BRIGAID

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

Final Version of the TIF

Deliverable 5.5

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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

Executive Summary

Currently there is no internationally accepted framework for assessing the readiness of innovations that reduce disaster risk. To fill this gap, BRIGAID has developed 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.

This report focuses on the 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. It is designed to be read pimarily by innovators as a supporting document for the application of different toolboxes made available through BRIGAID, but is also relevant for end-users of innovations and other stakeholders. In this report, Chapter 3 provides an overview of the different components of the TIF, including an overview of the planned testing phases and the link with the technologial readiness levels (TRL's). Definitions for the Performance Indicators (PI) are provided in Chapter 4, which also includes a description of how the test results which are to be integrated into the Climate Innovation Window (CIW) (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 the environment and socio-economic sectors that will feel direct consequences of climate change are provided in Chapter 6; guidelines for assessing the societal acceptance of innovations in Chapter 7.

Moreover, the appendices to this report provide additional support for the application of methods and tools described herein. In Appendix A, the reader will find a detailed description of the methodology behind the normalized loading conditions across Europe and in Appendix B, the reader will find a discussion of the variability in institutional cultures across Europe. Appendix C provides a copy of the self-assessment TIF Tool and accompanying guidelines that are available to innovators who participate in BRIGAID. Finally, Appendixes D and E provide reports of feedback obtained during the development of the TIF (i.e., the frontrunner workshop and innovator, and decision maker interviews, respectively). Many of the tools and methods described herein are available online, e.g., the loading conditions (http://www.arcgis.com/home/item.html?id=312d18a14b524d6db594641342925a53) and the climate innovation window (http://climateinnovationwindow.eu/). This document will continue to be updated based on innovator and stakeholder feedback during testing Cycles 2 and 3 of BRIGAID.

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 (i.e., Climate Innovation Window (CIW)) that connects innovators, end-users, qualified investors, and grant and fiscal incentive advisors throughout Europe. This report focuses on the 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. 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 favourable public reception
Market Readiness	Market readiness is the potential of an innovation to develop a solid business case and attract investors.

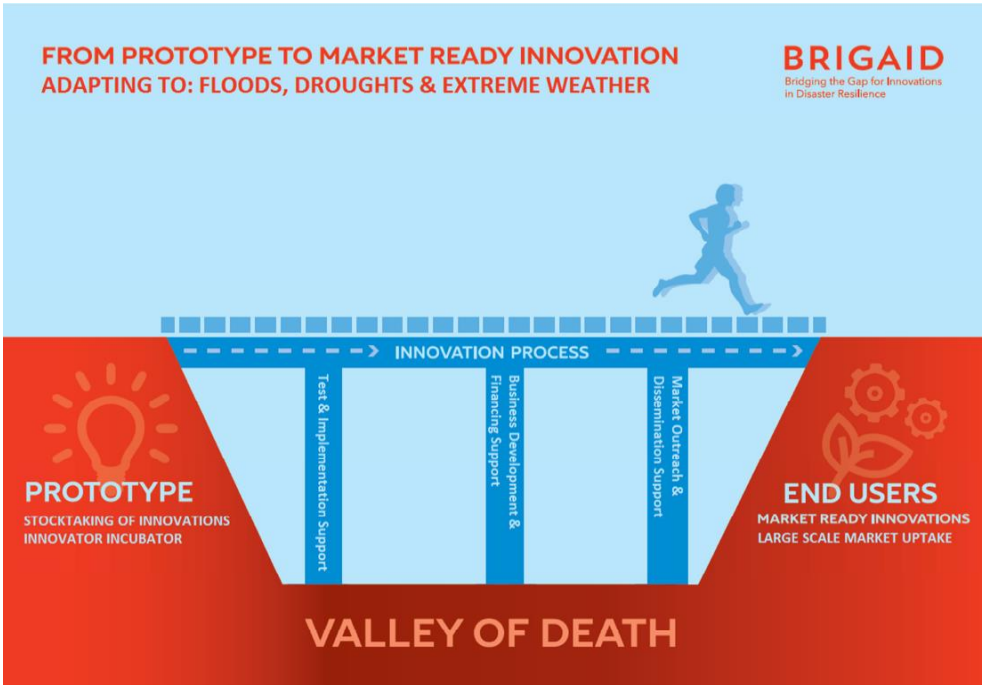


Figure 1-1 Bridge across the Valley of Death

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).

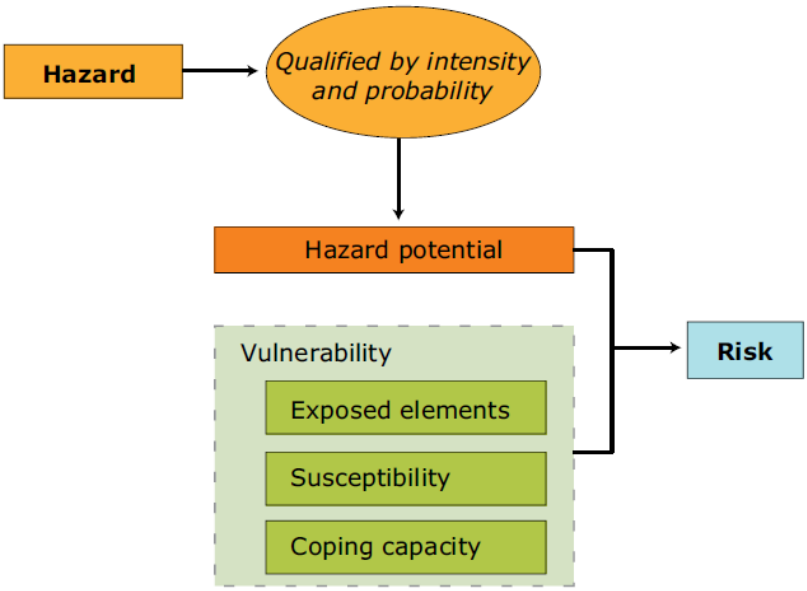


Figure 1-1 The concepts of risk, hazard potential, and vulnerability in the risk-hazard framework. Note that exposure is shown here as part of vulnerability, but in some definitions of risk (or in risk frameworks) exposure may also regarded as separate from the vulnerability assessment (EEA, 2012).

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 and perform actual field testing. 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. A list of categories and examples of measures for climate adaptation can be found in the publication by Noble et al. (2014).

1.2 Report Context and Objectives

The present report is the Deliverable D5.2 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 5.2as follows:

> *"Final version of the TIF: Report containing guidelines for applying the TIF, comprising of testing guidelines, guidelines for identifying potential challenges with respect to social acceptability, guidelines for establishing TRLs and levels of social acceptability, and*

methods to derive sector specific effectiveness of innovations express as Performance Indicators (PIs).”

This report focuses on the 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 the environment and various socio-economic sectors, including: agriculture, energy, forestry, nature/ecology/environment, agriculture, health, infrastructure, and tourism; and
- provide guidelines and tools (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. An overview of the results of this task are provided in Chapter 4 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 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 is provided in Chapter 6. In addition, interviews were conducted with stakeholders, end-users, and innovators to assess the social acceptability of the TIF. The results of these interviews are described in Appendix E.

- 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 TIF presented in this report also incorporates guidelines for assessing the potential impact of innovations on the environment and different socio-economic sectors. These 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).

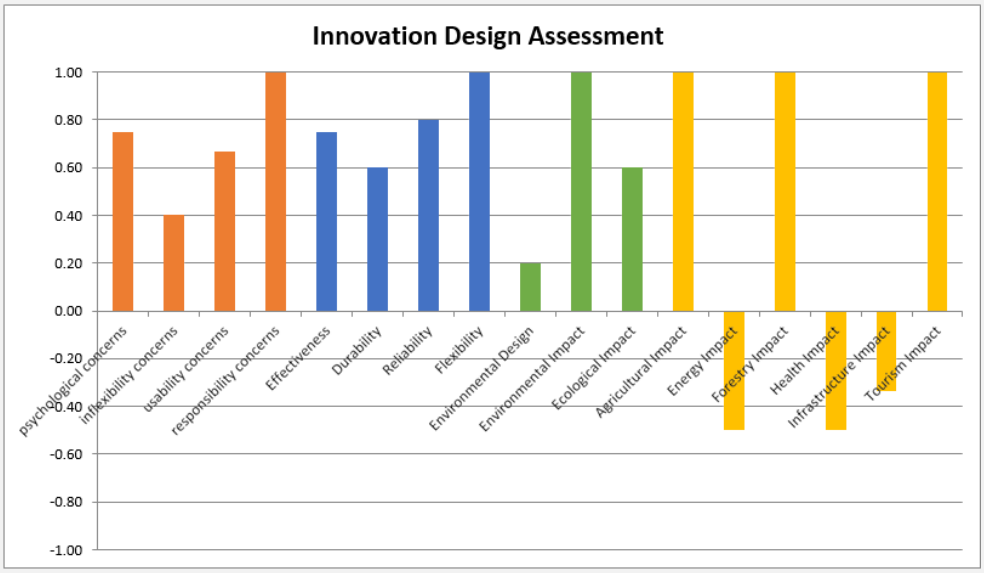
The results of this workshop and lessons learned are described in Appendix D.

The TIF focuses on the development of support tools for innovators. These support tools have been 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) (see Box 1-1). The scoring template will provide tangible results that are to be included in the Climate Innovation Window (CIW) (a.k.a. Innovation Sharing Platform (WP7)) (see Chapter 2).

Box 1-1 Support tool for assessing socio-technical readiness at the end of each testing phase

The TIF Tool is designed to help innovators identify possible societal, technical, environmental and sectoral concerns that their innovations may raise early on – and iteratively throughout the development – so that they may modify their designs and not become locked into those that are less likely to appeal to end users. The Tool should be applied at three 'stage-gates' – critical points in development at which innovators should pause to identify and address social, technical, environmental and sectoral concerns.

The self-assessment consists of twenty (20) questions related to societal acceptance, nineteen (19) questions related to technical design, twenty-one (21) questions related to environmental impacts, and twenty-four (24) questions related to sectoral impacts. If relevant, questions also appear related to cyber-security (see Appendix G). The results and recommendations are summarized in a chart as shown below. The complete toolbox and summary guidance can be found in Appendix C of this document.



The table below summarizes the results of the TIF screening.

1	Your innovation raises	few	societal concerns overall, having scored	10	out of a possible	16	and is	close	from/to societal readiness.
1.1	Your innovation raises	few	psychological concerns, having scored	3	out of a possible	4	and is	close	from/to societal readiness.
1.2	Your innovation raises	many	inflexibility concerns, having scored	2	out of a possible	5	and is	far	from/to societal readiness.
1.3	Your innovation raises	few	usability concerns, having scored	4	out of a possible	6	and is	close	from/to societal readiness.
1.4	Your innovation raises	few	responsibility concerns, having scored	1	out of a possible	1	and is	close	from/to societal readiness.
2	Your innovation raises	few	technical concerns overall, having scored	15	out of a possible	18	and is	close	from/to being ready in terms of its technical design.
2.1	Your innovation raises	few	concerns related to its technical effectiveness, having scored	3	out of a possible	4	and is	close	from/to being ready/effective in terms of its technical design.
2.2	Your innovation raises	few	concerns related to its durability, having scored	3	out of a possible	5	and is	close	from/to being ready/effective in terms of its technical design.
2.3	Your innovation raises	few	concerns related to its reliability, having scored	4	out of a possible	5	and is	close	from/to being ready/effective in terms of its technical design.
2.4	Your innovation raises	few	concerns related to its flexibility, having scored	5	out of a possible	5	and is	close	from/to being ready/effective in terms of its technical design.
3	Your innovation raises	some	environmental concerns overall, having scored	12	out of a possible	21	and is	close	from/to being ready in terms of its environmental design.
3.1	Your innovation raises	some	concerns related to its Environmental Design having scored	1	out of a possible	5	criteria. Your innovation may have a	positive	on the environment.
3.2	Your innovation raises	many	concerns related to its Environmental impact, having scored	6	out of a possible	6	criteria. Your innovation is may have a	positive	on the environment.
3.3	Your innovation raises	no	concerns related to its Ecological impact, having scored	6	out of a possible	10	criteria. Your innovation is may have a	positive	on the environment.
4	Your innovation raises	no	concerns related to	Agricultural impacts, having scored positively on	4	out of	4	criteria. Your innovation may have a	positive	impact on the	Agricultural Sector
5	Your innovation raises	many	concerns related to	Energy impacts, having scored positively on	-2	out of	4	criteria. Your innovation may have a	negative	impact on the	Energy Sector
6	Your innovation raises	no	concerns related to	Forestry impacts, having scored positively on	4	out of	4	criteria. Your innovation may have a	positive	impact on the	Forestry Sector
7	Your innovation raises	many	concerns related to	Health impacts, having scored positively on	-2	out of	4	criteria. Your innovation may have a	negative	impact on the	Health Sector
8	Your innovation raises	many	concerns related to	Infrastructure impacts, having scored positively on	-2	out of	6	criteria. Your innovation may have a	negative	impact on the	Infrastructure Sector
9	Your innovation raises	no	concerns related to	Tourism impacts, having scored positively on	3	out of	3	criteria. Your innovation may have a	undetermined	impact on the	Tourism Sector

Refer to the accompanying TIF Tool guidance document for detailed help on interpreting your results from these societal testing questions and to the TIF method document for detailed background on the theory and method that underpins them.

1.4 Report Organization

The following chapters provide a summary of the theoretical background and development of the TIF. Chapter 3 provides an overview of the different components of the TIF, including an overview of the planned testing phases. Definitions for the Performance Indicators (PI) are provided in Chapter 4, which also includes a description of how the test results which are to be integrated into the Climate Innovation Window (CIW) (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 the environment and socio-economic sectors that will feel direct consequences of climate change 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 analysed 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

[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).

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.

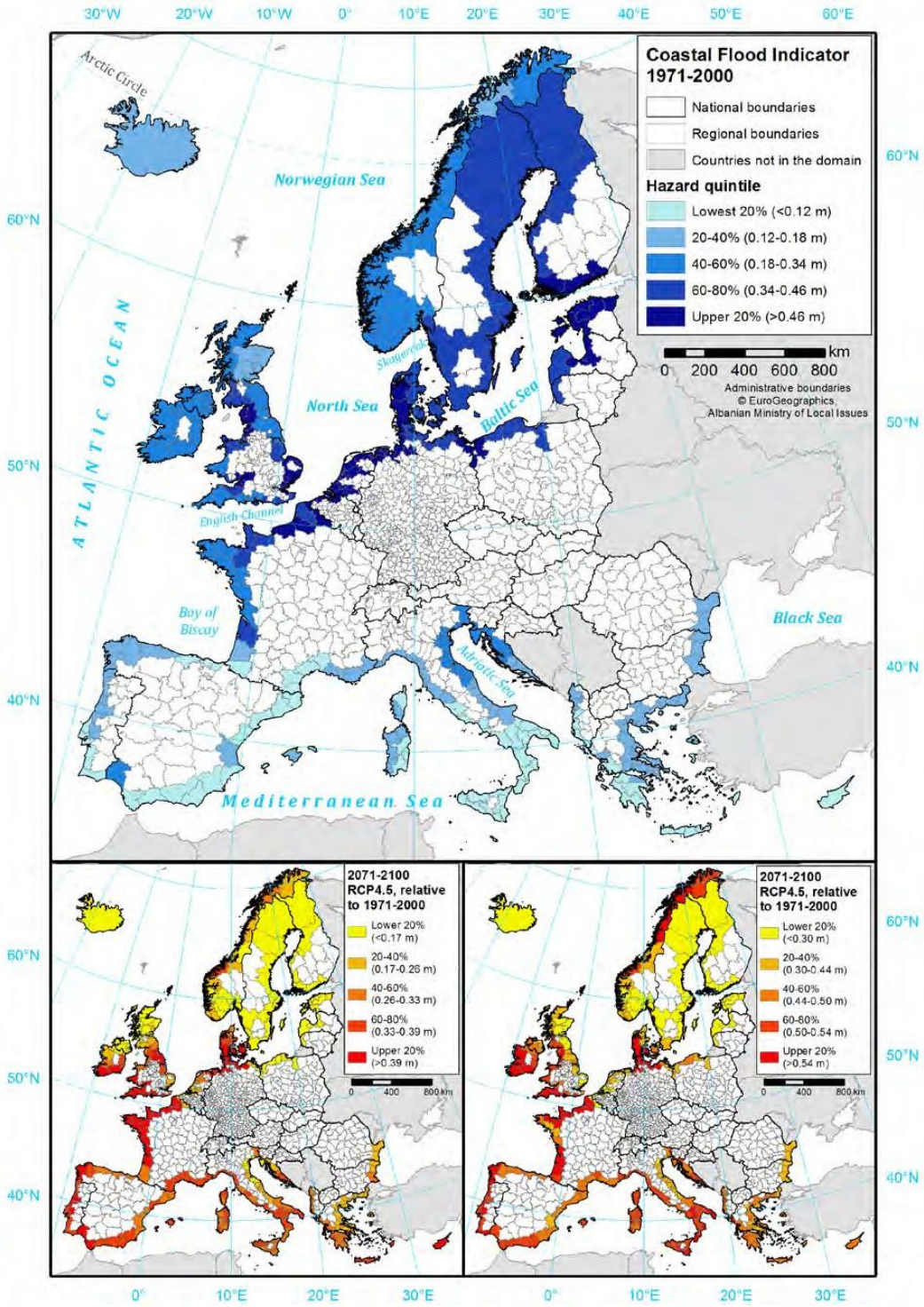


Figure 2-1 Quintiles of normalized coastal flood hazard indicator at regional level for historical scenario (main map) and relative change (subtraction) between 2071–2100 and 1971–2000, in two scenarios.

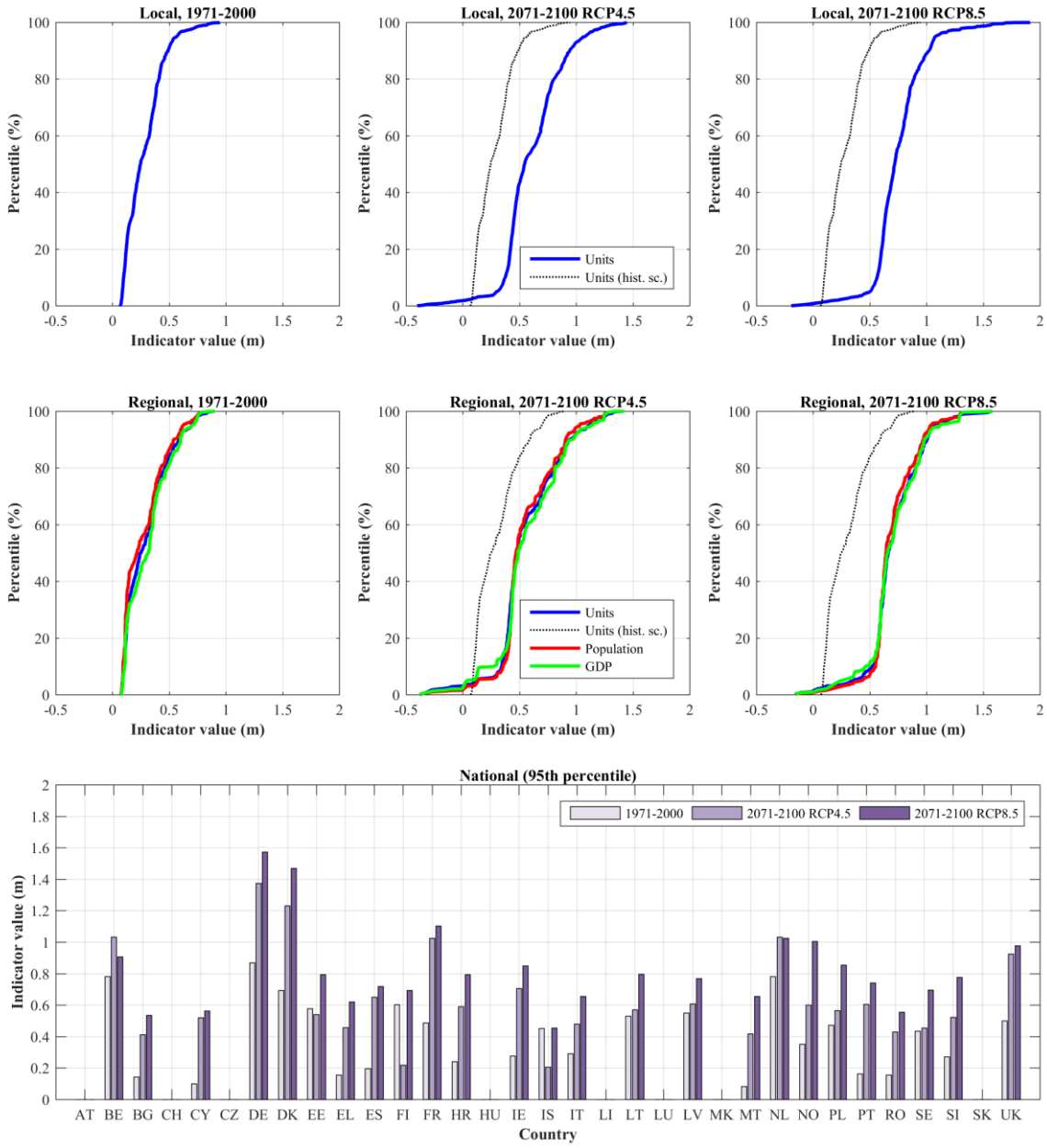


Figure 2-2 Normalized coastal floods hazard indicator at local, regional and national level, by climate change scenario. Histograms only for units connected to the coastline (6275 local, 394 regional). For country codes, see Appendix A.

