- Does the innovation prevent inundation or stimulate drainage during extreme rainfall?
- Does the innovation produce pollutants (including excessive nutrients) that affect the quality of the surface water (e.g. eutrofication), ground water, or soil quality?

### *Testing in a Laboratory Environment, TRL 4-5*

It the impact of this innovative adaptation measure on agriculture could be tested in the laboratory environment, then design (with the help of experts) a suitable test site, and collect relevant information to fill in the impact assessment framework in a quantitative way (where possible).

If testing is not possible, then a simulated model (designed with the help of experts) with relevant information may provide data that can be used for inference in place of an actual test site.

### *Testing in an Operational Environment, TRL 6-8*

If the innovative measure is implemented at a given location, then it should be possible to assess the impact in more detail, and also to assess, to some extent, the effect on the goods and services provided by the impacted ecosystem. However, in an agricultural system the impacts may take a while to present themselves.

The collection of site specific information about the characteristics of the area, and about the type of agriculture, etc. can be helpful in describing the potential impacts.

A discussion with local experts and stakeholders is crucial for the implementation of innovations.

## Measuring of economic impacts in Agriculture

Value is how much a desired object or condition is worth relative to other objects or conditions. Economic value is a measure of the benefit provided by a good or service to an agent. It is generally measured relative to units of currency. Economic values are expressed as "how much" of one desirable condition or commodity will, or would be *given up* in exchange for some other desired condition or commodity.

Impacts on productivity affect farmer income and employment. A number of approaches, derived from the field of environmental economics, can be used to assess the economic impacts of climate change. Depending on the welfare measure used (price, cost or value), the methodologies developed can be classified into one of the three following categories: pricing, cost-pricing and valuating. The most suitable methodologies for valuing the impacts of climate change on the agricultural sector are market-based methods based on the change in agricultural output.

One such approach used to estimate the economic impact of climate change consists of calculating (V), i.e. the change in agricultural production due to climate change multiplied by the market price of the agricultural product. This approach can be expressed by the formula:

$$V = \sum_{a}^{b} [(Q^b - Q^c) * P^b]$$

where: V = the cost of climate change;
$Q^b$ = the anticipated quantity produced in year b;
$Q^c$ = the average quantity produced during a baseline period; and
$P^b$ = the expected producer price for the product in year b.

Parameter ‘a’ is given a year value. Parameter ‘b’ is equal to a+x, with x given the values [0 to 9] so that estimates are produced for all the years within the decade being studied (Karamanos et al. 2011).

This model however only deals with farming. The following methods deal with the contribution of water resources to the production process, estimation of the costs of providing alternative sources of water, as well as other techniques used to estimate environmental resources more generally. They are divided here according to whether the techniques rely on observed market behavior to infer users’ value of water resource functions (indirect techniques), or on whether they use survey methods to obtain valuation information directly from households (direct techniques).

# E.5. Health

The impact of a climate event on health, and therefore also the preventable health impact by innovations, depends highly on the type of climate event. For each type of event (grouped according to the BRIGAID classification), we will briefly describe the type of health implications that could be associated with them in a European setting. Whether a certain health impact will occur depends on the severity and the duration of the climate event, and on the exposure and vulnerability of the population within a country.

## Relationship between climate events and health

### *Floods*

A distinction is made between coastal floods and river floods. So far in the 21st century, no individuals have been affected by coastal floods yet, although this might change due to climate change. For river floods (including flash floods), the number of people that has died in the EU this century is around 1,000, while the number of affected individuals is more than 3 million (1). For both coastal floods and river floods, the potential health effects are similar. On the short term, meaning within minutes, hours or days, the following health outcomes are possible (2):

- Fatalities, due to drowning and trauma
- Injuries, including animal bites
- Toxic exposure
- Water-borne diseases, e.g. gastro-intestinal infections
- Respiratory problems, due to acute respiratory infections and mould growth
- Skin infections
- Vector-borne diseases

On the longer term (within weeks, months or years), floods can have the following impact on health:

- Worsening of non-communicable diseases, due to unstable medication uptake, and an increased vulnerability of people
- Psychosocial problems, e.g. PTSD, depression, anxiety and a reduced quality of life
- Birth outcomes, due to prenatal stress

### *Droughts*

A distinction needs to be made between droughts in developing and in developed countries. In developing countries, the most obvious and best recognised impacts of droughts are general malnutrition and mortality. Populations in resource-rich developed countries do not usually experience drought-associated malnutrition because their populations have diverse diets sourced from geographically scattered suppliers: a production shortfall in one geographical area is easily made up for by another (3). This applies also to European countries, where malnutrition and mortality due to droughts are not expected to become an issue.

Small risks that can also be present in developed countries are increases in water-borne diseases (due to switching from government-controlled to private water supplies, which generally have poorer quality control (4)), airborne and dust-related diseases, and mental diseases. Droughts are often associated with heatwaves and increase the risk of wildfires, but the health risks of those climate events will be discussed in their respective sections.

### *Extreme weather*

A distinction will be made between 'heatwaves', 'wildfires', 'storms' and 'heavy precipitation', since the expected health impact due to each of these events is very different.

### *Heatwaves*

There is no international definition for a heatwave, although the description is: a prolonged period of excessively hot weather, which may be accompanied by high humidity. Within the 21st century, heatwaves are solely responsible for 94% of all natural disaster deaths in Europe, which make them the single most important type of disaster with respect to health (1).

Certain groups of individuals are more vulnerable to the effects of heatwaves, such as the elderly, small children, the chronically-ill and homeless persons. Exposure to heat can on the short term (within hours) lead to heat exhaustion (due to loss of water and/or salts) or even a heat stroke. On the longer term (within a day or several days), heatwaves are directly linked to an increase in fatalities (5). In addition, they lead to an increase in the number of hospital admissions due to respiratory and kidney problems (6), and there are indications that they could be associated with circulatory problems also (7). Finally, there is a clear association between an increase in temperature and an increase in certain symptoms, such as sleep disturbance, fatigue and excessive sweating (8).

### *Wildfires*

Within Europe, wildfires occur mainly in warmer climates such as Portugal, Spain, France, Italy and Greece, although the frequency within countries such as the UK has increased as well (9). For countries where they are relatively uncommon, the risks might even be bigger since the local population is also less familiar with wildfires. Wildfires can lead to the following health outcomes:

- Fatalities, accidental as well as non-accidental (e.g. due to air pollution)
- Burns
- Respiratory problems, e.g. due to smoke inhalation and air pollution
- Circulatory problems, e.g. due to air pollution
- Heat-induced illnesses, e.g. heat stroke and heat exhaustion (by fire fighters)
- Ophthalmic problems, e.g. eye irritation, reduced visibility and corneal abrasions
- Psychosocial problems, e.g. PTSD, depression and anxiety

### *Storms*

Storms can be associated with floods, in which case the health outcomes mentioned under floods could occur. In addition, strong winds can be associated with fatalities, due to accidents and trauma, and an increase in injuries.

### *Heavy precipitation*

Heavy precipitation can lead to floods, which has the expected health outcomes mentioned above. By itself however, heavy precipitation is not expected to have a major impact on human health.

## Assessing the impact of climate innovations on health

As described above, the impact of innovations will be carried out in 3 stages: by means of a desk study, testing in a laboratory environment, and testing in an operational environment.

### *Desk study*

The first step will consist of determining whether the innovation has any expected impact on health, either beneficial or adverse. The answer is therefore only 'yes' or 'no'.

### *Testing in a laboratory environment*

There are some obvious issues related to testing the health impact of an innovation in a laboratory. Therefore, we propose to replace this phase with respect to health by an extended desk study. This means that for the innovations that answered 'yes' (on the impact of the innovation on health) within the desk study, a more detailed assessment will be made on how the innovation is expected to influence health. This includes an overview of the beneficial aspects, answering questions such as:

- What is the size of the population that is affected by the innovation?
- How does the innovation affect the population (preventing climate event, reducing exposure, reducing vulnerability)?
- Which health impacts can be prevented, and by which mechanism?

In addition, an assessment of the adverse impacts of an innovation on health will be made, which includes the following questions:

- Does the innovation produce pollutants?
- Does the innovation use chemical compounds that are harmful to humans?
- Does the innovation increase the risk of accidents / injuries (e.g. due to a slippery surface)?

Since not all innovators will have sufficient knowledge on health, the above questions will be answered by the innovator together with a health expert.