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).

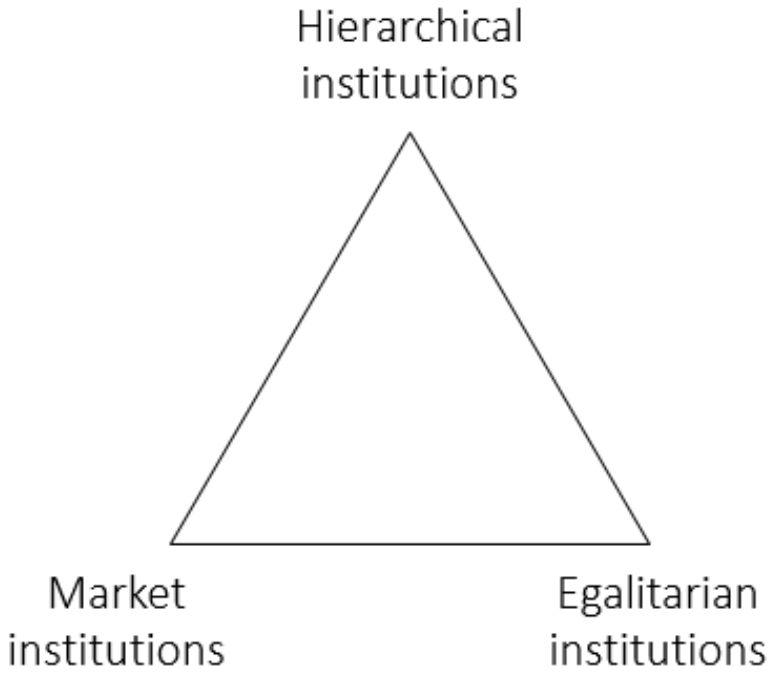


Figure 2-3 Three institutional cultures across Europe

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 favourable 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 (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.”

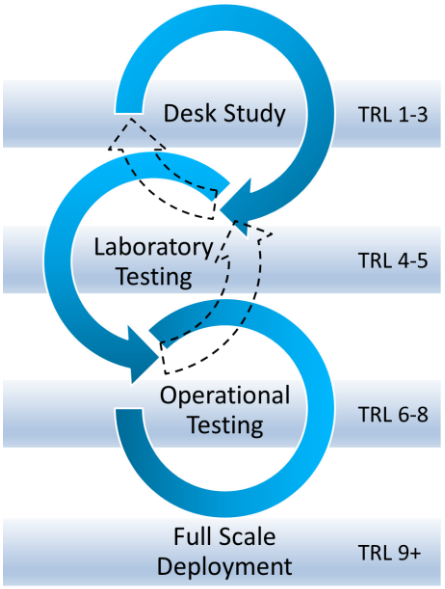


Figure 3-1 Conceptual model showing the four testing phases based on TRL definitions.

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 analysed. 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 analysed 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 analysed using the boundary conditions associated with the (intended) operational and market environment. This phase consists of analysing 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 artefacts and social arrangements that act together as a single system (Bijker et al., 1989). The TIF therefore adopts a broader concept ‘sociotechnical readiness’: the readiness of both implementation contexts (the social arrangements) and technological characteristics (the technical artefacts).

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 the environment and various socio-economic 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 on the environment and various socio-economic sectors (Section 4.2-4.4) PIs 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 4.5). 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, 2015; 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, durability, reliability, and flexibility. 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)
Durability	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 fulfils 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 (Wibowo and Ward, 2016)
Flexibility	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 susceptibility 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 susceptibility to flooding.

4.1.2 Durability

Durability 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[1] — and the long-term operation and maintenance requirements of the innovation.

In BRIGAID, three types of durability 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 durability are considered for *technological and informational innovations*:

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 fulfils 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 fulfil the intended functionality of the innovation. By quantifying the probability of each failure mode, the reliability of an innovation can be

[1] 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.

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 fulfil 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 Flexibility

Flexibility 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 flexibility 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 on the Environment and Socio-economic Sectors

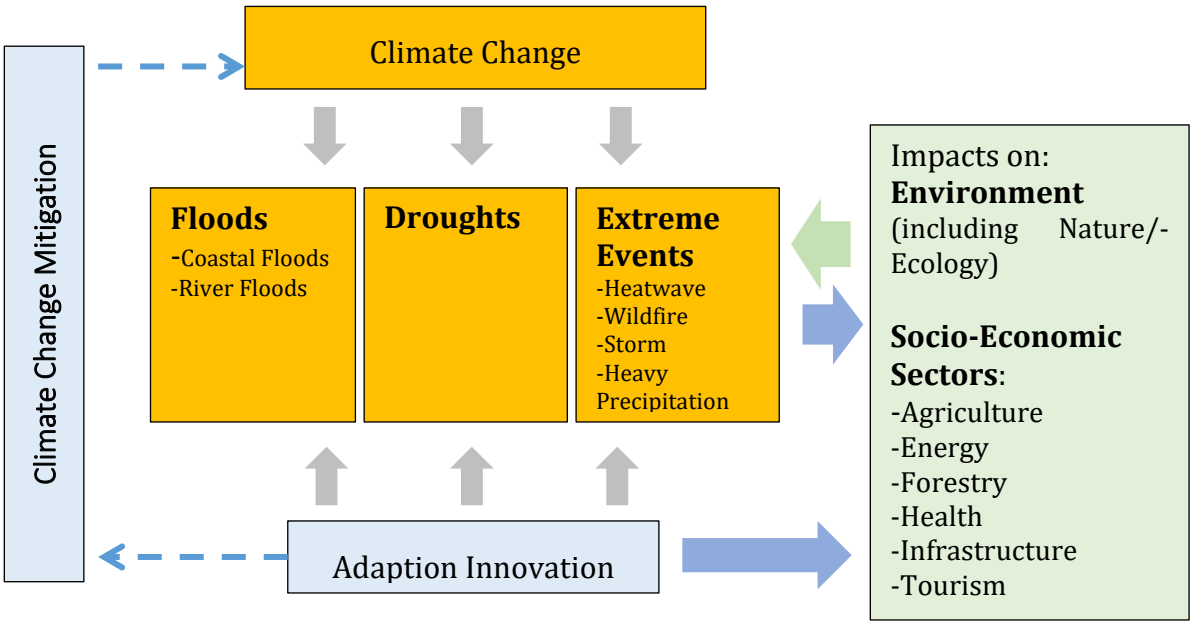


Figure 4-1 (Unforeseen) Impacts of Climate related Disasters (floods, drought and extreme events) and Adaptation Innovations on the Environment and Socio-Economic sectors (purple arrows). A healthy ecosystem may reduce the risks on floods, drought and extreme events (green arrow).

Climate adaptation innovations may be designed to mitigate risk or to directly offset the effects of climate change on the environment, including nature/ecology, or on various socio-economic sectors that are expected to be negatively affected by climate change, including: agriculture, energy, forestry, health, infrastructure, and tourism. The implementation of climate adaptation innovations can thus have intended (positive) impacts on the targeted sectors, but could also have unintended or unforeseen impacts on the environment or other socio-economic sectors (Figure 4-1) The impact may be positive or negative, direct or indirect[1], temporary – short or long term – or permanent, or reversible with some additional efforts. Some impacts may even be uncertain or dependent on local factors. To evaluate the impact of the innovation, several indicators have been developed for the environment and for each socio-economic sector. These 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.

Table 4-2 Indicators of innovation impact on the environment and key socio-economic sectors

[1] 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.

Sector	Factors Involved (Indicators)	Key References
Environmental Design / Sustainability	Deliberately use of ecosystems or natural processes; Areal footprint; Quantity of greenhouse gas emission; Recyclable materials; Promoting other ecosystem services	IUCN (2016); MEA (2005); TEEB (2010)
Environmental Impact	Surface water quality and quantity; ground water quality and quantity; sea water quality; soil quality; air quality; debris generation; noise or vibration generation; landscape quality	EEA (2017); European Commission (2016b); iSQAPER(2017)
Ecological Impact	Spatial extent of Natura 2000 (or otherwise protected) nature; Quality of protected habitats; Number of protected species (e.g., birds, vegetation, fish, mammals, other animals); Spatial extent of non-protected nature; Quality of non-protected habitats; number of non-protected species	EEA (2012); EU (2016)
Agriculture	Area available for agricultural production; Production conditions; Variety of Agricultural Products; Yield of one or more agricultural products	Dumanski et al. (1998)
Energy	Energy production capacity; Reliability of energy production ; Technical effectiveness of energy production; CO_2 footprint	EEA (2017)
Forestry	Area for wood production; Wood production conditions; Area for non-wood production; non-wood production conditions	RCM (2015)
Health	Avoided Deaths; Number of physical health affected people; Number of mental/psycho social affected people; Emission of chemical pollutions	CRED (2015)
Infrastructure	Quality of the built infrastructure; Area available for urban development; Capacity of transportation networks; Reliability of transportation networks; Capacity of infrastructural networks; Reliability of infrastructural networks	EEA (2017)
Tourism	Quantity of recreational area; Attractiveness of recreation area; Length of tourist season	Dupeyras (2013); Copernicus (no date)

It is important to note that the effect of climate change and the local, regional, and national impact(s) of an innovation on the environment and on key socio-economic 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 PIs for each sector are shown in Table 4-2 below. The following paragraphs 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.

4.3 Environment

The environment can be defined as the surroundings or conditions in which human beings, animals or plants live or operate. The EU has extensive environmental laws, including on the

emission of pollutants that affect air quality and water quality, noise pollution, the treatment of waste, thinning of the ozone layer, and sustainable energy production. The EU's environmental policy is intertwined with national environmental policy of the member states. Member states have to report regularly about the environmental condition and the efforts to protect and improve the environment. Furthermore, there are important international agreements on, for example, the reduction of greenhouse gases in order to mitigate climate change (e.g. the Paris Agreement under the United Nations Framework Convention on Climate Change).

Climate change is expected to have significant impact on many aspects of the environment (e.g., temperature, availability of water, amount of rainfall), including biological diversity and ecosystems (Alcamo *et al.*, 2007). Climate change will not only result in direct negative consequences on the quality of our physical living conditions, habitats, and the number of species, but also on the many benefits and services that humans derive from biodiversity, and subsequently for human well-being (Millenium Ecosystem Assessment, 2005).

Climate adaptation innovations may be able to provide direct protection of the environment from the impacts of climate change, but may also have an effect themselves on the environment, including on nature and biodiversity, and on the services provided by natural ecosystems. A very important 'Ecosystem Services' in view of climate change risk reduction, is the regulating service. This regulating service encompasses for instance, absorbing of excess flood water, buffering against coastal erosion or extreme weather events, damping of wave heights and absorbing of wave energy, the release of water (that was stored in the natural ecosystem) during periods of droughts, and buffering of temperature (e.g. by providing shade). Healthy ecosystems can thus help to mitigate climate change impacts, and promoting healthy ecosystem could be seen as an adaptation measure itself. Where species and ecosystems are well protected, even natural adaptation may take place (without interventions of human beings), 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). Furthermore, many natural systems, such as forests, peatlands, or salt marshes are major carbon sinks. Protecting them can also help to limit atmospheric greenhouse gas concentrations and mitigate further global warming. 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).

Nature Based Solutions are a special type of innovative adaptation measures. They deliberately use nature or natural processes (or mimic natural processes) and the services they provide to address societal challenges such as climate change or natural disasters. Nature-based Solutions are often used in conjunction with other types of interventions.

If it is clear that an innovation will have significant effects on the environment (e.g. the construction of a dike or a water retention area), or that implementation of innovation will need substantial space (that is for instance, currently designated as nature area), then there is likely a legal requirement for an Environmental Impact Assessment (EIA). In this EIA the impact of the plan or project must be compared with some alternative solutions. An EIA normally requires a substantial amount of detailed information on several topics (amongst other on species and habitats), supplied and analysed by experts. Information on EU's laws on Environmental Impact Assessment of major projects and of public plans and programs together with other related information can be found on www.ec.europa.eu/environment/eia. Furthermore, each EU country provides its own information on national EIA obligations (see national websites on Environmental Impact Assessment).

4.3.1 Environmental Design / Sustainability

Regarding the impact on the environment, sustainability (which was first introduced in the Brundtland report of 1987) forms an important ambition for climate change innovations. Sustainability can be described as the endurance of systems and processes. Sustainable adaptation innovations are not harmful to the environment nor depleting natural resources, and support long-term ecological balance (IUCN, 2016). Therefore, Nature Based Solutions are considered very sustainable because they aim for the optimal and long-term use of natural processes and the services provide by nature. But also engineered or technical solutions can support ecological processes and systems (e.g. by providing useful information to optimize management decisions in a changing climate or during extreme events).

The physical implementation of an innovation may require space at its implementation location. Some innovations are implemented at the cost of natural area, while, for instance, Nature Based Solutions, will probably result in an increase of the areal of nature (and are thus sustainable).

Although Nature Based Solutions often explicitly aim to use the regulating service of an ecosystem, they may also positively or negatively affect other ecosystem services, like the provision of products (e.g. food, fibres, wood, fresh water, medicines), the regulation of nutrients, and the provision of opportunities for recreation and tourism (Millenium Ecosystem Assessment, 2005). Also, non-nature based measures may affect ecosystem services (negative or positive) by using space currently in use for nature, by affecting environment conditions, or by supporting ecological processes and systems.

Construction, transportation to its implementation location, and/or application of the innovation may result in additional CO_2 emissions compared with the current situation. In view of sustainability, it might be wise to explore opportunities for the use local materials. They may reduce transportation, and subsequently the amount of carbon dioxide released by transportation. Some adaptation innovations form a sink for carbon dioxide (e.g. because the innovation increases permanent vegetation development that could store carbon dioxide), and form a measure to mitigate climate change as well.

Another important aspect in view of sustainability is the amount of resources that are needed for the construction of an innovation. An innovation is more sustainable if it constructed of recycled or recyclable material. Recyclability fits also in the Circular Economy concept and in the Cradle to Cradle concept.

Performance Indicators to assess the **environmental design characteristics/ sustainability**:

- Nature Based Solutions / Based on the deliberately use of ecosystems and the services they provide?
- Areal Footprint;
- Carbon Footprint;
- Resource Footprint;
- Footprint on the services provided by natural Ecosystems.

4.3.2 Environmental Impact

The construction, implementation, and/or application of an innovation may directly affect the environmental quality by emitting or releasing pollutions. Environmental quality is a set of properties and characteristics of the environment (water, soil and air). It forms a measure of the condition of the environment. Pollution can be defined as the addition of any substance (solid, liquid, or gas) or any form of energy (such as heat, sound, or radioactivity) to the environment at a rate faster than it can be dispersed, diluted, decomposed, recycled, or stored in some harmless form.

Regarding fresh water, pollutants like excessive amounts of nutrients, oil spilling, chemicals, salt, plastics, or an increase in water temperature, will negatively affect the quality of e.g. aquatic ecosystems, drink water production, health situation, availability of water for irrigation, fish production, tourism. These pollutants may also affect the quality of the ground water, of the soil (including the water holding capacity of the soil), or of the sea. In fact, pollution can travel long distances along rivers to ultimately impact on marine ecosystems, fish production, tourism, and the health situation. For instance, the run-off of nutrients in upstream areas can result in toxic algae blooms along the coast.

Soil quality is very important for terrestrial ecosystems, agricultural and forestry production, health situation, etc. Furthermore, soil is applied in large amounts to support buildings and roads.

In the EU the environment is protected from pollution by several EU and national regulations and standards and it is monitored by governmental agencies. For instance, the Water Framework Directive (Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy) is an example of water policy, aiming for rivers, lakes, grounds and coastal waters to be of good quality.

The construction, implementation, and/or application of the innovation may also affect the surface water and ground water quantity by using water, streamlining extreme discharges, buffering and/or retention of extreme discharges.

Especially air quality is very important for the health situation, and air pollution can result in diseases, allergic reactions and even deaths. Furthermore, air pollution may affect buildings. An innovation may (temporarily or permanently) produce air pollutants like chemicals, particulates (e.g. dust), biological molecules, etc. (NB Carbon Dioxide is already included in the Carbon Footprint question).

The construction or implementation of some innovations may result in debris or (temporarily) noise. Some debris is easily recyclable (which makes the innovation more sustainable), while other debris may need further processing or must be stored.

An innovation may also affect the quality of the landscape by affecting the visible features (like hydrological or ecological aspects, settlement patterns, cultural history, scenic characteristics, or land use patterns) of an area of land, its landforms, and how they integrate with natural or other man-made features.

Performance Indicators to assess the **Environmental Impact** are:

- Surface Water Quality;
- Surface Water Quantity;
- Ground Water Quality;
- Ground Water Quantity;
- Sea Water Quality;
- Soil Quality;
- Air Quality;
- Amount of Debris;
- Level of Noise or Vibration;
- Landscape Quality.

4.3.3 Ecological Impact

The conservation of biodiversity, restoration of nature, and greening the economy and the society as a whole to make them more sustainable are important ambitions of the EU. 'Green' aspects, like strengthening the functioning of natural ecosystem by increasing the extent of nature area, improving the quality of natural habitats and the number of species, will certainly favour implementation of the innovation.

Ecosystems are 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).

Due to its physical geography and the long history of cultural development, Europe harbours 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).

Several of these 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.

Maps and information available on e.g. http://natura2000.eea.europa.eu/# provide a first impression of the nature values present.

Performance Indicators to assess the **Ecological Impact** of innovations are:

- Spatial extent of protected nature area;
- Quality of protected 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;
- Spatial extent of non-protected nature area

- Quality of non-protected habitats (the natural environment in which a species or group of species lives)
- Non-protected species like Birds, Vegetation, Fish, Mammals, Other animals.

4.4 Socio-Economic Sectors

Changes in climatic conditions and their impact on environmental systems have a wide range of effects on economic activities and on human health and well-being (EEA, 2017). Climate adaptation innovations are designed to mitigate safety risks (see section 4.1) or to directly offset the effects of climate change on economic activities like agriculture, energy, forestry, health, infrastructure, and tourism. Implementation of climate adaptation innovations will thus have intended impacts on the targeted sectors that are expected to be negatively affected by climate change, but may also have unintended or unforeseen impacts on the environment or on other sectors. Impact may thus be positive or negative, and could be direct or indirect (see 4.2), temporary (short or long-term) or permanent, or reversible with some additional efforts. Some impacts may even be uncertain, or depending on local factors. Like for Environmental Aspects, several indicators have been developed to assess the impact on important socio-economic sectors. These 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, which may already be altered by previous adaptation measures) 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 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.

4.4.1 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:

- Area available for agricultural production;
- Production conditions (e.g. increasing soil quality or water availability);
- Variety of agricultural products (e.g., crops, dairy, meat, fruit, fish, aquaculture);
- Yield of agricultural production.

4.4.2 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. 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).

It is necessary to underline that 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 21st 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.

The impact of innovation should be seen in the context of the entire energy sector and global energy trends. The IPCC Fifth Assessment Report defines an energy system as *all components related to the production, conversion, delivery, and use of energy*. The energy sector, comprises all energy extraction, conversion, storage, transmission, and distribution processes that deliver final energy to the end-use sectors (industry, transport, and building, as well as agriculture and forestry) (IPCC, 2014).

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

- Energy Production Capacity (e.g., by generating energy or fuel for energy production, or by increasing energy distribution);

- Reliability of Energy Production (e.g., by improving cooling water conditions for energy plants or by improving the safety of energy supplies);
- Efficiency of energy production (e.g. by changes in the technology of energy generation and distribution);
- Carbon Footprint.

4.4.3 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:

- Area available for wood production (incl., timber and biomass);
- Wood production conditions(e.g., by increasing forest resilience against windstorms, wildfires, pest and diseases, or water availability);
- Area available for non-wood production (incl., cork, fruits, honey, mushrooms, pastures, game and fishing);
- Non-wood production conditions(e.g., by increasing forest resilience against windstorms, wildfires, pest and diseases, or water availability).

4.4.4 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 susceptibility 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:

- Number of fatalities in the area exposed to the hazard;
- Number of people affected in their physical health (i.e., number of people injured);
- Number of people affected in their mental psycho-social health;
- Emission or release of chemicals or products that are harmful to humans.

4.4.5 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:

- Quality of the built environment (e.g., residential, commercial, and industrial)
- Area available for urban development
- Capacity of existing transportation system (e.g., roads, railways, waterways, and airports)
- Reliability of existing transportation systems
- Transport capacity of critical infrastructural networks (e.g., power, water, waste management)

4.3.6 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:

- Area available for recreation;
- Attractiveness of area;
- Length of tourist season.

4.5 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.