### *Testing in an operational environment*

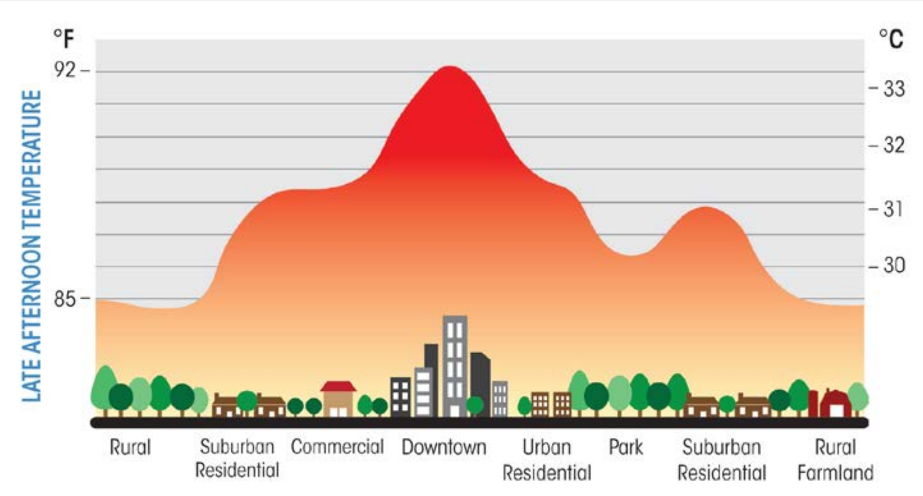
Measuring the health impact of an innovation in an operational environment is not an easy task. The expected impact on individuals is often very small, which is why a large sample would be needed. In addition, a representative (non-exposed) control group would need to be included to be able to assess whether the innovation has an impact. For those reasons, it might nog be achievable to measure the health impact of an individual innovation in the field.

An alternative way to quantify the health impact of an innovation would be to strengthen the evidence base on the impact of climate disasters on health. If an innovation is able to e.g. prevent a climate disaster from taking place within a certain population, you can then consequently calculate the averted health burden. Therefore, literature reviews and field studies will be carried out within BRIGAID, to gather more evidence on the health impact to one or more types of climate disasters. The more logical choice would be to choose types for which the expected health impact is highest in Europe (floods and/or heatwaves and/or wildfires). The exact strategy has to be determined still.

**Box E5-1 Example of Impact Assessment of "Green in the city as a climate buffer against heat stress" on Health**

Exposure to high ambient temperatures leads to an increase in mortality, as was seen by the heatwave that affected Europe in 2003 and caused more than 15,000 excess deaths in France alone. A study showed that for a 1 °C increase in temperature above a city-specific threshold, mortality increases by almost 2%. In addition, heatwaves lead to an increase in hospital admissions and an increase in symptoms in general, especially among the elderly. Around 50% of elderly people perceive their indoor environment as too warm during a heatwave, and there is a strong relationship between high outdoor and high indoor temperatures.

Due to the urban heat island effect, temperatures are usually several degrees Celsius higher in cities than in rural areas, even when they experience the same climate. Within cities, temperature differences between areas are caused by differences in building density and levels of vegetation. One way to reduce the urban heat island effect in a city area is by increasing the amount of trees and vegetation. In this example, the amount of vegetation in a city center (with a population of ± 1000 individuals) is increased, due to which the temperature extremes during the summer period are reduced by 2 °C.




| Sector | KPI | Impact of Innovative Measures compared to current situation | Score |
|---|---|---|---|
| Health | Deaths | Due to the relatively small population that is covered, the reduction in the number of deaths do to extreme heat will not be massive. However, in the long term (over several years), there will be a reduction in the number of people who died. | + |
| | People affected in their health | As seen above, around 50% of elderly people experience symptoms during a heatwave. By lowering the temperature to which they are exposed, the number of symptoms will decline significantly | ++ |
| | Monetized effects | Although it's difficult to estimate the monetized effects, there might be a positive effect due to a reduced demand in health care. | + |

| | |
|---|---|
| * | Current situation forms the Reference Situation |
| ++ | much better than reference situation/current situation |
| + | better than reference situation |
| 0 | no impact (comparable to reference situation) |
| - | worse than reference situation |
| -- | much worse than reference situation |
| +/- 0/+ 0/- | impact (better or worse than reference situation) depends on local situation |

# E.6. Impact of Climate Change on Infrastructure

## Infrastructure and Networks

The term 'Infrastructure' encompasses any construction resulting from human intervention and, in a broader sense, denotes not only the natural or artificial environment in which people live, but also the effects that human action can have on the surrounding infrastructure. Based on the classification used in the Garnaut Climate Change Review (Garnaut, 2008), the elements of the built environment can be grouped into seven general categories:

- Buildings: for residential, commercial and industrial use;
- Supply networks: power and water processing and management infrastructure;
- Public transport: transport systems and means (roads, railways, ports, airports, urban railways, etc.);
- Telecommunications: fixed-line networks and towers for electricity and telecommunications;
- Public spaces: recreation areas, parks, and all outdoor areas that combine natural and built environments;
- World heritage properties: national heritage buildings and monuments;
- Other buildings: various types of infrastructure

The likely physical impacts of climate change on the building sector involve, first, changes in the energy consumption of climate-controlled buildings and, second, changes in the indoor conditions of buildings unequipped with climate control systems. Warmer climate conditions will obviously lead to a significant reduction in buildings' winter energy requirements. In summer, however, warmer temperatures will lead to a significant increase in energy requirements for air-conditioning, while also seriously decreasing thermal comfort in non air-conditioned buildings.

In most countries its transport network is quite important to daily life. By transport network we can mean any number of modes of transportation (car, plane, boat, train etc.) by which people, animals or goods are moved from one location to another. Transport is important because it enables trade between people, which is essential for the development of civilizations.

- 

For example rising temperatures and extended heat-wave periods can increase the problems of rail buckling and pavement deterioration. The stress of water and snow on roads may cause damage, requiring more frequent maintenance, repairs, and rebuilding. Weather extremes can generate floods or landslides leading to delays, interruptions and detouring needs. Sea-level rise can threaten harbors and other transport infrastructure and services in coastal areas. Air transport can face challenges by changing wind patterns, flooding of airport infrastructure and other weather events

**Key Performance Indicators** for the impact of adaptation innovations on Infrastructure are:

- Build infrastructure
    - Residential/housing
    - Urbanisation pattern

    - Commercial/industrial
- Networks
    - Transport (roads, railways, rivers/ports)
    - Communication networks
    - Water supply network
    - Energy Networks
- Monetized effects.

### *Desk Study, TRL 1-3*

If the innovative measure be implemented permanently at a specific location, then use (general) information about e.g. type of construction and specifics about it, to describe the potential impact.

Some helpful questions to provide a score to the KPIs for the infrastructure sector are given below:

- What is the size of the population that is affected by the innovation?
- How does the innovation affect the population (preventing climate event, reducing vulnerability)?
- Does the innovation add any additional costs payable by the people (e.g. tollbooths)?
- Does the innovation alter the foreseen area (e.g. roads, bridges, tunnels)?
- Does the innovation increase/decrease the possibility of accidents?

### *Testing in a Laboratory Environment, TRL 4-5*

If the adaptation can be tested in a laboratory environment, then design (with the help of experts) a suitable test site/experiment. Otherwise, a simulated model (designed with the help of experts) with relevant information may provide data that can be used for inference in place of an actual experiment.

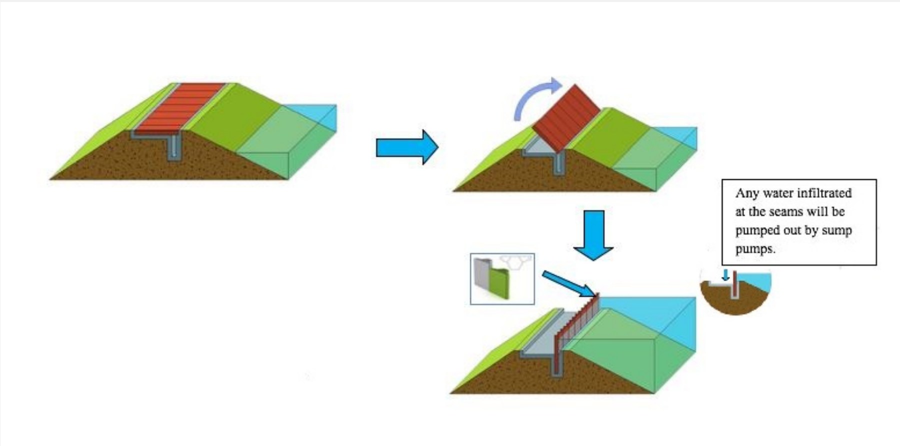
### *Testing in an Operational Environment, TRL 6-8*

If the innovative measure is implemented at a given location, then it should be possible to assess possible impacts in more detail, and also to assess, to some extent, the effect on the services provided by the impacted infrastructure network.

A discussion with local experts and stakeholders is crucial for the implementation of innovations.

**Box E6-1 Example of Impact Assessment of "Flip-Flap Cofferdam" on Infrastructure**

Due to climate change the frequency of river floodings has increased throughout Europe. The purpose of this innovation is to prevent flooding in urban areas. During non emergencies it will be used as boardwalk for pedestrian and/or bicycle traffic. It is intended for large rivers where the flood wave is known in advance.




| Sector | KPI | Impact of Innovative Measures compared to current situation | Score |
|---|---|---|---|
| Infrastructure | Build Infrastructure | Depending on the altitude of the buildings as compared to the level of the river there could be considerable damage prevention to the building infrastructure | ++ |
| | Networks | The road, railway as well as electrical and communication networks should benefit considerably from lack of damages due to flooding. | ++ |
| | Monetized effects | There should be a positive effect due to reduced damages done by flooding. | ++ |

| | |
|---|---|
| * | Current situation forms the Reference Situation |
| ++ | much better than reference situation/current situation |
| + | better than reference situation |
| 0 | no impact (comparable to reference situation) |
| - | worse than reference situation |
| -- | much worse than reference situation |
| +/- 0/+ 0/- | impact (better or worse than reference situation) depends on local situation |
| --/++ | potential huge impact (better or worse), however, this depends on local situation |

## Measuring of economic impacts on Infrastructure

There are a variety of techniques used to measure economic impacts on Infrastructure (Litman, 2006),

# E.7. Tourism

## Impact of Climate Change on Tourism

Tourism is an important, even vital, source of income for many regions and countries. Its importance was recognized in the *Manila Declaration on World Tourism of 1980* as "an activity essential to the life of nations because of its direct effects on the social, cultural, educational, and economic sectors of national societies and on their international relations."

Climate is a principal resource for tourism, as it co-determines the suitability of locations for a wide range of tourist activities, and, as such, makes tourism vulnerable to climate change. High temperature and other weather extremes, together with water shortages, are just some of the impacts that climate change is expected to have on the tourism industry. Aside from physical impacts of climate change such as temperature increase, pollution increase or decreased water availability due to decreased rainfall, there are also economic impacts of climate change on tourism which include: possible decline in the number of tourist arrivals, possible decline in average tourist length of stay, works to reduce pollution and gas emissions, works (incl. engineering) to address the physical impacts of climate change and extreme events (dams, water recycling systems).

## Assessing the impact of climate innovations on Tourism

KPI's for Tourism are:

- Attractiveness of a destination
- Visitor Satisfaction
- Seasonality
- Monetized effects.

### *Desk Study, TRL 1-3*

Some helpful questions to provide a score to the KPIs for the tourism sector are given below:

- What is the size of the population that is affected by the innovation?
- How does the innovation affect the population (preventing climate event, reducing vulnerability)?
- Does the innovation add any additional costs payable by the tourist?
- Does the innovation alter the foreseen area (hopefully improving attractiveness)?

For the effects of tourism on climate change:

https://climate.copernicus.eu/resources/information-service/climate-change-impact-tourism

### *Testing in a Laboratory Environment, TRL 4-5*

If the impact of this innovation can not be tested in the laboratory environment, then a simulated model (designed with the help of experts) with relevant information may provide data that can be used for inference in place of an actual experiment.

### *Testing in an Operational Environment, TRL 6-8*

If the innovative measure is implemented at a given location, then it should be possible to assess the impact in more detail, and also to assess, to some extent, the effect on the goods and services provided by the impacted ecosystem.

The collection of site specific information about the characteristics of the area, and about the type of tourism, tourism population, etc. can be helpful in describing the potential impacts.

A discussion with local experts (restaurant owners, hotel owners, even owners of local markets) and stakeholders is crucial for the implementation of innovations.

## Measuring of economic impacts in Tourism

We can consider two sources of economic impacts of climate change on tourist activity: the change in revenue and the increase in operating expenses of tourism enterprises. The economic impacts on revenue are far more important than those on operating costs at the moment. To estimate the change in revenue, at the regional and seasonal level, we used the Tourism Climatic Index (TCI, Mieczkowski, 1985).

The TCI combines different climate variables —either recorded or estimated by meteorological studies— into a single index, designed to evaluate the climatic suitability of a region to support outdoor tourism activities. The TCI has been widely used in relevant studies, and a number of authors have even suggested adding or modifying the variables and weights used in the index (see, for instance, Amelung and Viner, 2006; de Freitas et al., 2008).