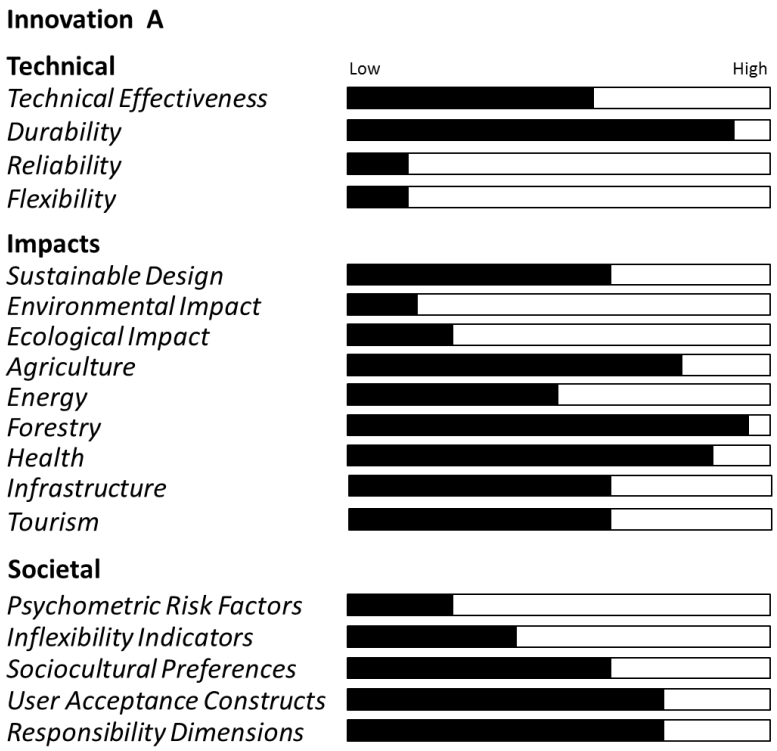


Figure 4-2 Conceptual profile of an innovation ("A") based on initial Performance Indicators (PI). Note that the social performance indicators are described in Chapter 7.

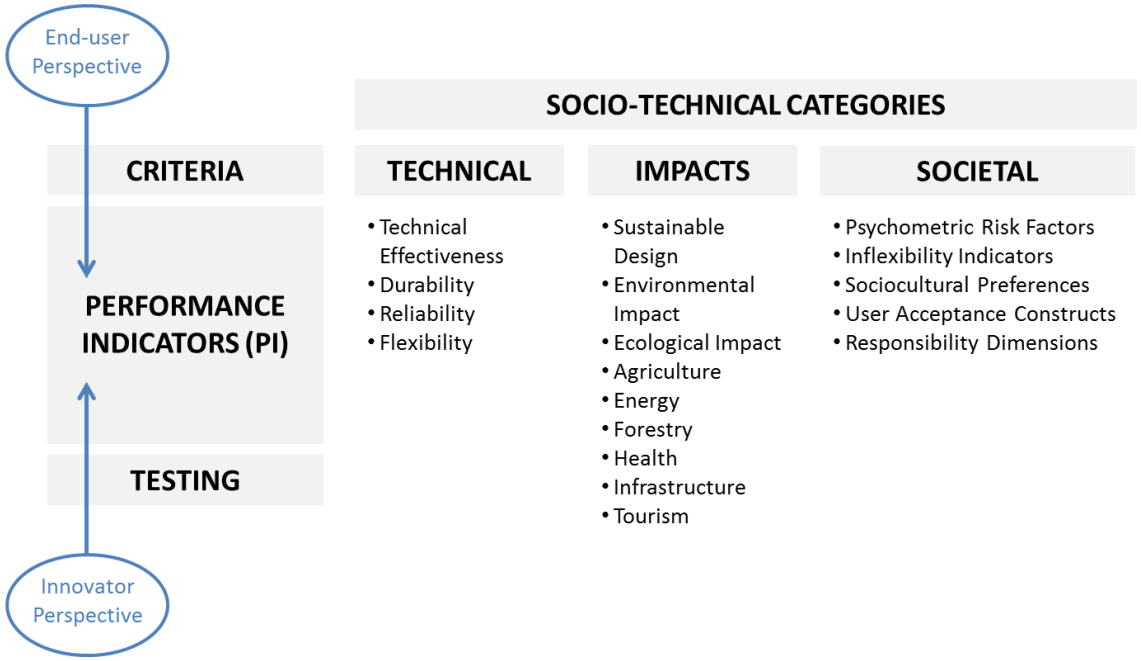


Figure 4-3 Conceptual design of the Innovation Sharing Platform (ISP) which connects the perspectives of innovators and end-users through Performance Indicators (PI).

5 Technical Testing Guidelines

5.1 Testing

The goal of testing is to quantitatively assess the technical Performance Indicators (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 TIF Tool and 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 durability 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)?
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 **Fout! Verwijzingsbron niet gevonden.**)? Which failure modes cannot be tested? *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?
Durability 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?
Flexibility 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 durability (i.e., based on the planned operation and maintenance), and reliability (e.g., a safety factor). 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. 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.) For *engineered/built environment Innovations*: • (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 • 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).

	For *technological/informational Innovations:* • 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 • 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 durability under the design criteria	Evaluate whether the durability 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 flexibility under the design criteria	Evaluate whether the flexibility 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 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	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

under operational conditions	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.) 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; • 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 • (if applicable) for implementation reliability: analyse 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). For *technological/informational Innovations:* repeat the tests performed in the previous phase using the new data or in real-time; • 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: analyse 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 durability established in laboratory testing still holds for the operational conditions	Evaluate whether the durability 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 flexibility established in laboratory testing	Evaluate whether the flexibility 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

still holds for the operational conditions	satisfied with the test results and current innovation design, proceed to full scale deployment (TRL 9).

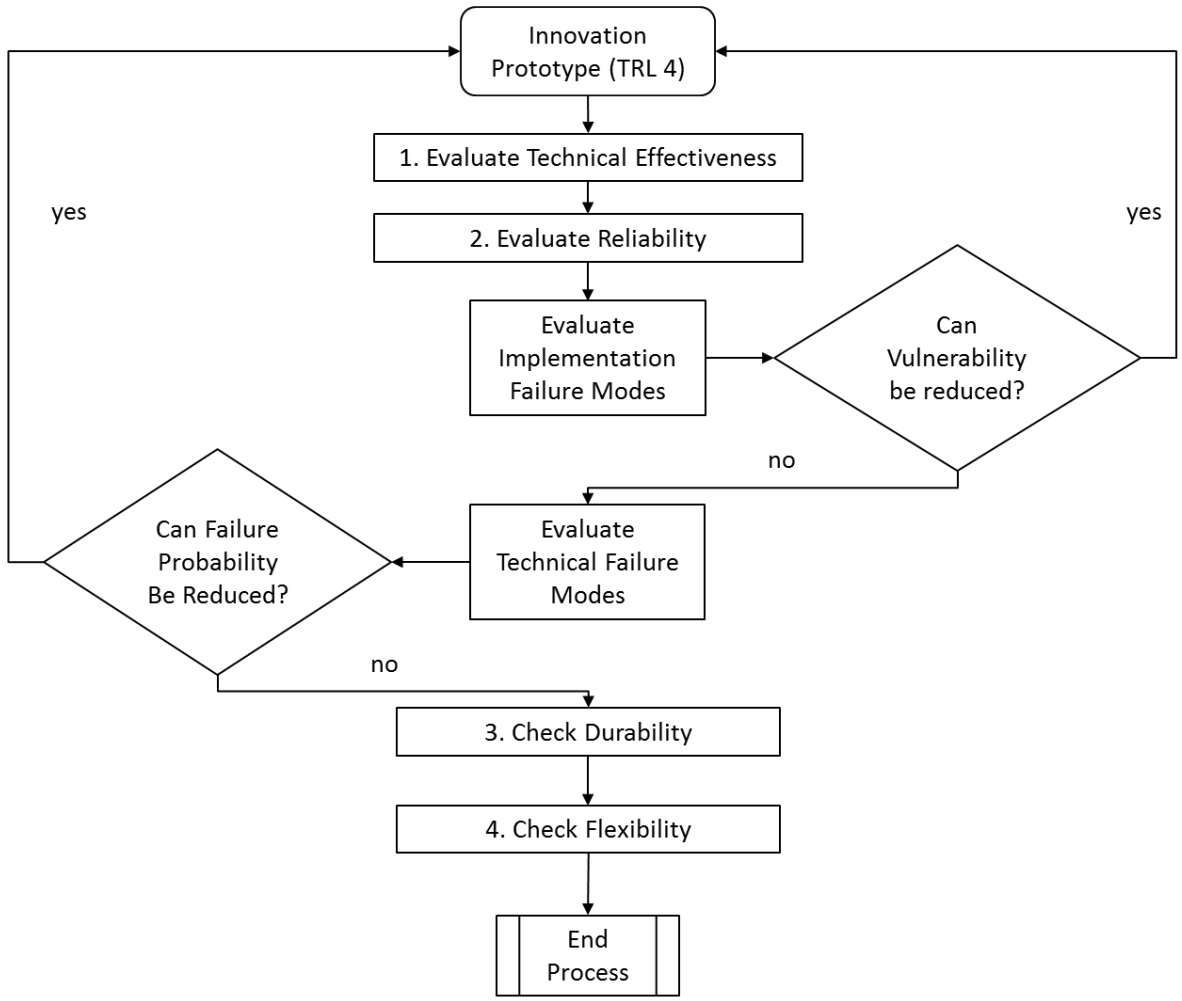


Figure 5-1 Overview of iterative process introduced in laboratory testing.

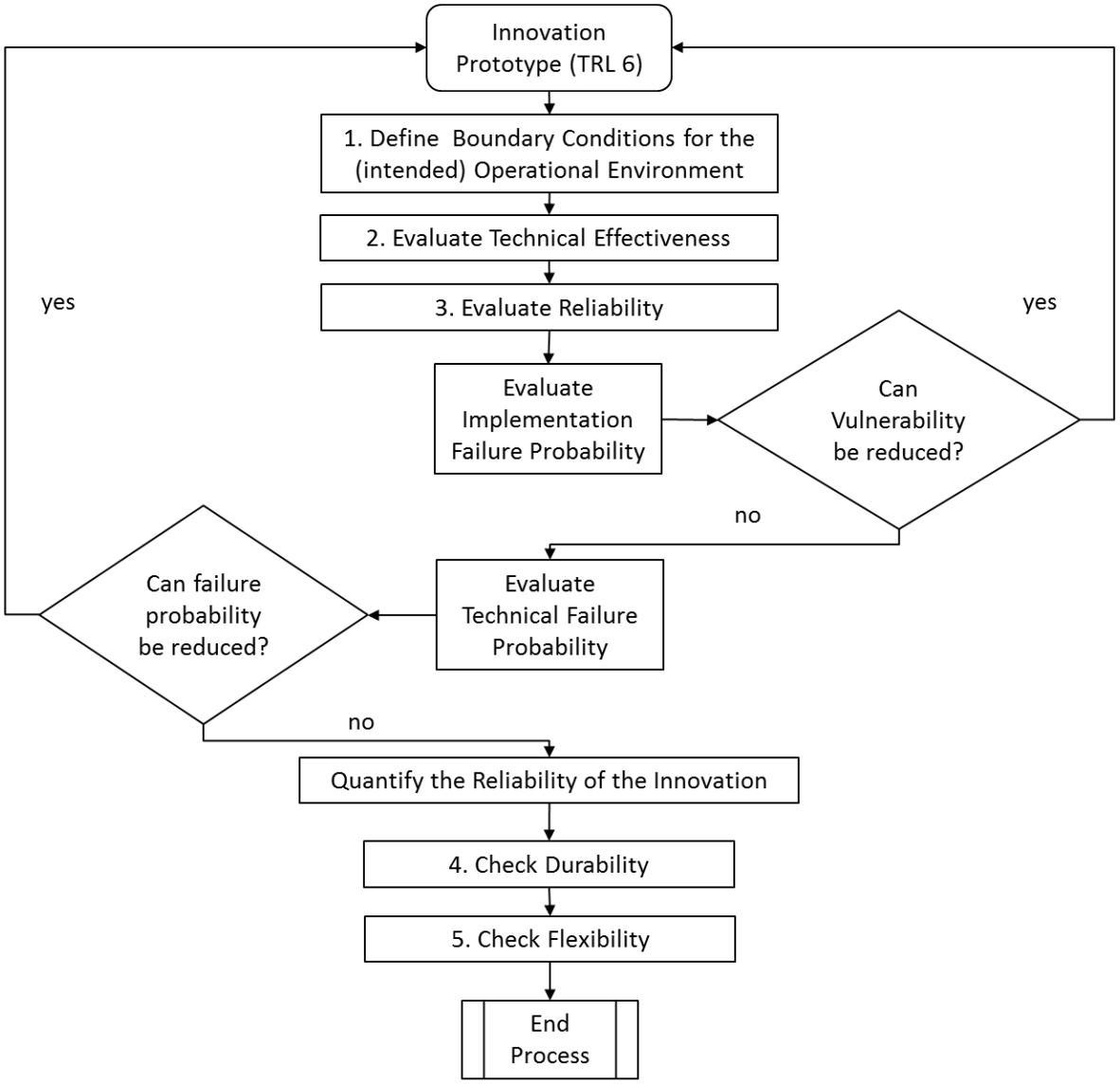


Figure 5-2 Overview of iterative process introduced in operational testing.

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 analyse 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) analyse 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 analysing 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 analysing 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/	Inductive, bottom-up analysis to show how component reliability contributes to the	Graphical; dependencies between failure modes explicit; high potential for	Does not consider external events

Dependence Diagram (DD)	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 a given failure rate	evaluating cascading failures; can be used to solve for reliability quantitatively
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 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 5-3 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.

- **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.

- **Durability**: 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.

- **Flexibility**: considering the hazard (floods), risk reduction capacity and expected reliability, TFB's can be applied at a large number of locations throughout Europe. The flexibility 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:

Table 5-5: Failure modes for temporary flood barrier.

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.

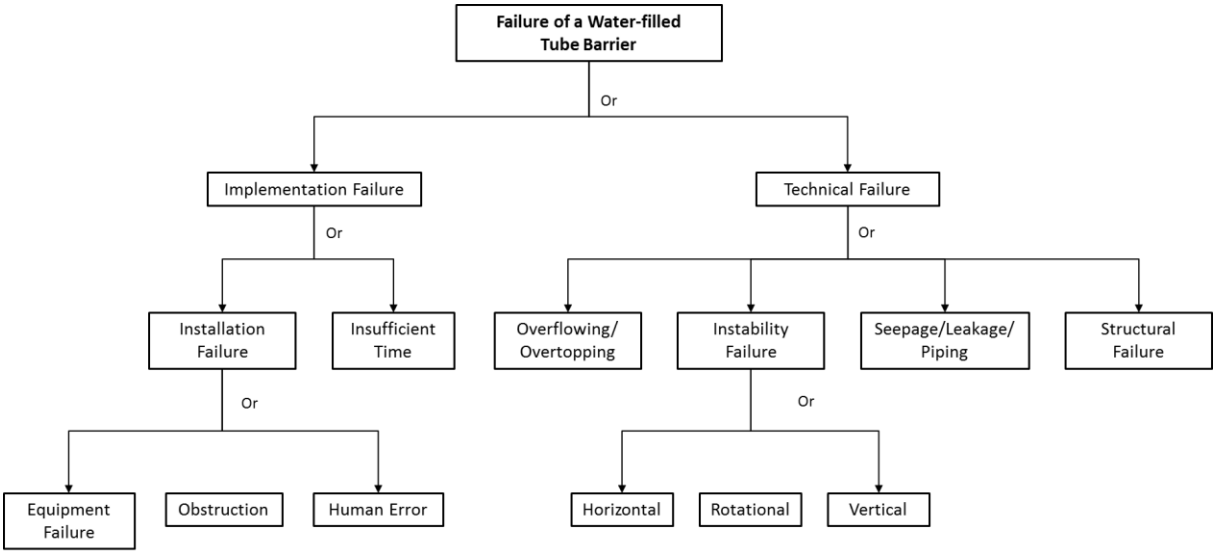


Figure 5-4 Example fault tree for a water filled tube barrier (TFB)

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 environment and key socio-economic sectors expected to be impacted by climate change, and to aid the innovator in design optimization (e.g., by enhancing its performance or co-benefits, or to reduce its negative impacts) when desired (see Figure 4-2). It is important to highlight that while a climate adaptation innovation is intended to mitigate risk to people, property, agriculture, or infrastructure from climate-related hazards, it could also negatively affect the environment or have unforeseen effects on various socio-economic sectors.

If the innovation will affect the environment in a positive way (such as an increase in the extent of nature area, improvement of ecosystem functioning, reduced carbon footprint, etc.) then this may lead to support for the development, speed up the market uptake and the implementation of the innovation. It may even help to find funding to further develop the innovation. Similarly, if the adaptation innovation would favour the conditions for one or more of the socio-economic sectors, then this may result in (financial) support from these sectors.

On the other hand, if the innovation has foreseen negative effects on the environment (e.g., because it releases pollutants, produces waste or noise, reduces the areal extent of nature, adversely effects habitats or species), then this may result in societal resistance or legal obstacles against the innovation. In this case adjustments in the design may be required to overcome these issues.

The Performance Indicators for the Environment (Section 4.3) and for the key Socio-Economic Sectors (Section 4.4) form the key pillars of BRIGAID's Impact Assessment Framework. The information obtained will be used to identify potential hurdles and to obtain more in-depth insight in terms of the environment and potential negative impacts on the key socio-economic sectors. The framework described below is designed to help to shift the innovation upwards along the TRL scale, ultimately bringing the innovation closer to implementation.

The following tools and assessments associated with each of the testing phases and their corresponding TRLs (introduced in Chapter 3) are described below:

I. **Desk Study, TRL 1-3**: This phase consists of applying the TIF Tool, an excel toolbox and associated guidance document (see Appendix B). Using the tool, the innovation, its functionality, and Performance Indicators (PI) are qualitatively analysed by the innovator himself. This qualitative assessment is intended to provide an initial screening of the potential impact of the innovation on the environment and each socio-economic sector (even if the final implementation location is still unknown). The TIF Tool automatically provides scores for each PI and helps the innovator to determine whether additional further evaluation or testing may be needed for the environment or the sectors.

II. **Laboratory Testing, TRL 4-5:** If impacts on the environment or on one or more of the socio-economic sectors are foreseen by the innovator himself (as indicated by the

results of the TIF Tool), then more elaborate evaluation or testing may be required. This phase consists of applying the more detailed Impact Assessment Framework (see section 6.2.2). This Impact Assessment Framework (Table 6-1) is a detailed qualitative or semi-quantitative evaluation of the PIs and likely requires the assistance of experts. 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. A Desk Study Questionnaire is available to familiarize the innovator with the terminology used in BRIGAID and to identify important testing aspects for environmental issues (see Appendix E). There are several methods available to quantify the impacts or to calculate monetized effects (section 6.2.3).

III. **Operational Testing, TRL 6-8:** This phase consists of analysing the relevant PI in an operational environment (test location). This may involve detailed measurement of emission of certain pollutants, or the detailed observation of short-term effects of the innovation on its environment (in a test location). Besides a suitable and representative test location, information on the end-user's requirements are needed in this phase. 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 environment and on important socio-economic sectors. Although this phase is not included within BRIGAID, the Impact Assessment Framework provides suggestions for monitoring critical mid- and long-term impacts.

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 the environment and on different sectors. The focus of the TIF Tool is on guiding the innovator himself through a preliminary qualitative screening of the potential impacts and to reach TRL 4. For the next phases (Laboratory (TRL 4-5) and Operational (TRL 6-8) testing a more detailed (and if possible a quantitative) assessments of impacts is needed for which the input of experts will likely be required.

The following section 6.2 describes the methods and Section 6.3 describes how the Impact Assessment Framework (TRL 4-5) was applied to the Prescribed Burning example. More detailed background information, evaluation methods, and examples are provided in Appendix E.

6.2 Methods

6.2.1 Preliminary Screening Questions and TIF Tool (TRL 1-3)

To determine whether an innovation will directly impact the environment and the socio-economic sectors, a number of questions are proposed to help the innovator perform a preliminary screening (Box 6-1 and TIF Tool). 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. To apply the TIF Tool some basic characteristics of the innovations are required. 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., areal footprint), construction materials and chemical characteristics, and the physical (e.g., space) and environmental alterations that will be necessary to implement the innovation. The associated guidance document to the TIF Tool (Appendix B) provides general background information about the Performance Indicators to apply the Tool by the innovator himself.

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** (temporary impacts may last over the **short term** or **long term**) or **permanent**;
- **reversible** (requiring effort to restore the 'reference' situation) or **irreversible;**
- **certain** or **uncertain.**

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 environment or on the agriculture sector, energy sector, forestry sector, health situation, infrastructure (including transport), or tourism sectors? (Note: the TIF Tool (Appendix B) will provide the first indication of this potential impact.)

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

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 negative, explore whether there are legal requirements necessitating an Environmental Impact Assessment (EIA). If so, then follow the described EIA procedure (which may take substantial time and require the help of an expert.)
  - 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 tensions foreseen 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 Section 6.2.3 and Appendix E)?
- Can laboratory testing provide additional information about these impacts (e.g., volume of chemical release)?

In this preliminary phase, there may be no information available about the potential implementation location (or test site), while for a realistic assessment of the potential impact of an innovation a detailed and explicit description of the present situation at the implementation location is needed. The results of the TIF Tool thus provide a general impression of the potential impact of the innovation, and whether and which kind of environmental and socio-economic issues may arise during further development, marketing and implementation of the innovation. This may result in a need to redesign the innovation.

6.2.2 Impact Assessment Framework (TRL 4-5)

If, during preliminary screening (preliminary questiona and TIF Tool), the innovator foresees that the innovation will have an impact on the environment or on a sector, the next step will be to qualitatively fill in the Impact Assessment Framework (see Table 6-1). This consists of filling in a brief description of the impact and to assign a indicative score by symbols (e.g., ++, +, 0, - , --),colors, and/or numbers. This helps to present the outcomes in a clear and accessible way. Box 6-2 provides some helpful desk study questions to assist the innovator in qualitatively

filling in the Impact Assessment Framework. However, to evaluate the impacts in a realistic way (both qualitatively and quantitatively), the assistance of experts may be needed. In section 6.3 an example of a detailed Impacat Assessement (including the monetized effects) is provided.

It is important to note that the flexibility 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 (where traditional meaures may already be in place) 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.

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

	Performance Indicators (PI's)	**Impact of Innovative Measure (compared to current situation)** direct/indirect; temporary/permanent; short/long term; probability; reversibility	**Score**
Environmental Impact			
Sustainability of Design	Deliberate use of nature or natural processes		
	Area required for implementation on-site		
	Emission of greenhouse gases by the innovation's implementation or construction		
	Made of recycled or recyclable materials		
	Favouring Ecosystem Services?		
	Remarks		
		Overall Score (T)	
Environmental Impact	Surface water quality		
	Surface water quantity		
	Ground water quality		
	Ground water quantity		
	Sea water quality		
	Soil quality		
	Air quality		
	Debris generation		
	Noise or Vibration generation		
	Landscape quality		
	Remarks		
		Overall Score (T)	
Ecological Impact	Area of protected habitats		
	Quality of protected habitats		

	Natura 2000 (or otherwise protected) species(birds, vegetation, fish, mammals, other animals)		
	Area of non-protected nature		
	Quality of non-protected habitats		
	Number of non-protected species		
	Remarks		
		Overall Score (T)	
Socio-Economic Sectors			
Agriculture	Area available for agricultural production		
	Production conditions		
	Variety of Agricultural Products		
	Yield of one or more agricultural products		
	Remarks		
		Overall Score (T)	
Energy	Energy production capacity		
	Reliability of energy production		
	Technical efficiency of energy production		
	Carbon footprint		
	Remarks		
		Overall Score (T)	
Forestry	Area available for wood production (including timber and biomass)		
	Wood production conditions		
	Area available for non-wood production		
	Non-wood production conditions		
	Remarks		
		Overall Score (T)	
Health	Number of fatalities		
	People affected in their physical health (injuries)		
	People affected in their mental/psycho-socio health (including stress)		
	Remarks		
		Overall Score (T)	
Infrastructure	Area available for build infrastructure (e.g. Residential housing, Urbanisation pattern, Commercial/Industrial)		
	Quality of the build infrastructure		
	Capacity of Transportation Networks (e.g. roads, railways, waterways, ports, airports)		
	Reliability of Transportation Networks		

	Capacity of critical Infrastructural Networks (energy, drinking water, sewage system, communication)		
	Reliability of critical Infrastructural Networks		
	Remarks		
		Overall Score (T)	
Tourism	Quantity of recreational area		
	Attractiveness of area for recreation		
	Length of tourist season		
	Remarks		
		Overall Score (T)	

*	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
NA	Not applicable

After filling in a (qualitative) score for each performance indicator (PI), a total score (T) for the environment and each sector can be calculated as a weighted average of the relevant performance indicators (this step is not included in Table 6-1). 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 (see section 6.3 for an example (without weights assigned)).

For several sectors it is possible to quantify or to monetize the impacts (see 6.2.3).

It is important to note that the application of the Impact Assessment Framework (as well as the TIF Tool) is an iterative process. Depending on the results for each indicator, the innovator may choose to optimize the design of his innovation prototype to reduce negative or promote positive impacts on the environment, or increase co-benefits in different sectors (Figure 6-1). After adjustments in the design, the innovation will probably perform better in the Impact Assessment Framework.

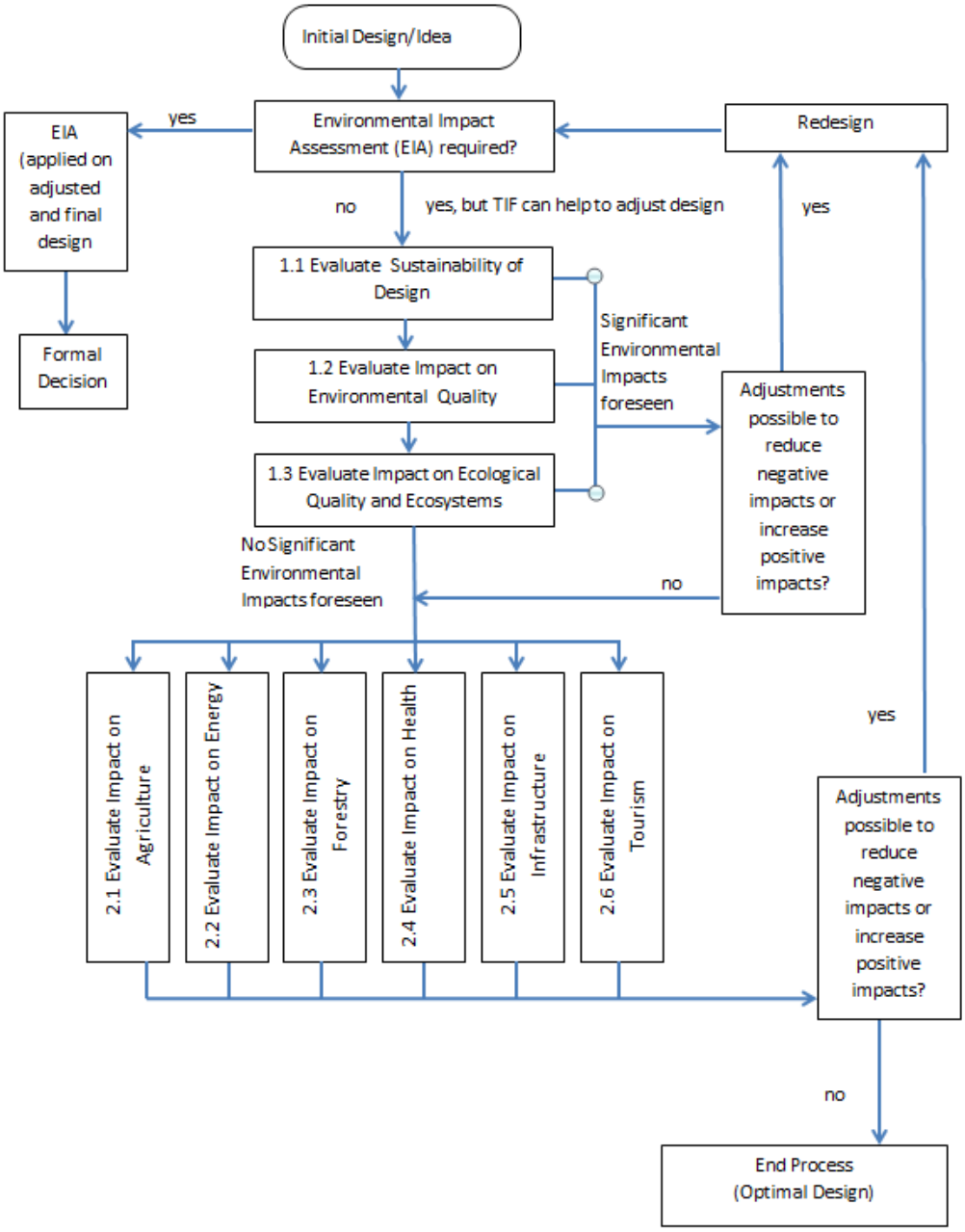


Figure 6-1: Overview of iterative process resulting from the Impact Assessment.

6.2.3 Operational Testing (TRL 6-8)

After completing the impact assessment and any necessary laboratory testing, a next step would be to analyse 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 short term impact of the innovation on the performance indicators for each of the relevant socio-economic and environmental sectors.

Additional to monitoring of the short-term impacts on the implementation site, , mid- and long-term impact (also on a higher spatial scale) monitoring (by experts) is recommended, and may continue beyond the length of the testing cycle within BRIGAID. The Impact Assessment Framework helps to identify critical indicators.

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

Environment

- **Sustainability of the Design :** Does the innovation deliberately use ecosystems and their services? Would implementation of the innovation result in a change in area currently in use for other functions? Does the construction or operation of the innovation affect the quantity of greenhouse gases in the environment? Is the innovation made from recycled or recyclable materials? Does the innovation include specific design features or components which preserve or enhance ecosystem services?
- **Environmental Impact:** 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 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 production or operation of the innovation produce debris or noise? 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?
- **Ecological Impact:** 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?

Socio-Economic Sectors

- **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?
- **Energy**: Does the innovation impact the energy production capacity? Does is impact the reliability or the efficiency of energy production? What is the carbon footprint? 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?
- **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? Is the length of the tourist season affected? Can the changes/losses be monetized?

6.2.4 Methods for (Quantitatively) Evaluating Monetized Effects

The development, marketing, or decisions about the implementation of some innovations would benefit from a quantitatively evaluation of one or several aspects (Performance Indicators). Quantification, or even monetizing of the impacts on the environment or important economic sectors could help to raise funding (e.g., in case the innovation forms a sink for carbon, or would result in an increase in nature area or in new services provided by ecosystem at stake), or to decide about the most cost-effective innovation to battle climate risks .

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.

In Appendix E we provide an overview of applicable cost assessment methods to calculate the monetized impactions of innovations on different sectors. Here, three cost categories are summarized:

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, 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). Several natural habitats, like wetlands or riparian forests, can help mitigate climate change impacts by providing a natural buffer against extreme events such as floods or droughts . 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, 2016). 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.

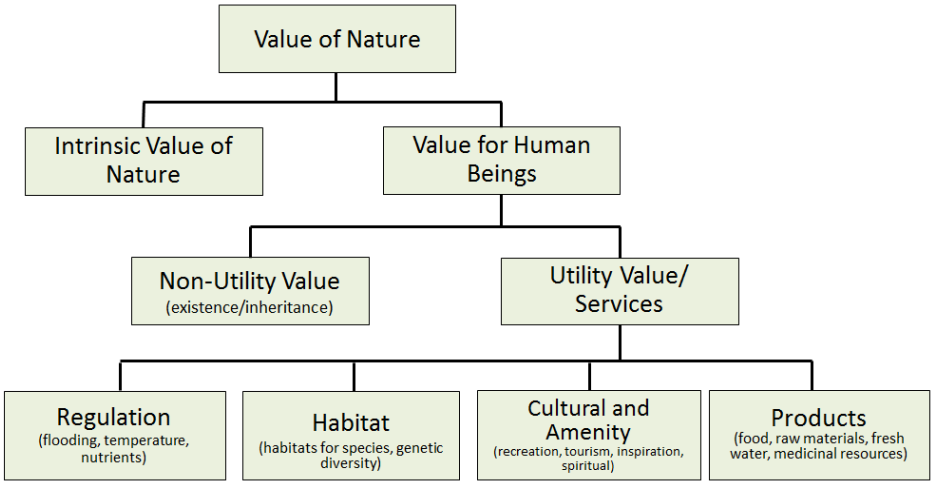


Figure 6-1 Value of nature for human beings (adapted from the Millennium Ecosystem Assessment (2005))

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 evaluation of 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 monetizing the impact of innovations are 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).

6.3 Example of Impact Assessment (TRL 4-5)

6.3.1 System and Functionality Description of a Prescribed Burning (PB) Tool

Prescribed Burning (PB) is a tool to be used in forests in order to reduce risk of wildfire. Fire ignition and spread are both enhanced by cumulated drought, high temperature, low relative humidity and the presence of wind. Reduction of wildfire hazard is the primary reason for the use of PB. The use of this technique decreases the intensity of a subsequent wildfire, primarily by reducing fuel loads, especially of the finer elements in the more aerated fuel layers that govern fire spread, but also by disrupting the horizontal and vertical continuity of the fuel complex. Prescribed burning, a management tool of fuel facilitates fire suppression efforts by reducing the intensity, size and damage of wildfires. This reduction of wildfire hazard leads to the protection of forests, as well as wildland resources and infrastructures at the urban interface, which ultimately affects human safety.

The use of this technique although it can have very positive effects, simultaneously produces some impacts in the forest “burned”, especially if the prescription is not well done and the fire becomes more intense than expected. In these situations, it can kill some trees that are more fragile due to diseases or pests. (nonetheless this can become positive in a longer term since it helps to reduce the risk of pests and diseases). However, some other tree bugs can appear, affecting trees particularly 3 years after the prescribed burning.

In Mediterranean countries, like Portugal, 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 wildfire preventive tool, has been quite successful by reducing fuel loads which contributes to a decrease in wildfire intensity and consequently diminishing the damages and losses in the area.

In this fictive example the Prescribed Burning technique is applied 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 located in the North of Portugal. The area to intervene is 2 hectares. This intervention is only happening when the meteorological conditions are suitable and safe to burn (window of opportunity), generally between October and April. The use of this technique requires and Prescribed Burning Certified Technician (team leader) cooperating with a team of two burning technicians (also certified) and a team of five forest firefighters/workers.

Figure 6-2 Prescribed burning to prevent uncontrolled forest or brush fires (source: www.bombeiros.pt)

6.3.2 Impact Assessment (no weights assigned to PIs)

Performance Indicators (PI's)	**Impact of Innovative Measure (compared to current situation)** direct/indirect; temporary/permanent; short/long term; probability; reversibility	**Score**
Environmental Impact		

Sustainability of the Design	Deliberate use of nature or natural processes	Wildfires are a natural phenomenon in Mediterranean areas, and can naturally be induced by lightening during extensive dry periods. The process of burning outside the dry period is applied to prevent unplanned burning.	++ (+2)
	Area required for implementation on-site	The measure is applied to a defined area, but does not affect the extent or the function of the area involved.	0
	Emission of greenhouse gases by the innovation's implementation or construction	It has a negative direct, short term and temporary (a few hours) effect since it will produce some smoke. The release of some of the carbon stored in the soil and burned plants (shrubs and grasses) is a direct, long term but temporary impact.	- (-1)
	Made of recycled or recyclable materials	The vegetation burned will regrow naturally. Since the grow rates of the plants in this area can be very high, the return rate of the PB intervention is most likely 5-10 years.	+ (+1)
	Favouring Ecosystem Services?	It favours (on the longer term) the production function of the forest (by preventing the massive unplanned burning of trees) and the amenity function by reducing the risk on wildfires.	++ (+2)
	Remarks		
		Overall Score (T)	Pos. (+4)
Environmental Impact	Surface water quality	There might be a slight run-off of burned carbon, however, However, PB is applied in small areas with a fire of low intensity.	+/-
	Surface water quantity	No foreseen impact	0
	Ground water quality	No foreseen impact	0
	Ground water quantity	No foreseen impact	0
	Sea water quality	No foreseen impact	0
	Soil quality	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.	- (-1)
	Air quality	It has a negative direct, short term and temporary (a few hours) effect since it will produce some smoke.	- (-1)
	Debris generation	It will in the short term result in some dead, burned organic material, however, this will be soon recycled in a natural way (and form nutrients for the remaining trees).	0
	Noise or Vibration generation	During the burning it will produce some noise, but this is very temporarily, and people are informed and prepared.	0
	Landscape quality	On the short term it has an adverse impact on the landscape quality, but on the longer term it will result in rejuvenation of the forest landscape.	+ (+1)
	Remarks		
		Overall Score (T)	No/ Minor Neg. (-1)

Ecological Impact	Area of protected habitats	The measure is applied to a defined area, but does not affect the extent or the function of the area involved. Normally, PB is not applied in protected habitats	0
	Quality of protected habitats	When applied in a protected area, the use of prescribed burning will help to diminish the risk of unplanned and massive burning of protected habitats. However, because it helps to reduce the understorey, it will temporary affect the animal and plant communities present in the understorey.	-/+ (0)
	Natura 2000 (or otherwise protected) species(birds, vegetation, fish, mammals, other animals)	Normally, PB is applied in small areas and not in protected areas. It is applied in late fall, winter and early spring, thus outside the breeding period. Simultaneously, mammals can run, birds can fly and amphibians are under the soil hibernating. Furthermore, the fire is slow and with low intensity. However, it will favour plant species that are more resistant against fire or that are able to recover faster than others.	- (-1)
	Area of non-protected nature	The measure is applied to a defined area, but does not affect the extent or the function of the area involved.	0
	Quality of non-protected habitats	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.	-/+ (0)
	Number of non-protected species	PB will have some impacts n species, however, they are small since the fire intensity is low and not intense. As mentioned above, PB is applied in fall, winter or early spring, thus outside the breeding season. Some animals may flee the area temporarily, and could potentially return after their habitat is restored. It will favour plant species that are more resistant against fire or that prefer open areas. There is no foreseen impact on fish, because there is hardly any run-off	- (-1)
	Remarks	On the short-term the impact is negative, but on the longer term the impact may be positive on the forest ecosystem, because of rejuvenation of the plants and trees.	
		Overall Score (T)	No / Minor Neg. (-2)
Socio-Economic Sectors			
Agriculture	Area available for agricultural production	It has a direct and long-term impact as it safeguards agricultural areas from the possible spread of wildfires.	+ (+1)
	Production conditions	It has hardly any effect on agricultural production conditions (maybe a short term effect from smoke).	0
	Variety of Agricultural Products	No impact on available area	0
	Yield of one or more agricultural products	PB is not applied on agricultural land, so it has no impact	0
	Remarks		

		Overall Score (T)	No/ Min. Pos (+1)
Energy	Energy production capacity	No foreseen effects.	0
	Reliability of energy production	It has a positive, short and long term impact on preventing loss of wood being a renewable fuel source.	+ (+1)
	Technical efficiency of energy production	NA	
	Carbon footprint	It has a positive long term impact on preventing decrease of carbon sequestration potential. In short term, PB cause emission of carbon from biomass, however this emission under EU regulation is considered neutral.	+ (+1)
	Remarks	On the short term it will result in CO2 emission, but it will diminish the risk on unplanned and massive emission of CO2 by wildfires. however this emission under EU regulation is considered neutral.	
		Overall Score (T)	Pos. (+2)
Forestry	Area available for wood production (including timber and biomass)	No impact on available area	0
	Wood production conditions	In a very short term, PB can seem negative due to direct impact by dying of some small or fragile trees, however that is very temporary and in the 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.	+ (+1)
	Area available for non-wood production	No impact on available area	0
	Non-wood production conditions	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.	+ (+1)
	Remarks		
		Overall Score (T)	Pos. (+2)
Health	Number of fatalities	Wildfires have an impact on mortality of people, due to direct exposure to the fire, smoke inhalation or reduced visibility (leading to accidents). Since the intensity and size of wildfires is reduced by applying this technique, the associated number of fatalities will also be reduced accordingly. Because Prescribed Burning is planned and will be announced, the measure itself is not expected to result in fatalities.	+ (+1)
	People affected in their physical health (injuries)	Wildfires lead to increase in physical symptoms of individuals, for example respiratory problems, burns and corneal abrasions. Since the intensity and size of wildfires is reduced by applying this technique, the associated number of people affected in their physical health will also be reduced. The intervention itself,	+/- (0)

		however, has a temporary adverse effect on health, because the increase in smoke and air pollution.	
	People affected in their mental/psycho-socio health (including stress)	Wildfires are associated with mental and psychosocial problems, especially among children, due to property damage and physical injury. By reducing the intensity and size of a particular wildfire, these kinds of health impacts can be prevented	+ (+1)
	Remarks	The intervention has a temporary, adverse effect, since it will lead to a small increase in smoke and air pollution in areas where it is applied. This can affect the prescribed burning team, as well as people living in the vicinity. Measures can be taken to protect vulnerable people, such as the use of breathing protection for workers, or advising locals to keep their windows closed or to leave their house for a certain time.	
		Overall Score (T)	Pos. (+2)
Infrastructure	Area available for build infrastructure (e.g. Residential housing, Urbanisation pattern, Commercial/Industrial)	No impact on available area	0
	Quality of the build infrastructure	No impact	0
	Capacity of Transportation Networks (e.g. roads, railways, waterways, ports, airports)	No impact	0
	Reliability of Transportation Networks	It has a positive, long term effect on the reliability of the transportation networks because it helps safeguard against damages to the network that could be caused by wildfires	+ (+1)
	Capacity of critical Infrastructural Networks (energy, drinking water, sewage system, communication)	No impact on	0
	Reliability of critical Infrastructural Networks	It has a positive, long term effect on the reliability of the critical Infrastructural networks because it helps safeguard against damages to the network	+ (+1)
	Remarks		
		Overall Score (T)	Pos. (+2)
Tourism	Quantity of recreational area	Possibility of fewer recreational areas due to PB, however this would be short term and temporary.	-/+ (0)
	Attractiveness of area for recreation	It has a negative direct, short term and temporary (a few hours) effect on tourism since it will produce some smoke and the area will appear burned for at least 1 month. After that the area will be more attractive since the plants will grow and the forest will look more “clean”	+ (+1)
	Length of tourist season	Because it reduces the risk on Wildfire, the length of the tourist season will be safe guarded.	++ (+2)