Despite its drawbacks, the TCI has the advantage of being easy to calculate and easy to comprehend and thus remains widely used. The parameters that go into the final TCI are temperature, rainfall, sunshine, and wind speed and chill. The formula used to calculate the TCI is:

$$TCI = 8CID + 2CIA + 4P + 4S + 2W$$

where: *CID* is the maximum daily temperature in combination with the minimum possible humidity;
*CIA* is the average 24-hour temperature;
*P* is the average rainfall (in mm/month);
*S* are the total hours of sunlight per day; and
*W* is the average wind speed (in km/h).

The values of these parameters are not incorporated into the index as such: first, the continuous variables are converted into a scale of discrete values ranging from a perfect 5 (denoting optimal conditions for tourism activity) to a minimum value of -3 (Sartzetakis and Karatzoglou, 2011).

There are also a variety of other techniques used to measure economic impacts on tourism (Litman, 2006).

# E.8. Quantifying the Impacts

There are many methods available to assess the impacts of hazards, and of adaptation measures, in a more quantitative way, i.e. based on costs (or benefits, in case of positive costs) (see e.g. FAO's document 'Economic valuation of water resources in agriculture, and Economic Evaluation For Transportation Decision-Making (Litman, 2001).

Although some methods are applicable only for specific sectors, most valuation methods and techniques are generic applicable. They are, however, addressed to scientists, and require primary data and/or secondary data collection.

Normally, there are different cost types distinguished (see e.g., Meyer et al. (2013)).

Within BRIGAID we provide an overview of applicable cost assessment methods for the impacts of innovations targeting climate-related disasters: floods, droughts, and extreme weather on the different sectors. We consider three cost categories:

1. Direct costs are costs or benefits to the socio-economic sectors or to the environment due to direct physical implementation (preparation, construction or operations in a particular location).
2. Indirect costs are costs or benefits induced by either direct costs or benefits or interruption of the socio-economic sectors. They can occur away from the immediate location or timing of the proposed action, or as a consequence of the operation of the innovative measure. These losses include, for example, include production losses of supliers and customers of companies directly affected by the implementation of the measure.
3. Intangible costs refer to costs and benefits for goods and services that are not measurable (or at least not easily measurable) in monetary tems because they are not traded on a market.

When using any of these analysis methods it is important to specify the Base Case/Reference Situation, which refers to what happens without the proposed program or project.

### *Direct costs*

*Market-based transactions*. This is the change in agricultural (or forestry) production multiplied by the market price of the product.

*Dose-response functions.* In certain instances, dose-response functions can be established between changes in environmental variables (the dose) and the resultant impact on marketed goods and services (the response). Where this is the case, a dose-response function can provide the basis for valuation of the environmental variable of interest. Valuation is carried out by multiplying the physical dose-response function by the price or value per unit of the impact (usually some form of physical damage) to give a 'monetary damage function'. The latter is equivalent to the change in consumer surplus plus producer surplus caused by the impact. The use of dose-response functions is theoretically sound. Any uncertainty surrounding their use resides in the specification of the function itself and in predicting any behavioral responses that might occur. Dose-response functions are suitable for use in instances where the relationship between change in an environmental variable and the resultant impact on a good or service can be established (it cannot be used to estimate non-use values).

*Cost-Benefit analysis* compares total incremental benefits with total incremental costs. Unlike Cost-Effectiveness Analysis, Cost-Benefit Analysis is not limited to a single objective or benefit. For example, potential highway routes may differ in construction costs and the quality of service (speed and safety) they provide. Cost-Benefit Analysis places a value on each incremental benefit and costs of each option. These are then summed and compared. The results can be presented as a ratio, with benefits divided by costs (which is often called "Benefit/Cost" or "B/C ratio"). To perform Cost-Benefit Analysis it is necessary to monetize (measuring in monetary units) all relevant impacts. In recent years economists have developed techniques for monetizing non-market impacts, and some transportation agencies have adopted standardized values for travel time, crash damages and environmental impacts (Delucchi, 1996-98; FHWA, 1997; FHWA, 1998; Litman, 2002).

*Lifecycle Cost Analysis* incorporates the time value of money (Flintsch 2008). It is usually the preferred method for economic evaluation. Lifecycle Cost Analysis allows programs or projects to be compared that have benefits and costs occurring at different times.

*Cost-Effectiveness* is a relatively simple type of economic analysis. It measures the cost of achieving a specific objective, such as building a particular road. The quality of outputs (benefits) are held constant, so there is only one variable, the cost of inputs. All relevant costs are converted into appropriate, comparable monetary units.