	Remarks	On the short term (during the burning and some months after applying PB) PB will have an adverse effect, but on the longer term it will have a positive effect, because it reduces the risk of Wildfire in the area substantially.	
		Overall Score (T)	Pos. (+3)

*	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
NA	Not applicable

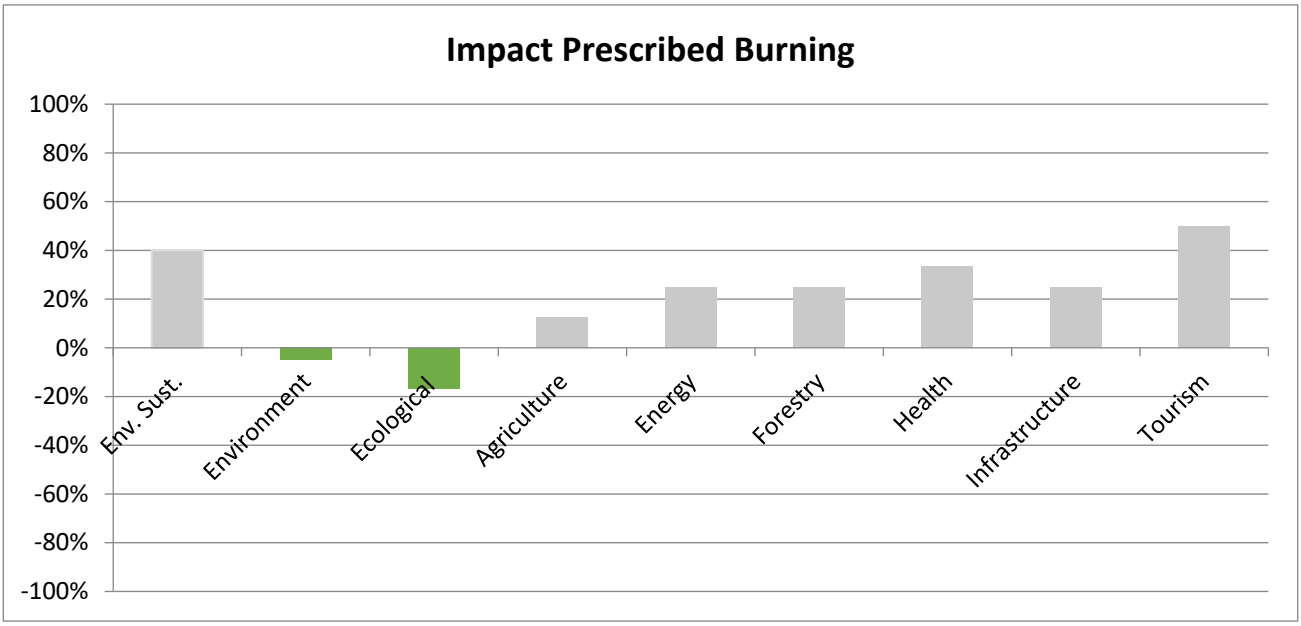


Figure 6-4 Summary of results of Impact Assessment Prescribed Burning.

6.3.3 Economic Impact Assessment on the Forestry Sector

In this example PB is applied on a Maritime Pine1 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 m3 and 20 with a global volume of 0.314 m3. Maritime Pine is considered to be a medium growth species, the commercial price of timber (diameter < 14 cm) is 32 €/ton in the factory

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

(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 €. Since the area burned was 2 ha, the loss will be 39.56 euros.

6.3.4 Further Testing (TRL 6-8)

Based on the results of the Impact Assessment, a next step could be the detailed analysis (based on measurements) of the impacts of Prescribed Burning on the Air Quality and on the Health of people in a demarcated area around the Prescribed Burning site.

Furthermore, a detailed study of the (Natura 2000 protected) species (birds, vegetation, fish, mammals and other animals) present at the site before and after applying the Prescribed Burning measure would provide quantitative information about the ecological impact of this innovation.

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 favourable 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).

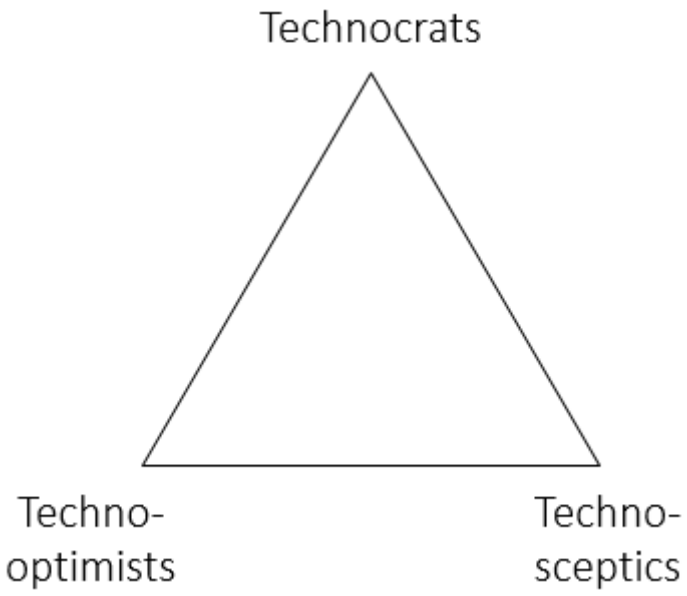


Figure 7-1 A triangular preference space for innovations

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

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 relevant 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[6], 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);
- Albania and Macedonia[7].

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.

[6] 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).

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

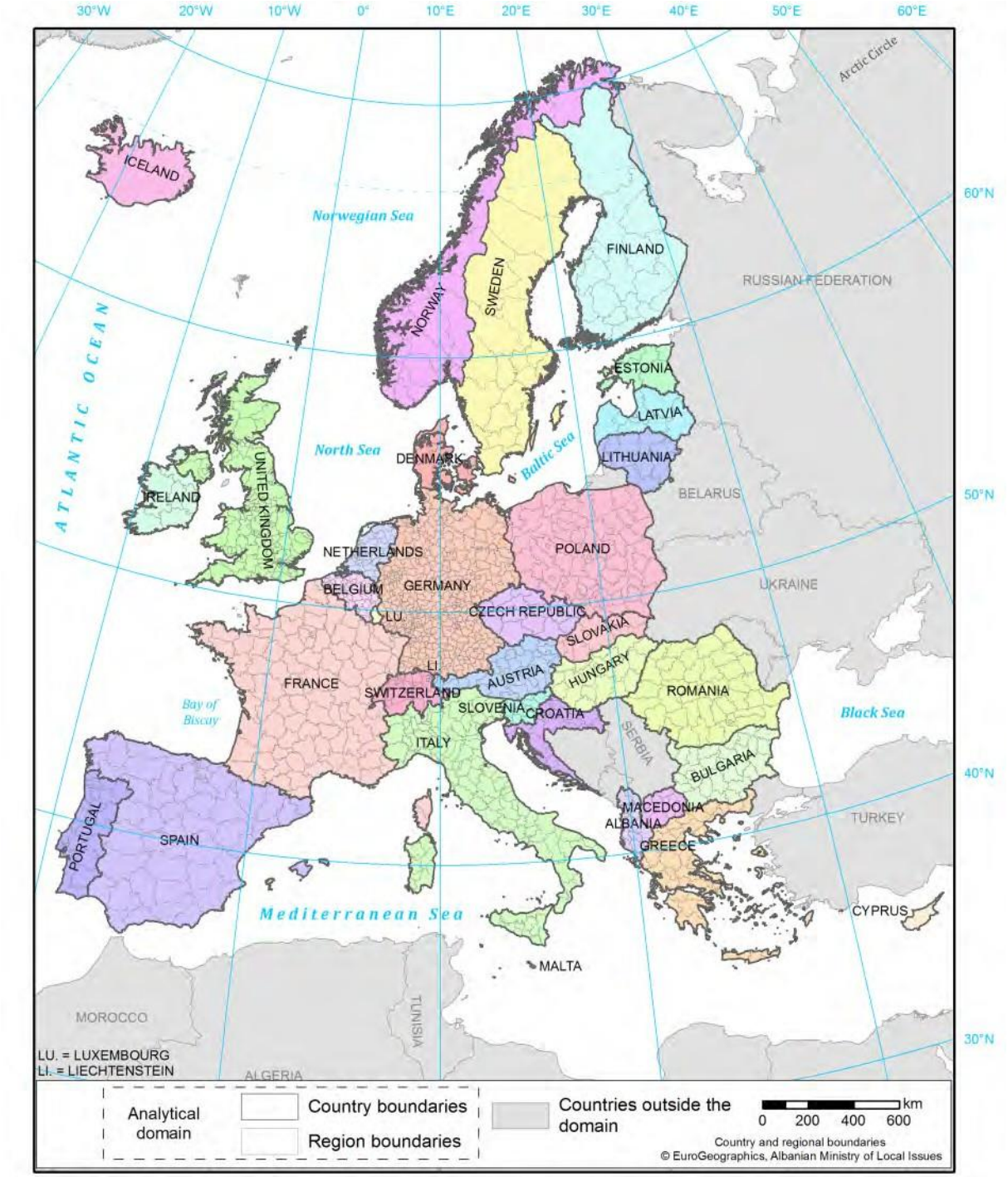

Figure A1. Spatial domain used in the analysis

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 meteorological drought is considered, as BRIGAID considers innovations that address many different types of meteorological drought impacts. The meteorological drought is the primary 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, meteorological 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 primary 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 primary 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 2016b) 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).

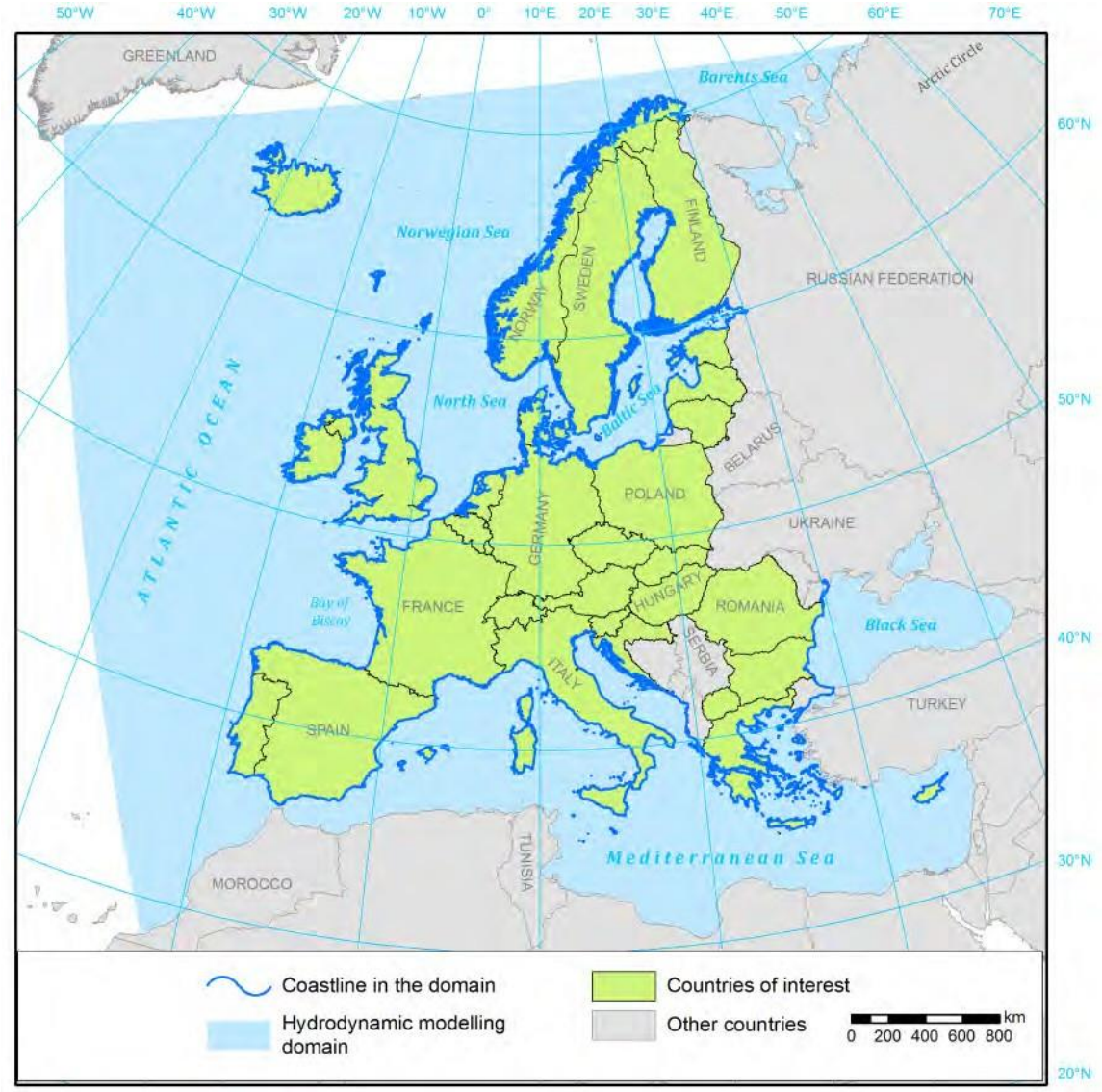

Figure A2. Domain used in RAIN project to obtain coastal flood hazard maps. Coastline geometry from CCM2 dataset (de Jager and Vogt 2010).

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)[8].

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

[8] 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 enormously 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[9]. 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 (2017) and Paprotny et al. (2017). Below, the main aspects of the methodology are summarized.

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

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 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.

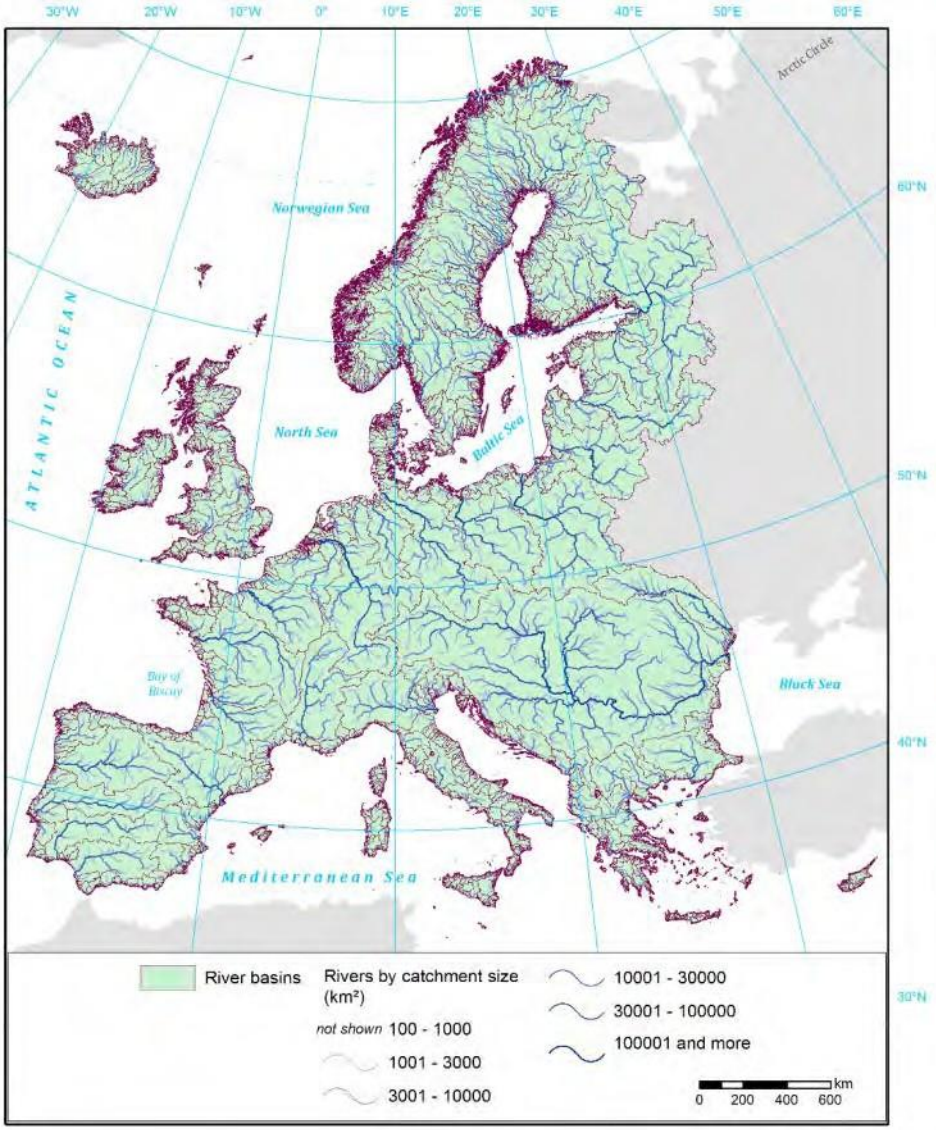

Figure A3. Domain used in RAIN project to obtain river flood hazard maps; for the sake of clarity, only rivers with a catchment area larger than 1000 km2 are presented on the map. Delimitation of rivers and basins from CCM2 dataset (de Jager and Vogt 2010).

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, 2017). 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[10], the boundaries were defined as to represent mean sea level.

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

- 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 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 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 enormously 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 meteorological 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 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 significant 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 10-m V wind component 2-m temperature 2-m dew point temperature	0.75
Windstorms	ERA-Interim	10-m U wind component 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 indicator 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 Forest Fire Danger Index (FFDI; Noble et al., 1980) is defined as:

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

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 FF 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:

$$RH = \frac{e_a}{e_s}\ x\ 100 \quad (8)$$

in which,

$$RH = 0.6108\exp(\frac{e_a}{e_s}\ x\ 100 \quad (9)$$

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

where e_a is the actual vapor pressure, e_i 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 wildfire 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 humidity, 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 99th percentile of daily wind speed.

The 99th percentile was selected as to consider more extreme wind storms than the European Environment Agency, which considers changes in the 98th 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, 99th, 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
AL	Albania	28 524	2 892 302	Qarku	12	Bashki	61
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 enótjtes*	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 București	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	**4 885 885**	**522 291 428**	**Total no. of regional units**	**1 394**	**Total no. of local units**	**117 583**

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[11]. The boundaries of LAUs were obtained from a map provided by Eurostat (2017), originally developed by EuroGeographics[12]. 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[13].

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

[11] 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.

[12] Except for Albania, where map was obtained from the Albanian Ministry of Local Issues.

[13] 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.

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 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[14] 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[15]. 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[16]. To complete the normalization process, the following statistical data at regional level were collected from Eurostat (2017)[17]:

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

A statistical summary of the 1394 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.

[14] 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).

[15] Except for Albania, where map was obtained from the Albanian Ministry of Local Issues.

[16] 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.

[17] 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.

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	4 885 885	3505	SE332 Norrbottens län	105 205	UKI42 Tower Hamlets	22
Population (‘000s), 1-1-2015	522 291	374.7	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	14 720	10.6	FR101 Paris	207	EL643 Evrytania	0.2
GDP per capita (‘000 euro)	28.2	X	UKI31 Camden and City of London	410.3	MK006 Pološki	1.9

4.3 National level

At national level, the normalization is carried out by calculating the 95th 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 95th 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 95th 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	0.24	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	1.42
		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*	28	41	96	25	39	87	30	71	188
		rcp4.5	31	48	122	27	45	105	29	79	205
		rcp8.5	32	55	146	30	49	123	32	89	213
Heat waves	Total number of heat waves in 30 years***	*Hist*	16	38	58	15	38	50	15	47	80
		rcp4.5	42	96	124	50	89	114	46	101	150
		rcp8.5	65	118	146	71	117	139	68	125	181
Wildfires	Average daily Forest Fire Danger Index [-]	*Hist*	0.43	0.51	0.78	0.41	0.50	0.76	0.37	0.63	1.26
		rcp4.5	0.46	0.58	0.92	0.45	0.56	0.90	0.41	0.72	1.54
		rcp8.5	0.49	0.66	1.11	0.48	0.61	1.08	0.46	0.82	1.93
Windstorms	99th percentile of daily wind speed [m/s]	*hist*	4.6	8.5	12.3	4.6	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	38.6	69.1	33.9	57.6	117.5
		rcp4.5	31.4	41.8	75.5	33.5	42.6	74.2	37.9	63.0	131.0
		rcp8.5	33.5	45.3	79.7	36.0	46.1	80.8	41.6	68.6	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% (6,288) of local administrative units, 29% (400) of regions and 76% (26) 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 Mediterranean 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. The highest surges 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 Mediterranean 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.

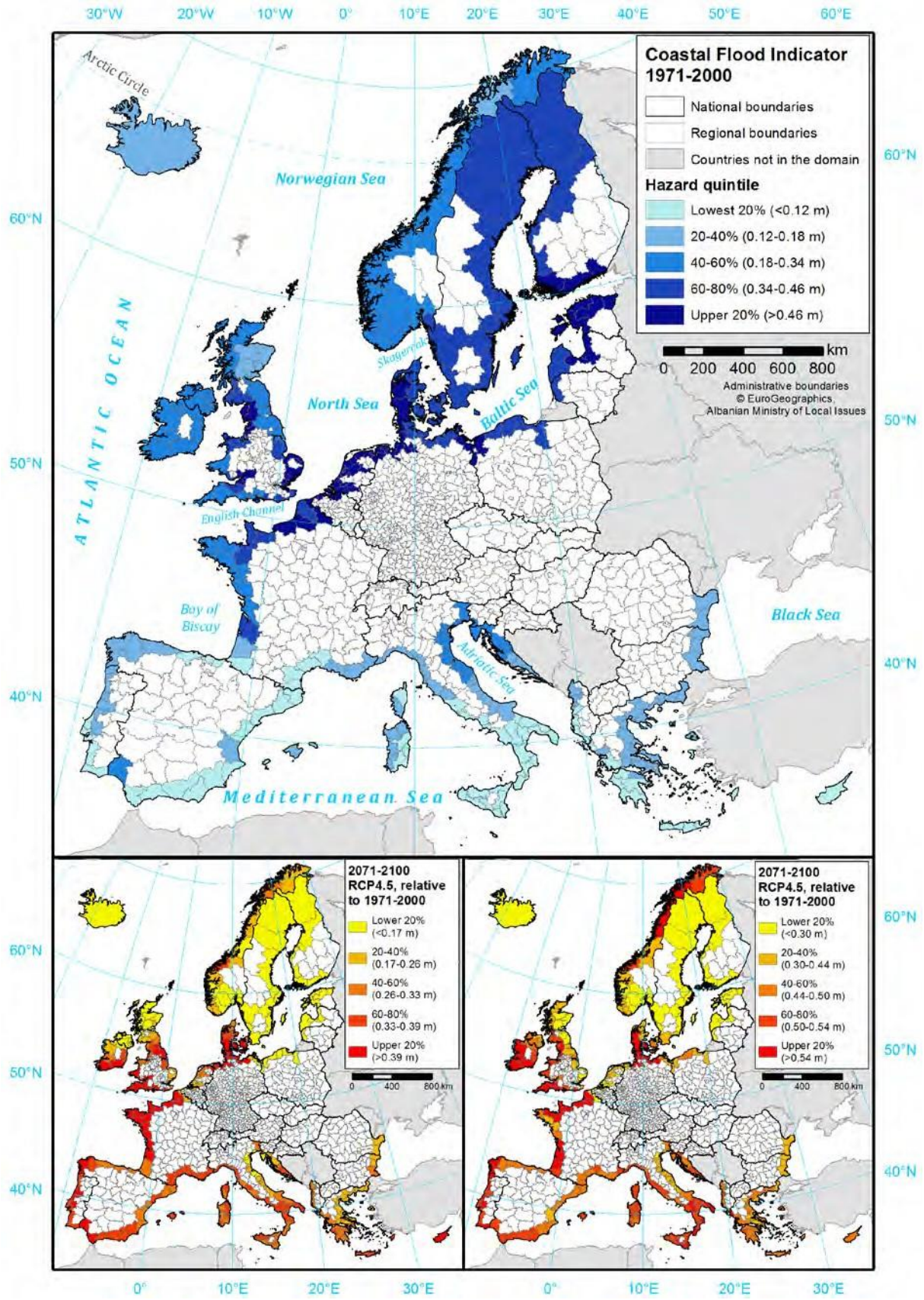

Figure A4. Quintiles of normalized coastal flood hazard indicator at regional level for historical scenario (main map) and relative change (subtraction) between 2071–2100 and 1971–2000, in two scenarios.

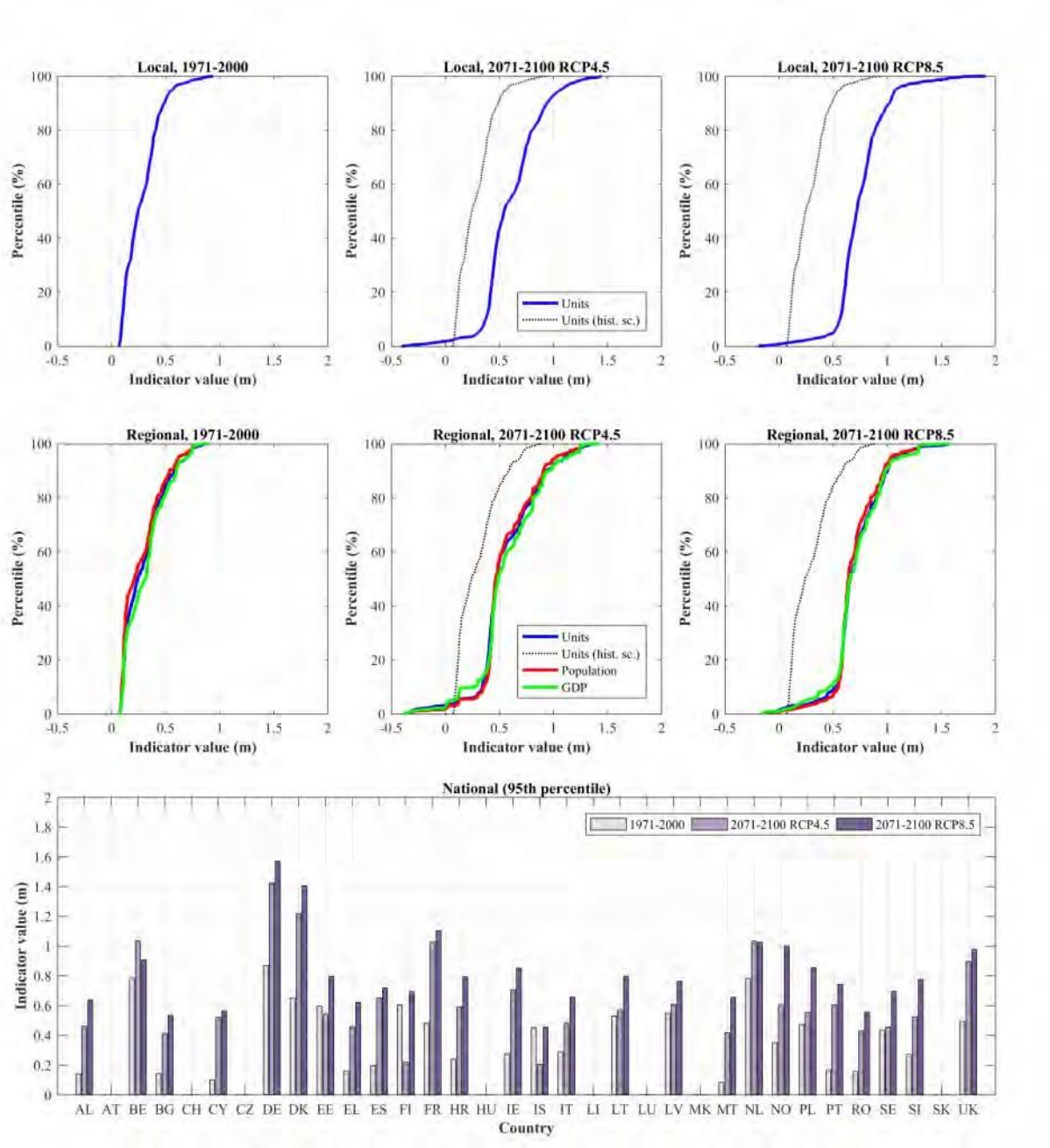

Figure A5. Normalized coastal flood hazard indicator at local, regional and national level, by climate scenario. Histograms only for units connected to the coastline (6275 local, 394 regional). For country codes, see Table A4.

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 extends over 293,000 km^2, or 6%, of the study area. A total of 42% (49,429) of local administrative units, 97% (1,350) 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 for 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.

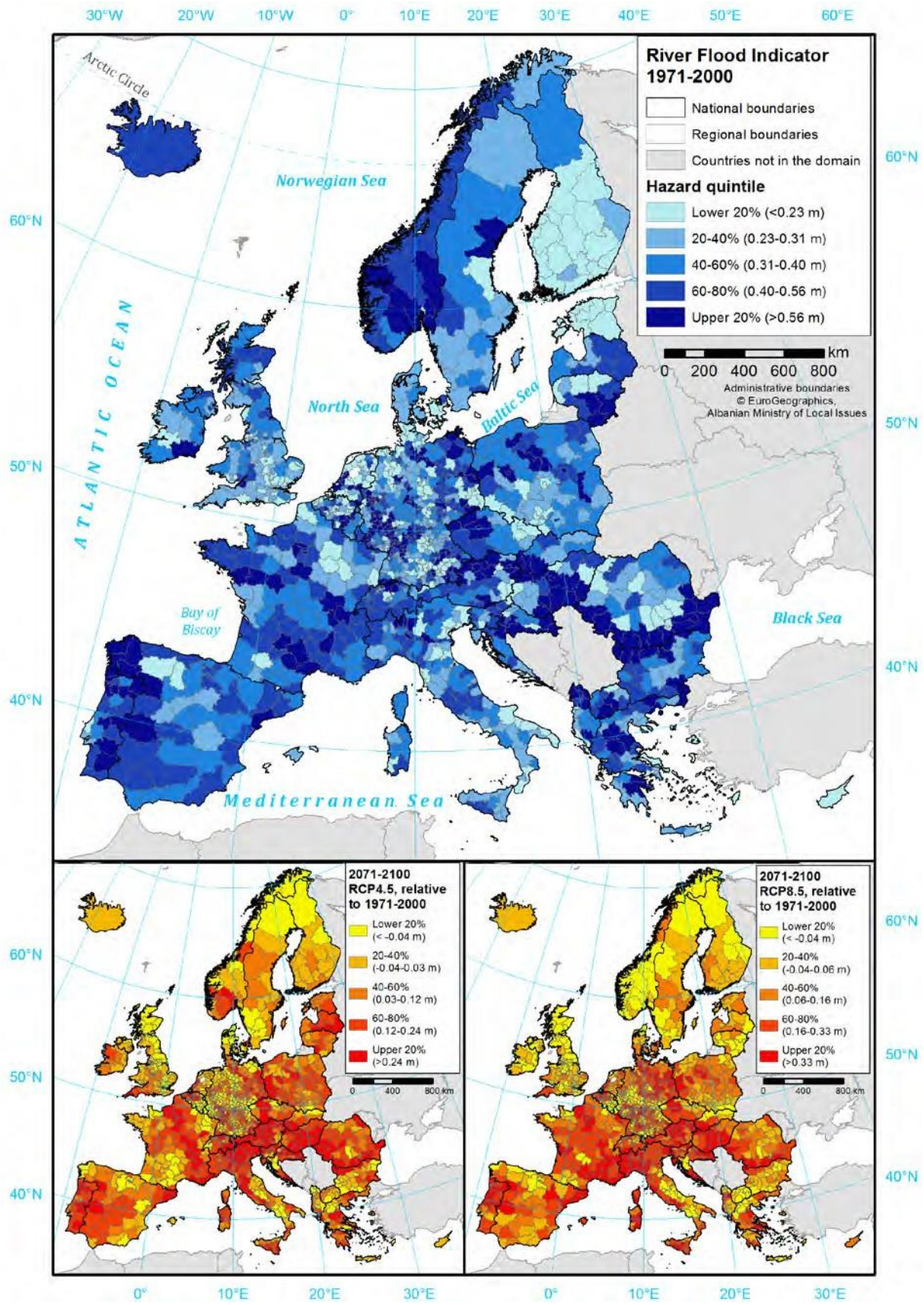

Figure A6. Quintiles of normalized river flood hazard indicator at regional level for historical scenario (main map) and relative change (subtraction) between 2071–2100 and 1971–2000, in two scenarios.

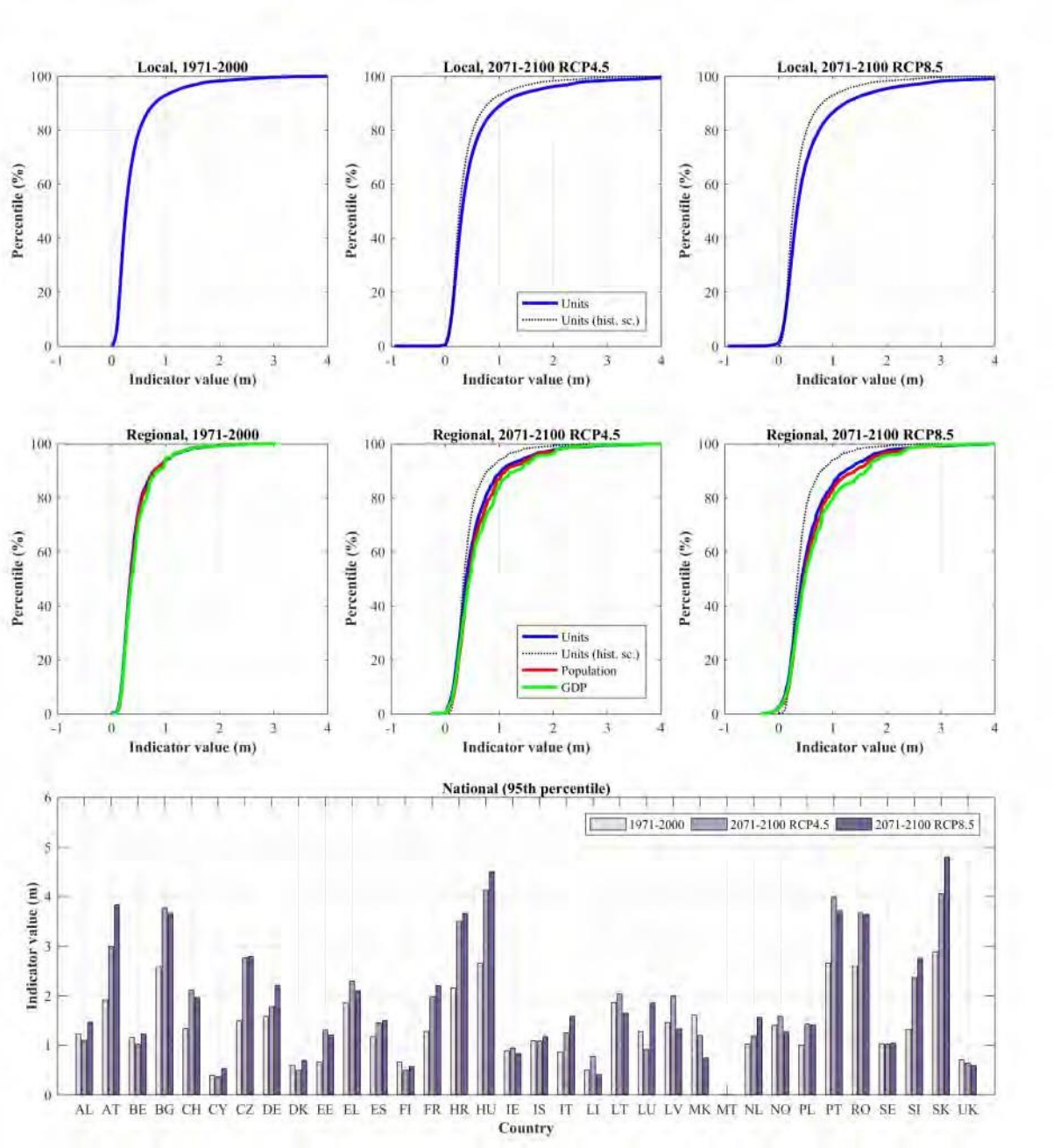

Figure A7. Normalized river flood hazard indicator at local, regional and national level, by climate scenario. Histograms only for units for which river water level estimates were available (49,369 local, 1338 regional). For country codes, see Table A4.

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 96. 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 - 96 (historical climate) to 31 – 122 (RCP4.5) and 32 – 146 (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 87 (historical climate) to 105 (RCP4.5) and 123 (RCP8.5). The mean number of CDDs at the regional level increases from 39 (historical climate) to 45 (RCP4.5) and 49 (RCP8.5). At the national level, the maximum number of CDDs increases from 188 (historical climate) to 205 (RCP4.5) and 213 (RCP8.5).

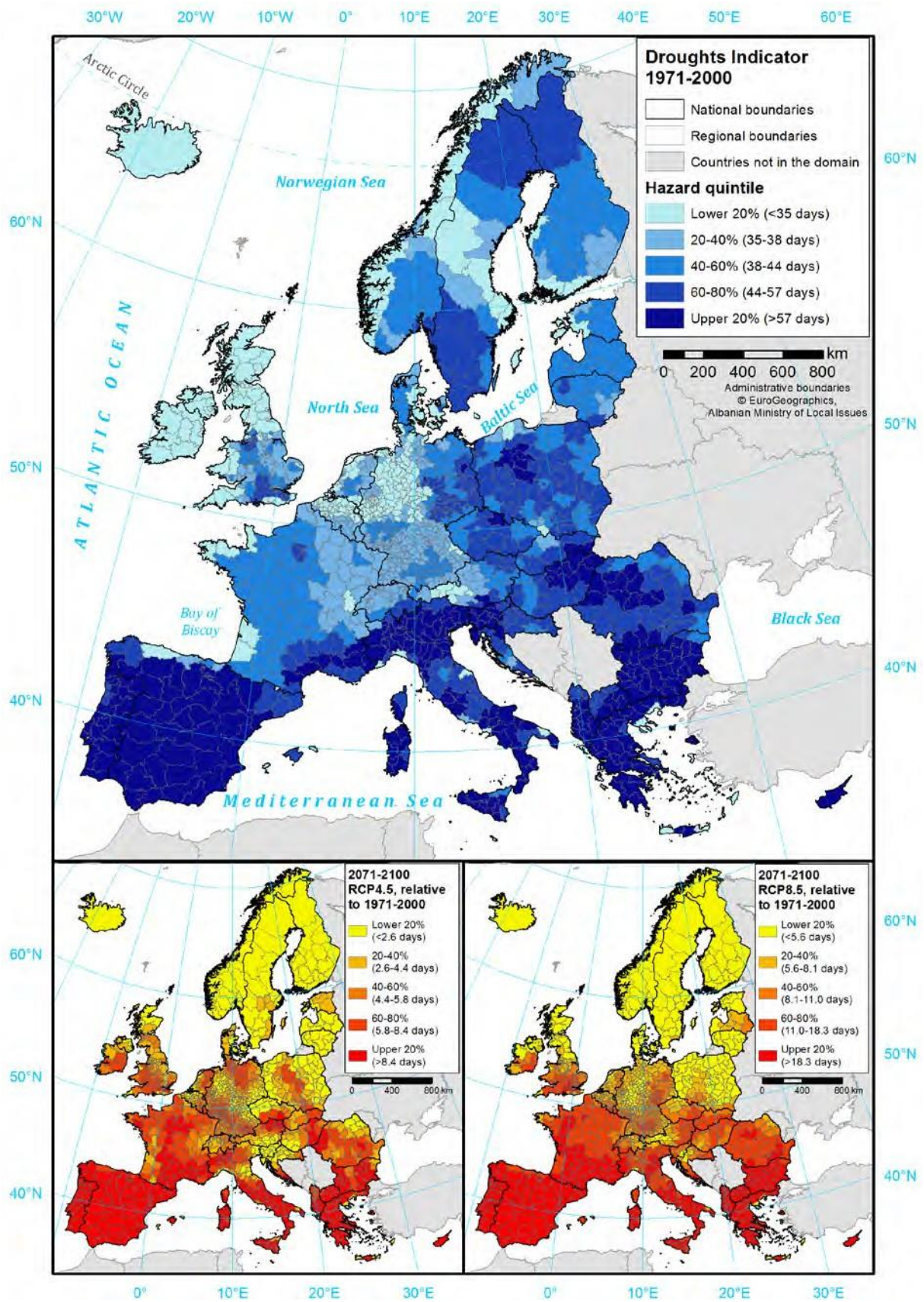

Figure A8. Quintiles of normalized drought hazard indicator at regional level for historical scenario (main map) and relative change (subtraction) between 2071–2100 and 1971–2000, in two scenarios.