### Indirect approaches

*Derived demand functions.* A household's or firm's inverse demand function can be employed to estimate the user's willingness to pay for water. The data are obtained preferably from observations on water use behavior of individual households. As this can be costly, aggregate data from suppliers is often used. Statistical regression analysis is employed to estimate the parameters of the demand equation.

*Benefits transfer method* The basic goal of the benefit transfer method is to estimate benefits for one context by adapting an estimate of benefits from some other context. Benefit transfer is often used when it is too expensive and/or there is too little time available to conduct an original valuation study, yet some measure of benefits is needed. It is important to note that benefit transfers can only be as accurate as the initial study.

*Hedonic pricing.* Hedonic pricing employs differences in the prices of marketed goods to derive the value of environmental characteristics. Marketed goods can be viewed as comprising a bundle of characteristics; for some goods, these include environmental characteristics. The differential prices that individuals pay for such goods reflect their preferences for environmental quality. Statistical analysis of the prices and characteristics of the goods is employed to derive an implicit value for environmental quality.

*Averting behavior and defensive expenditures.* Perfect substitutability provides the basis for the averting behavior and defensive expenditures technique. This technique focuses on averting inputs as substitutes for changes in environmental characteristics. For example, expenditure on liming might reflect the value of reduced water acidification. The approach requires data on change in an environmental characteristic of interest and its associated substitution effects. Simple aversive behavior models can give incorrect estimates of value where they fail to incorporate the technical and behavioral alternatives to individuals' responses to change in environmental quality. Although the technique has rarely been used, it is a potentially important source of valuation estimates as it gives theoretically correct estimates that are gained from actual expenditures and which thus have high criterion validity.

*Residual imputation approach and variants.* The use of water in a production process can be determined using the residual imputation approach. This is a form of a budget analysis technique that seeks to find the maximum return attributable to the use of water by calculating the total returns to production and subtracting all non-water related expenses. The value of the product is allocated among the range of marketed inputs that go into its production. The residual value is assumed to equal the returns to water and represents the maximum amount the producer would be willing to pay for water and still cover input costs (Naeser and Bennett, 1998).

*Replacement cost/cost savings methods.* The replacement cost estimates the benefits of an environmental asset based on the costs of replacement or restoration. The replaced or restored asset is assumed to provide a direct substitute for the original. The technique is used widely because the data required are usually readily available from actual expenditures or estimated costings. The underlying assumption is that the costs of replacement equal the benefits that society derives from the asset.

*Observations of market-based transactions in water.* The economic value of marketed goods and services is indicated by the market price, adjusted for any distortions. Market prices are adjusted to allow for any subsidies, taxes and trade distortions, converting them to 'shadow prices' that reflect the true economic value to society. Observations of transactions in water rights offer potential to provide relatively simple means of determining economic value.

### Intangible impacts

*Contingent valuation method.* The contingent valuation method can be useful for eliciting the value of several aspects of water resources including water quality, recreation and biodiversity. The contingent valuation method can also be used to measure what people are willing to accept by way of compensation for a deterioration in quality of a water resource. Bateman *et al.*(2002) provide details of the procedures involved in contingent valuation. In general, a survey is conducted in which people are asked questions regarding the amount of money they would be willing to pay for an improvement in an environmental good or service. This may be conducted through face-to-face interviews, telephone or mail surveys. One of the problems with the contingent valuation method is that it is subject to biases. The problem of strategic bias has long worried economists. The likelihood of the occurrence of strategic behavior depends on respondents' perceived payment obligation and their expectation about the provision of the good.

*Contingent ranking and conjoint analysis.* Contingent ranking is implemented in the same vein as contingent valuation except that the respondent has to rank order a large number of alternatives that comprise various combinations of environmental goods and prices. Conjoint analysis is related closely to contingent ranking. Individuals participate in a conjoint analysis experiment to undertake a large number of ranking tasks. Each ranking task involves a small number of alternative options. Based on the collected data, a type of utility index model is estimated for each individual Conjoint analysis has strong foundations in psychology and statistics, but has a rather less sound theoretical foundation in terms of individual choice theory.

*Multiple Accounts Evaluation* is an analysis method that uses various rating and ranking systems (CCS, 1993; Spackman, Pearman, Phillips, 2001). Each option is evaluated relative to various objectives. Rankings can be developed by technical experts, a public survey or an advisory committee. Many people consider this easier to understand and more transparent than a purely quantitative analysis, but it tends to be less precise and more susceptible to errors such as double-counting.