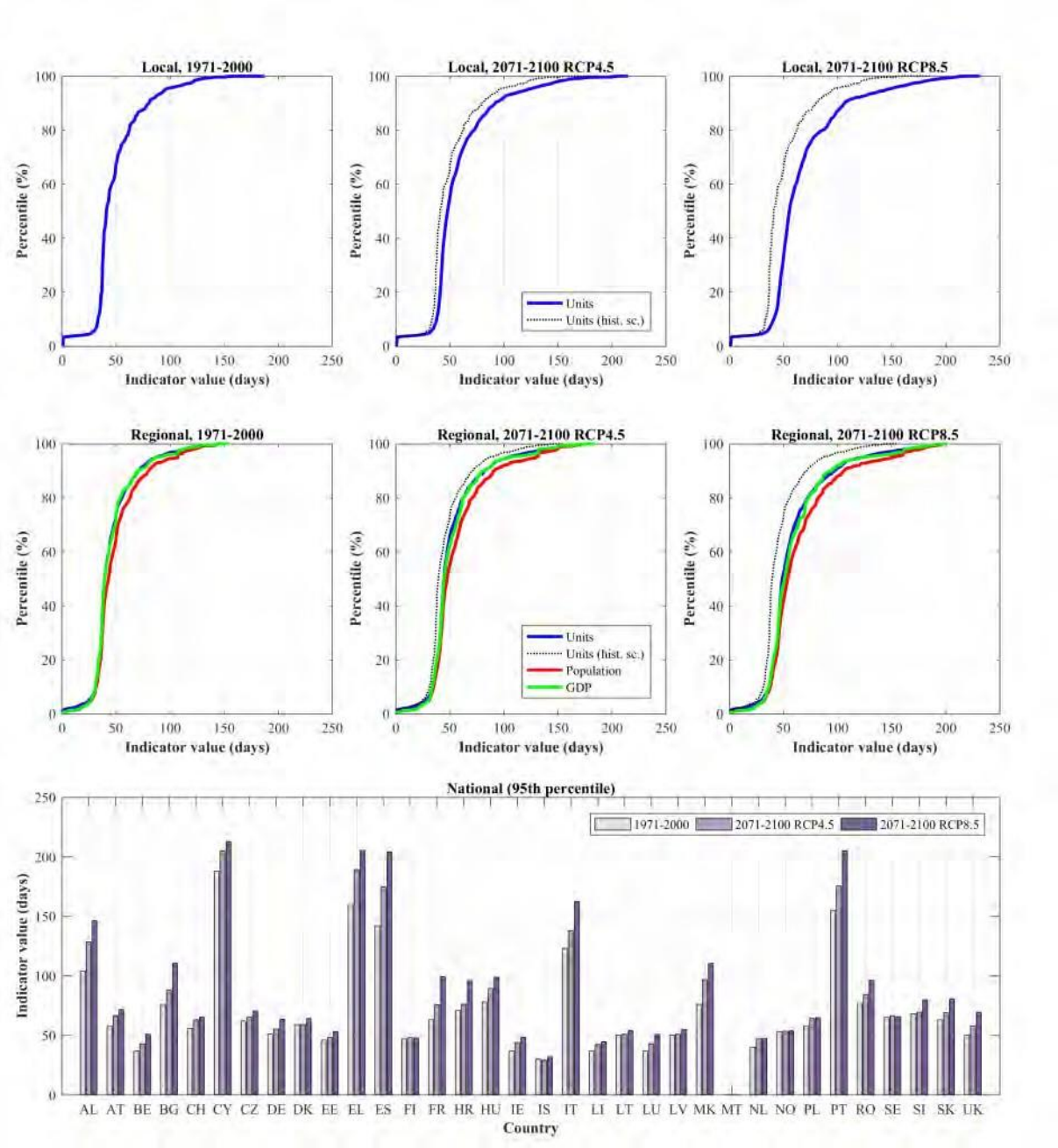

Figure A9. Normalized drought hazard indicator at local, regional and national level, by climate scenario. Histograms only for units for which estimates were available. For country codes, see Table A4.

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 16 and 58. 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 16 - 58 (historical climate) to 42 – 124 (RCP4.5) and 65 – 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 89 (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.

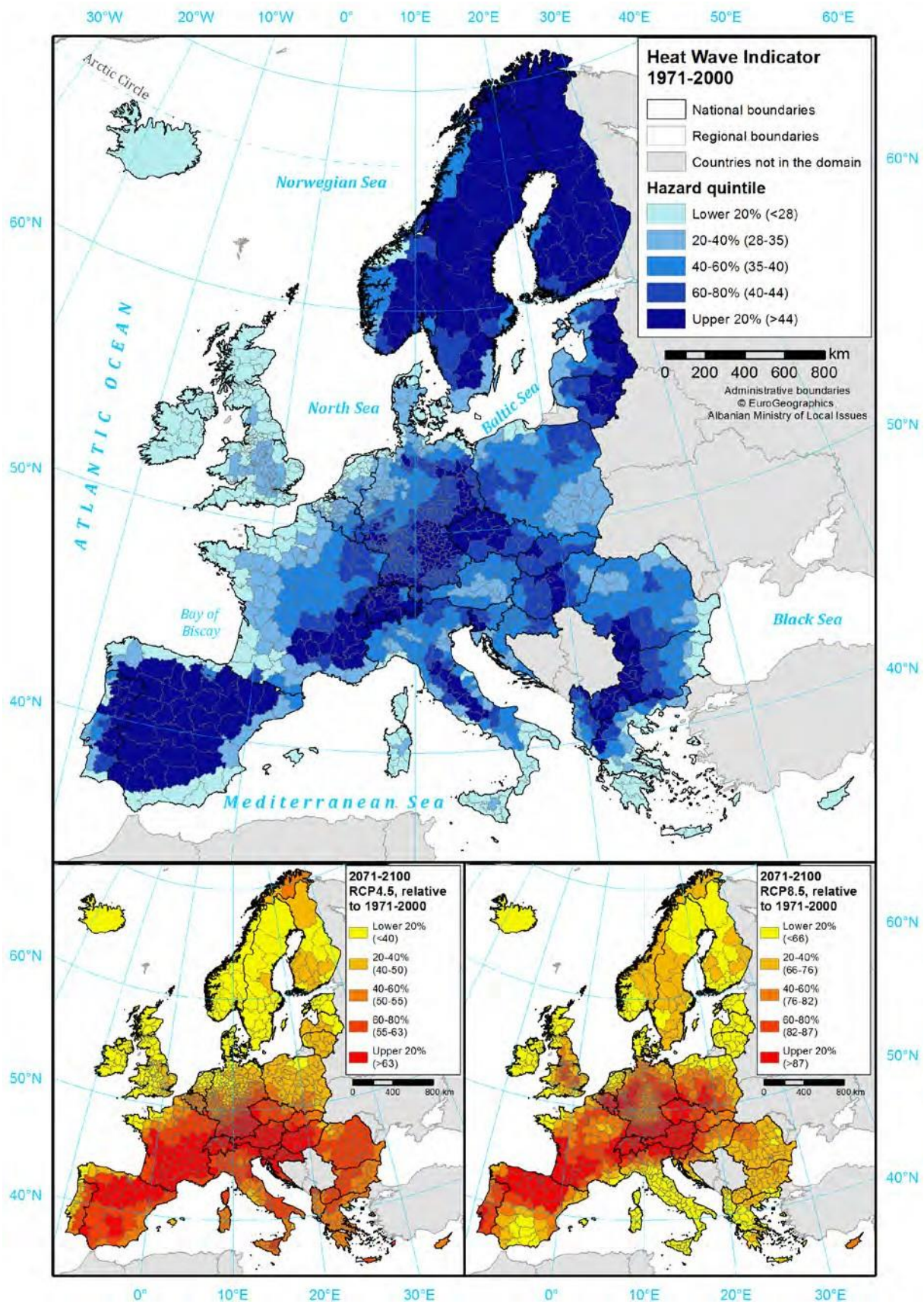

Figure A10. Quintiles of normalized heat wave hazard indicator at regional level for historical scenario (main map) and relative change (subtraction) between 2071–2100 and 1971–2000, in two scenarios.

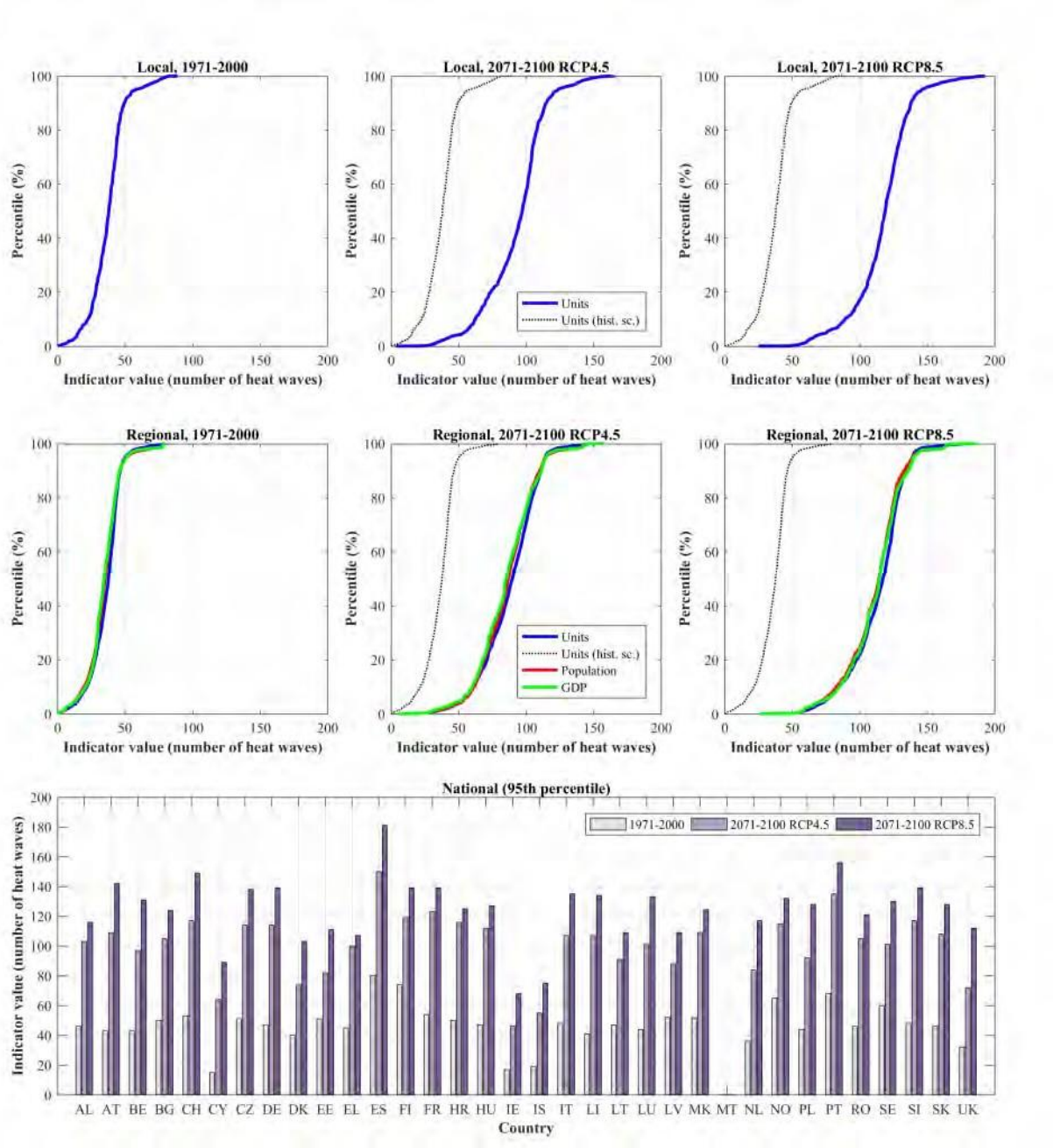

Figure A11. Normalized heat wave hazard indicator at local, regional and national level, by climate scenario. Histograms only for units for which estimates were available. For country codes, see Table A4.

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 0.78. 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 – 0.78 (historical climate) to 0.46 – 0.92 (RCP4.5) and 0.49 - 1.11 (RCP8.5). The changes are strongest for the more dry countries of Southern Europe. The maximum FFDI value at the regional level increases from 0.76 (historical climate) to 0.90 (RCP4.5) and 1.08 (RCP8.5). The mean FFDI value at the regional level increases from 0.50 (historical climate) to 0.56 (RCP4.5) and 0.61 (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 0.63 (historical climate) to 0.72 (RCP4.5) and 0.82 (RCP8.5).

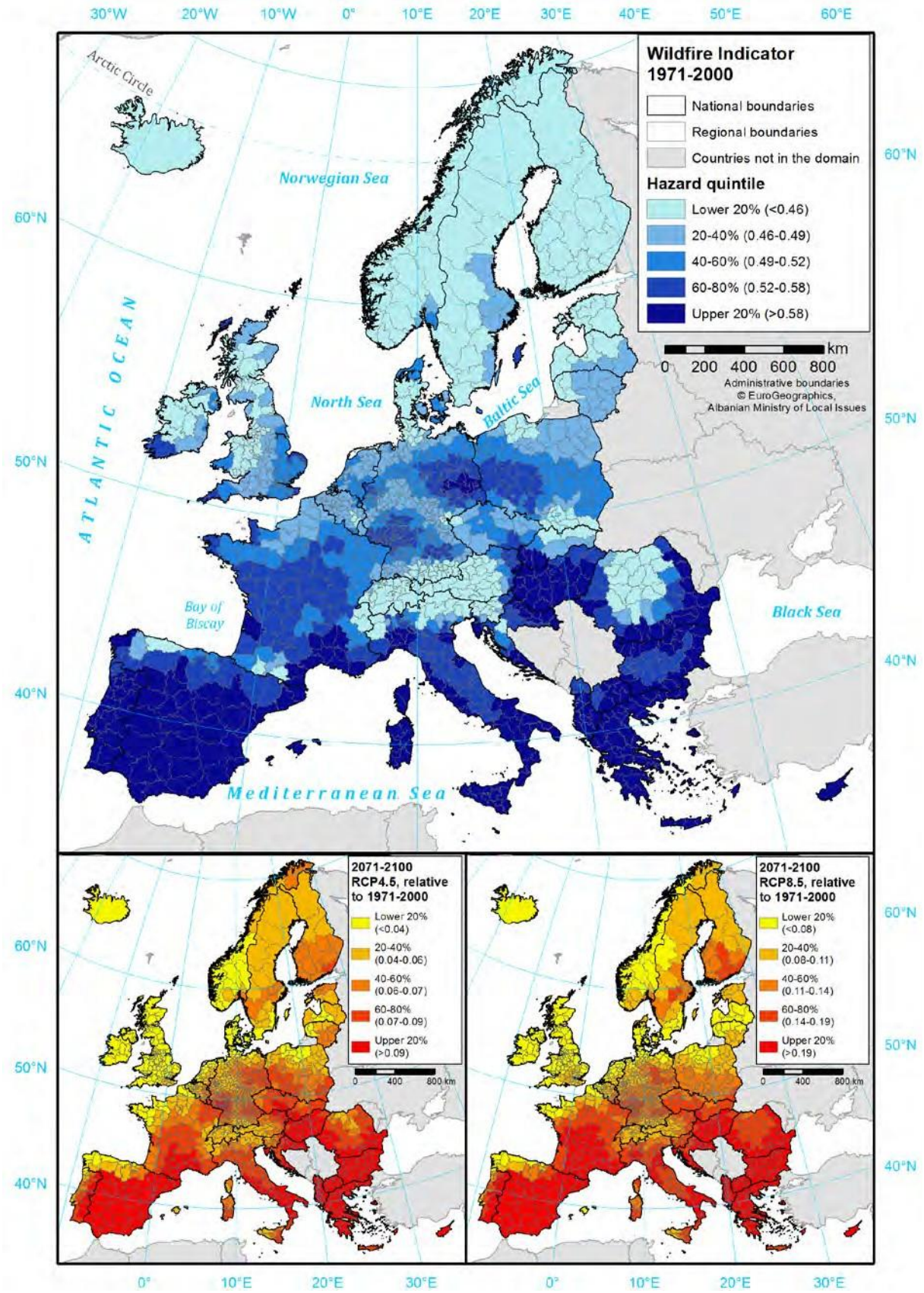

Figure A12. Quintiles of normalized wildfire hazard indicator at regional level for historical scenario (main map) and relative change (subtraction) between 2071–2100 and 1971–2000, in two scenarios.

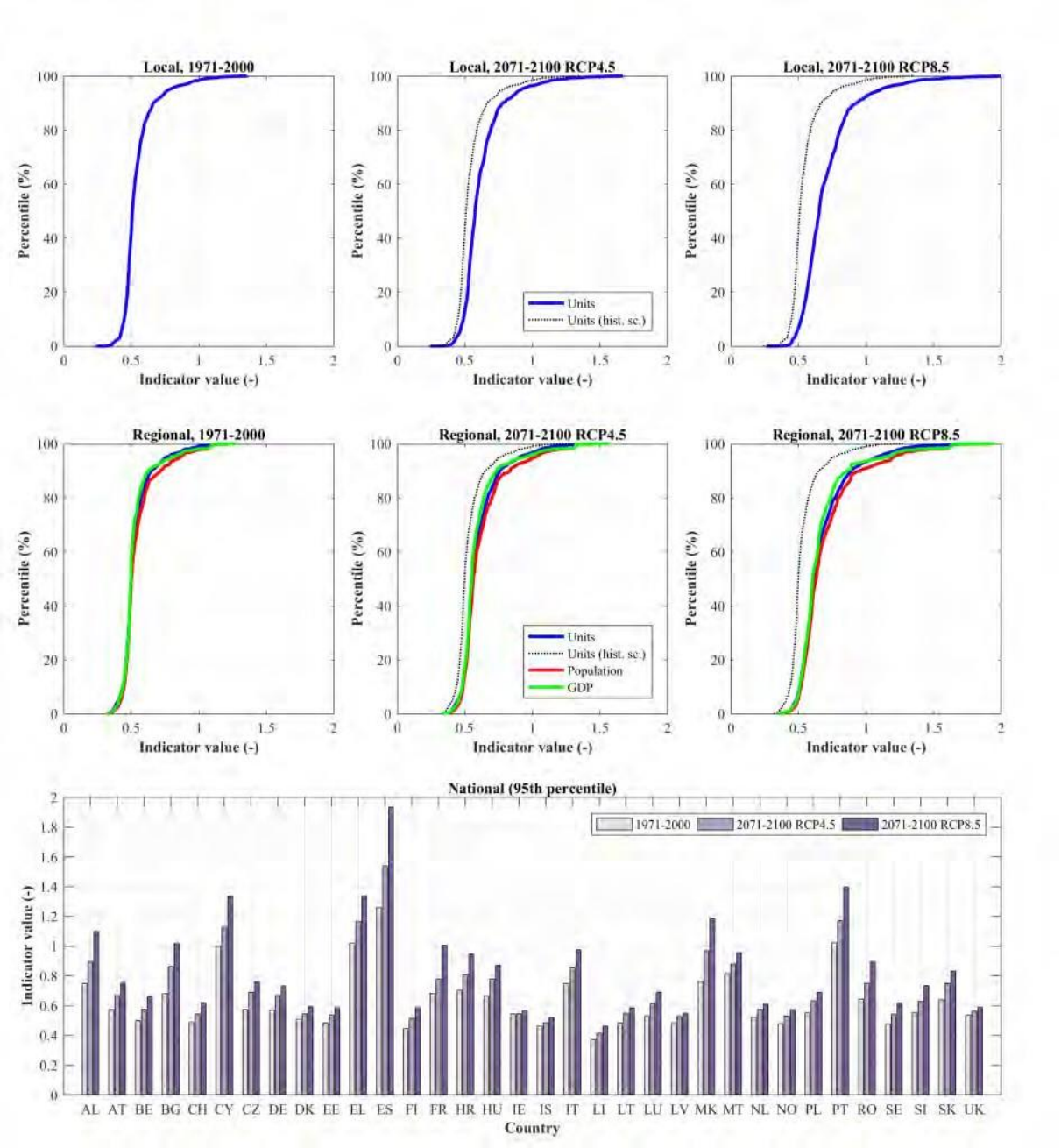

Figure A13. Normalized wildfire hazard indicator at local, regional and national level, by climate scenario. For country codes, see Table A4.

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 – 12.2 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.