*Disability Adjusted Life Years (DALY's)* is a measure of overall disease burden, expressed as the number of years lost due to ill-health, disability or early death. DALYs are calculated by combining measures of life expectancy as well as the adjusted quality of life during a burdensome disease or disability for a population.

Traditionally, health liabilities were expressed using one measure, the years of life lost (YLL) due to dying early. A medical condition that did not result in dying younger than expected was not counted. The years lost due to disability (YLD) component measures the burden of living with a disease or disability. DALYs are calculated by taking the sum of these two components:

DALY = YLL + YLD

YLD is determined by the number of years disabled weighted by level of disability caused by a disability or disease using the formula:

YLD = I x DW x L

In this formula I = number of incident cases in the population, DW = disability weight of specific condition, and L = average duration of the case until remission or death (years). There is also a prevalence (as opposed to incidence) based calculation for YLD. Premature death is calculated by YLL = N x L, where N = number of deaths due to condition, L = standard life expectancy at age of death (expectancy - age at death).

Although some have criticized DALYs as essentially an economic measure of human productive capacity for the affected individual, this is not so. DALYs do have an age-weighting function that has been rationalized based on the economic productivity of persons at that age, but health-related quality of life measures are used to determine the disability weights, which range from 0 to 1 (no disability to 100% disabled) for all disease. These weights are based not on a person's ability to work, but rather on the effects of the disability on the person's life in general.

*Quality Adjusted Life Years (QALY's)* is a generic measure of disease burden, including both the quality and the quantity of life lived. It is used in economic evaluation to assess the value for money of medical interventions. One QALY equates to one year in perfect health. If an individual's health is below this maximum, QALYs are accrued at a rate of less than 1 per year. To be dead is associated with 0 QALYs, and in some circumstances it is possible to accrue negative QALYs to reflect health states deemed 'worse than dead'.

The QALY is a measure of the value of health outcomes. Since health is a function of length of life and quality of life, the QALY was developed as an attempt to combine the value of these attributes into a single index number. The basic idea underlying the QALY is simple: it assumes that a year of life lived in perfect health is worth 1 QALY (1 Year of Life × 1 Utility value = 1 QALY) and that a year of life lived in a state of less than this perfect health is worth less than 1. In order to determine the exact QALY value, it is sufficient to multiply the utility value associated with a given state of health by the years lived in that state. QALYs are therefore expressed in terms of "years lived in perfect health": half a year lived in perfect health is equivalent to 0.5 QALYs (0.5 years × 1 Utility), the same as 1 year of life lived in a situation with utility 0.5 (e.g. bedridden) (1 year × 0.5 Utility). QALYs can then be incorporated with medical costs to arrive at a final common denominator of cost/QALY. This parameter can be used to develop a cost-effectiveness analysis of any treatment.

The economist Marc Pomp has valued each QALI at EUR 50.000,-. In the Netherlands, an investment of EUR 20.000,- is seen as cost-effective for a preventive intervention.

The method of ranking interventions on grounds of their cost per QALY gained ratio is controversial because it implies a quasi-utilitarian calculus to determine who will or will not receive treatment. However, its supporters argue that since health care resources are inevitably limited, this method enables them to be allocated in the way that is approximately optimal for society, including most patients. Another concern is that it does not take into account equity issues such as the overall distribution of health states – particularly since younger, healthier cohorts have many times more QALYs than older or sicker individuals. As a result, QALY analysis may undervalue treatments which benefit the elderly or others with a lower life expectancy.

*Ecosystem Service Approach*

As pointed out by the Millennium Ecosystem Assessment (MEA, 2005), nature offers besides its intrinsic value, a broad range of benefits for human beings (ecosystem services). This relationship between biodiversity and ecosystem services, is important for human well-being (Partidario & Gomes, 2013). Ecosystem services are often grouped into four broad categories: provisioning, such as the production of food, fiber and water; regulating, such as flood protection and the control of climate and disease; supporting, such as nutrient cycles and crop pollination; and cultural, such as spiritual and recreational benefits. Recently a lot of attention is drawn to methods to value these ecosystem services, e.g. The Economics of Ecosystem and Biodiversity (TEEB, 2010, see www.teebweb.org), which enables insight in the co-benefits or trade-offs of different measures and to compare their co-benefits and trade-offs.

## E.9. References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