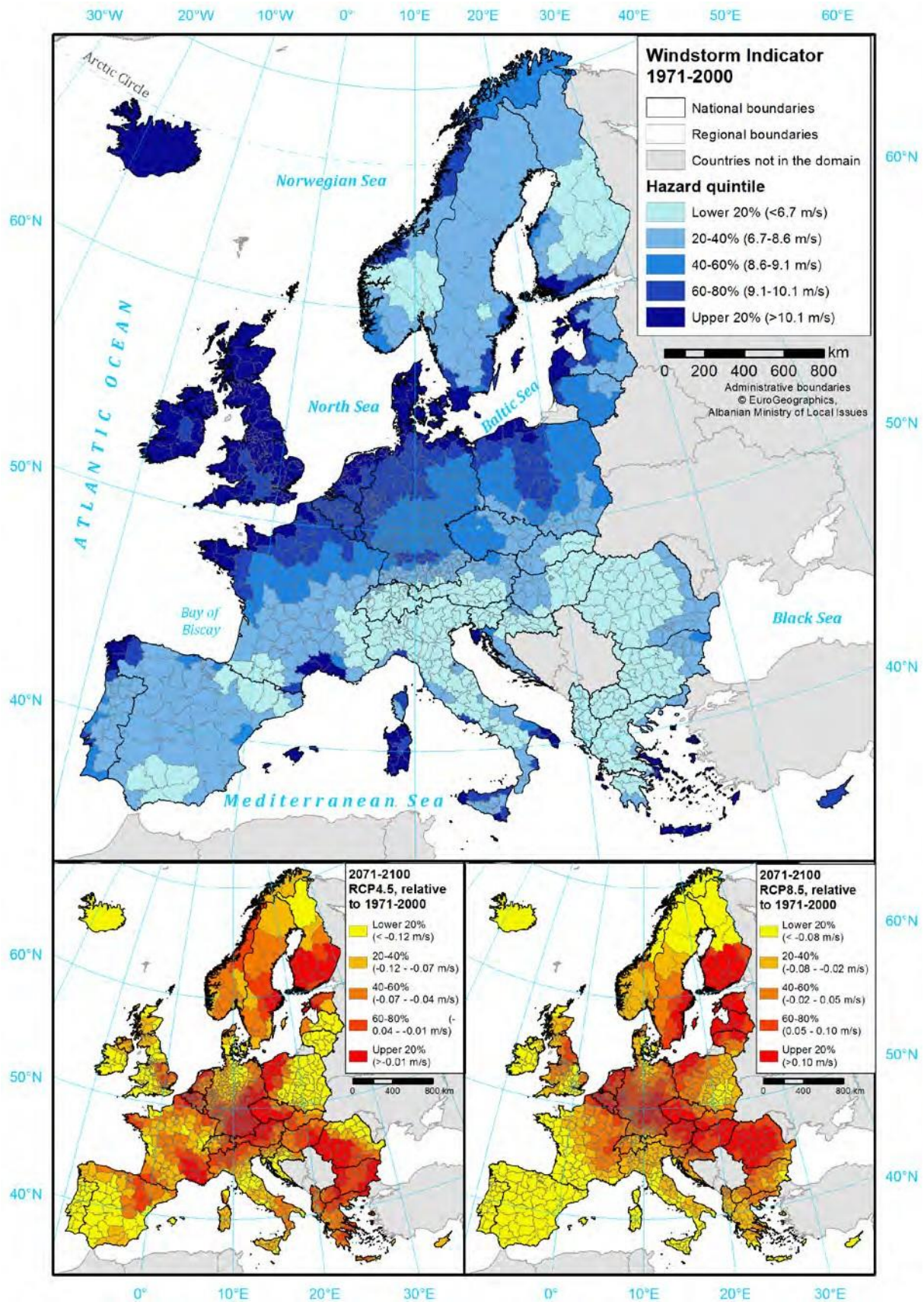

Figure A14. Quintiles of normalized windstorm hazard indicator at regional level for historical scenario (main map) and relative change (subtraction) between 2071–2100 and 1971–2000, in two scenarios.

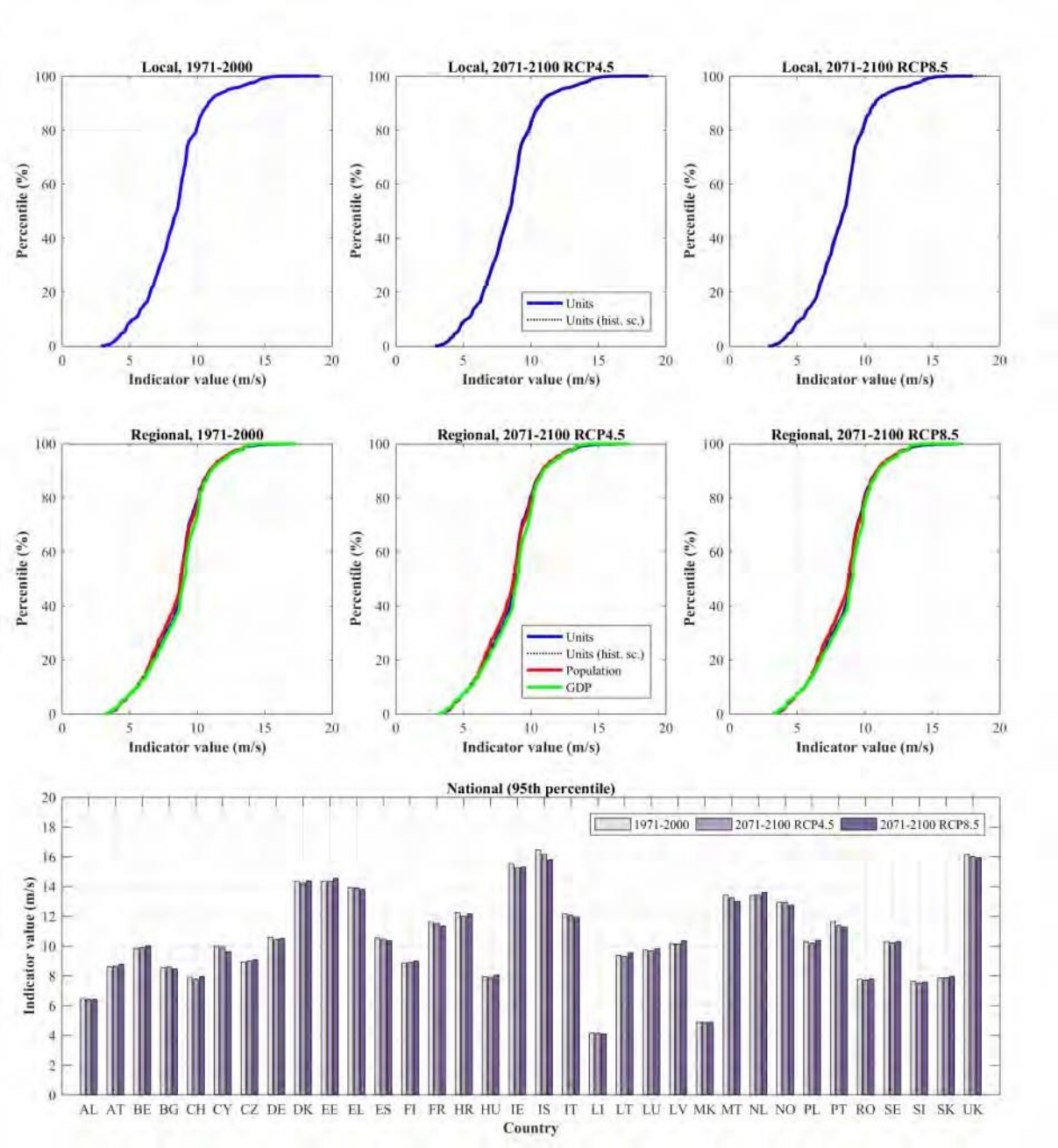

Figure A15. Normalized windstorm hazard indicator at local, regional and national level, by climate scenario. For country codes, see Table A4.

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 28.5 mm to 69.9 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 28.5 - 69.9 mm (historical climate) to 31.4 – 75.5(RCP4.5) and 33.5 – 79.7(RCP8.5).

The maximum intensities at the regional level increase from 69.1 (historical climate) to 74.2 (RCP4.5) and 80.8 (RCP8.5). At the national level, they increase from 117.5 (historical climate) to 131.0 (RCP4.5) and 143.5 (RCP8.5).

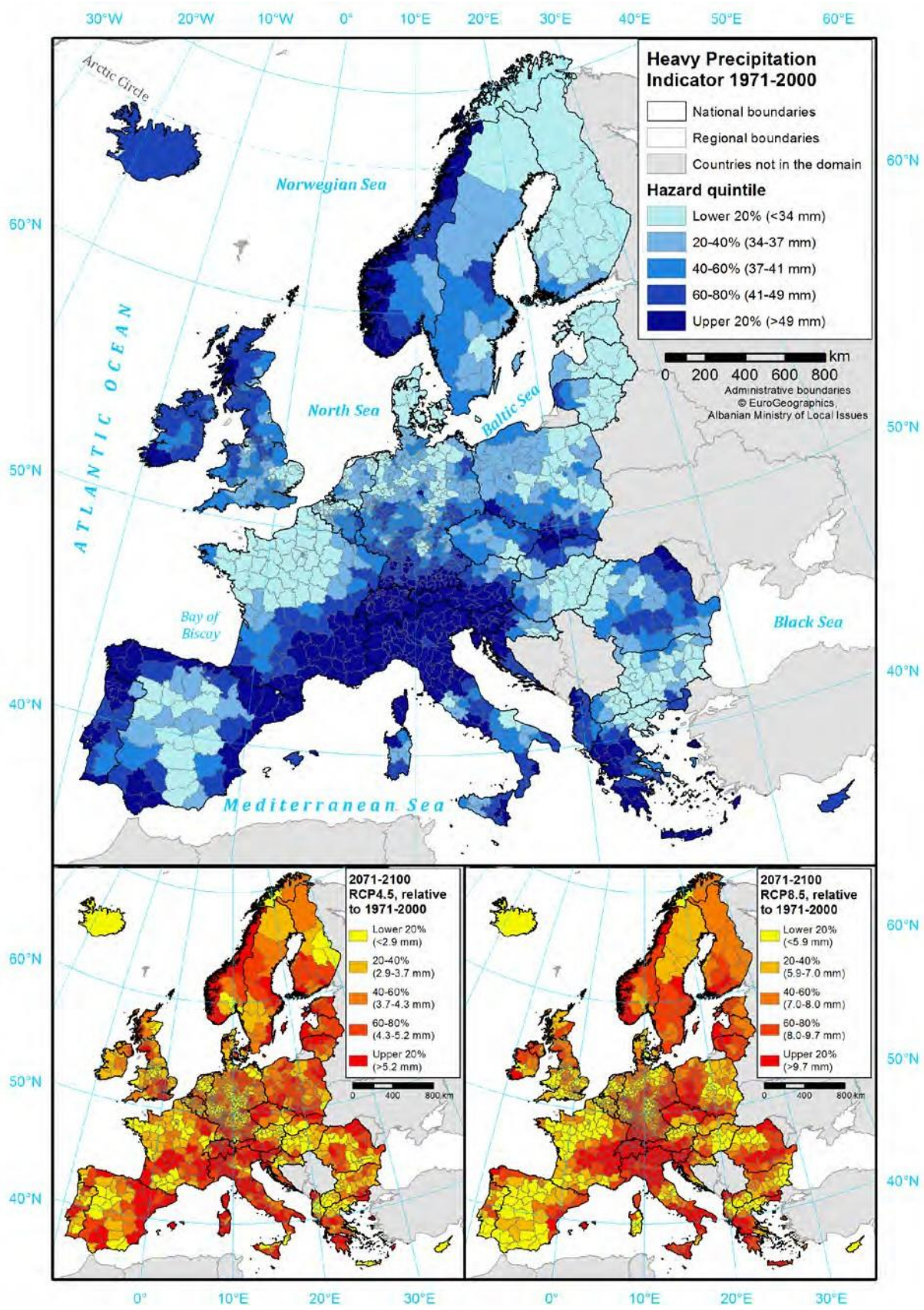

Figure A16. Quintiles of normalized heavy precipitation hazard indicator at regional level for historical scenario (main map) and relative change (subtraction) between 2071–2100 and 1971–2000, in two scenarios.

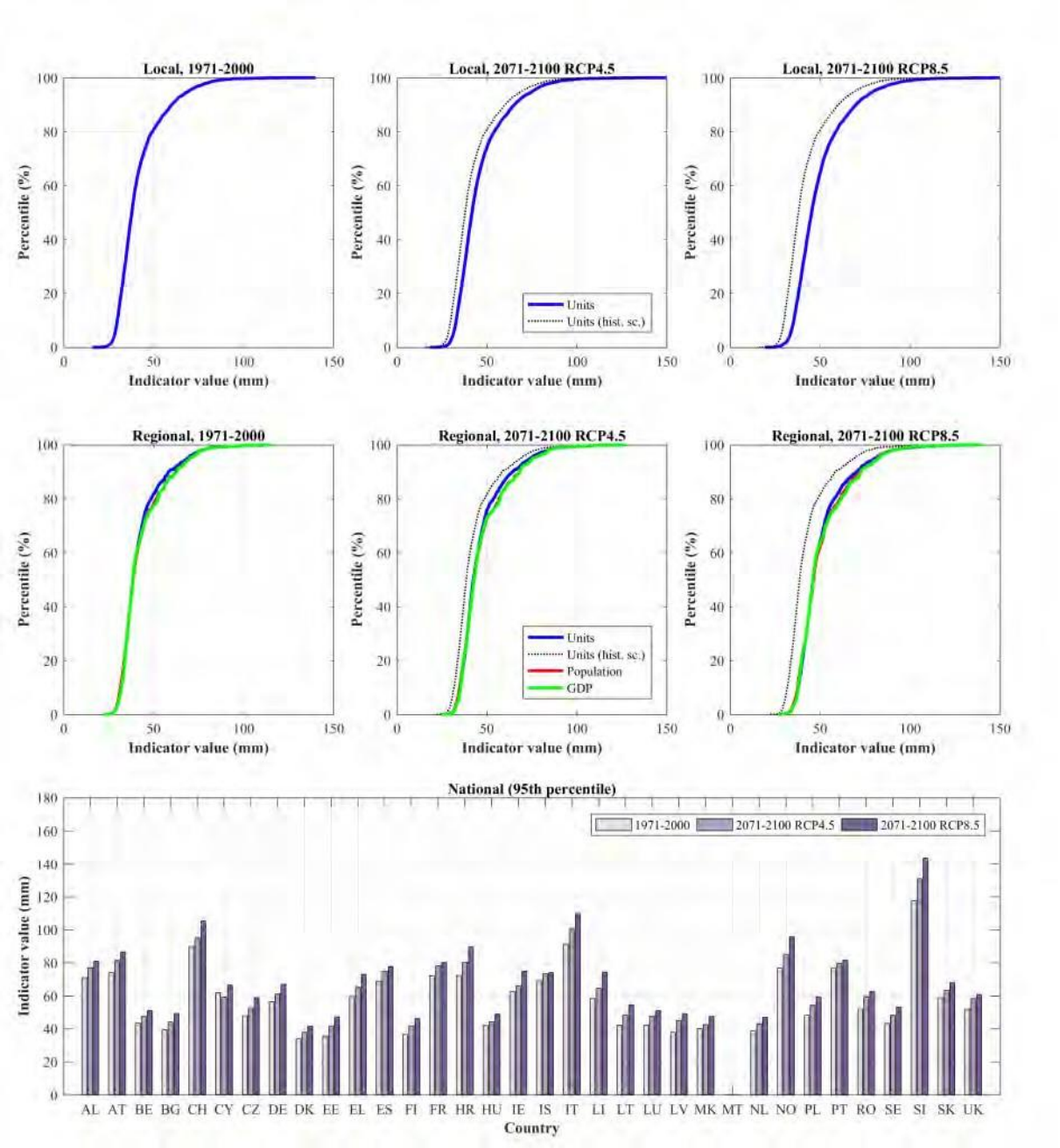

Figure A17. Normalized heavy precipitation hazard indicator at local, regional and national level, by climate scenario. Histograms only for units for which estimates were available. For country codes, see Table A4.

6 Data access

BRIGAID indicators of loading conditions at national, regional and local level are accessible through ArcGIS Online:
http://www.arcgis.com/home/item.html?id=312d18a14b524d6db594641342925a53

On this page, a summary of indicators and their definitions is provided together with a key to abbreviations used to display variables in the map. The map itself accessible by clicking on the BRIGAID logo (top-left corner), by clicking on “Open in Map Viewer” (top-right corner) or using a direct link:

http://www.arcgis.com/home/webmap/viewer.html?webmap=312d18a14b524d6db594641342925a53

The map opens with with an overview of Europe together with an example indicator graphicially represented at national level. When zooming in, the map will switch to regional units, and then local units.

Main functionalities of the map are shown in Fig. A18.

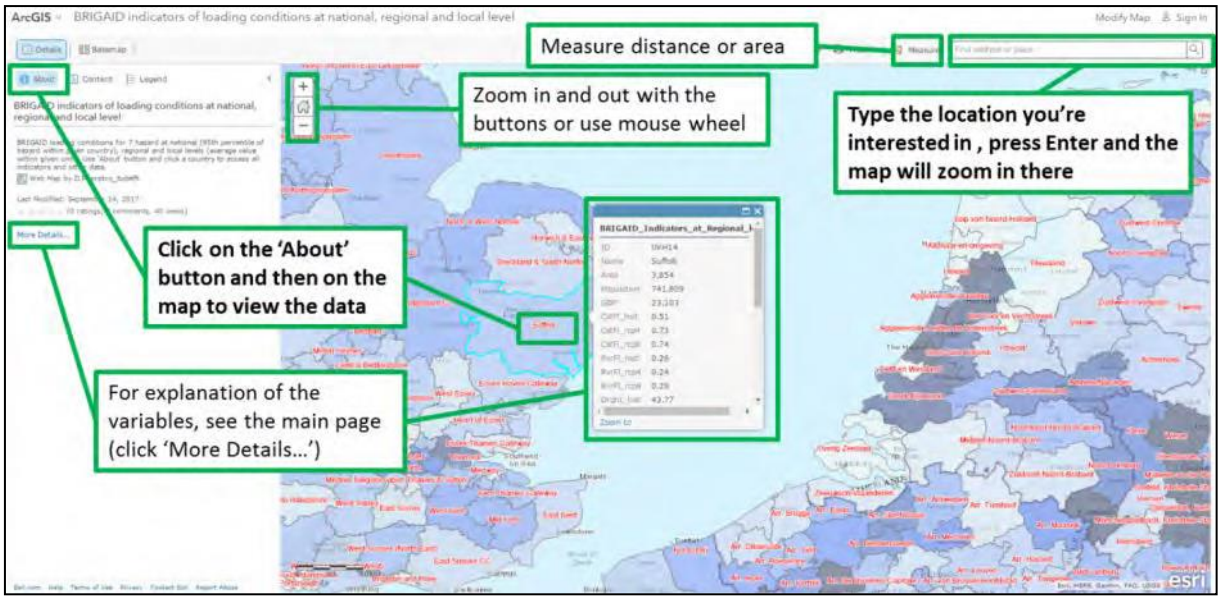

Figure A18. Map viewer of BRIGAID loading conditions.

The indicator that is presented in the map can be changed by the user; the procedure is simple and shown in Fig. A19 together with some other options of modifying the map.

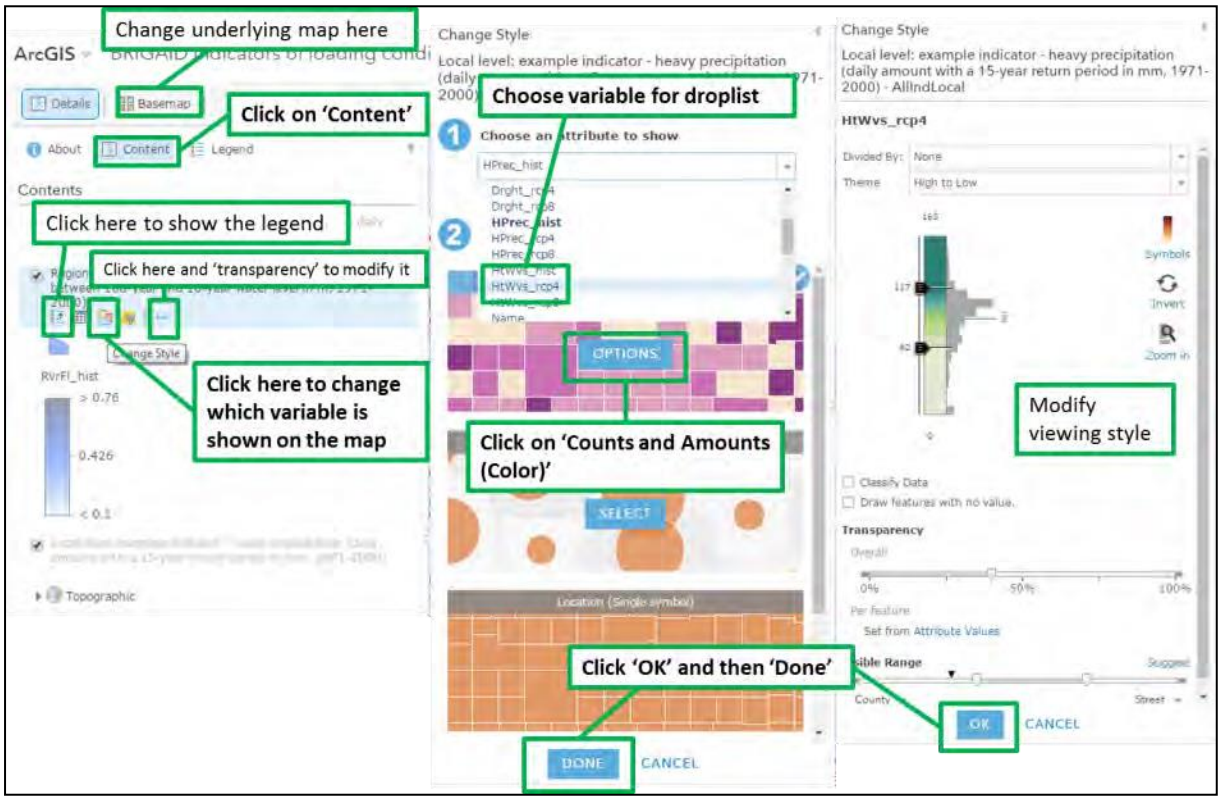

Figure A19. Modifying the map.

The map can be also printed using the 'Print' tool, next to the 'Measure' tool in the top bar.

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Appendix B. A Test and Implementation Framework (TIF) for Climate Adaptation Innovations: Tool Guidance Additional Guidelines for Technical Testing

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1 Introduction

This document is intended to guide climate adaptation innovators through interpreting the results to their self-assessment of the performance of their innovations using the BRIGAID Test and Implementation Framework (TIF) Tool. The TIF-Tool consists of nineteen (19) questions related to technical design, twenty-one (21) questions related to environmental impacts, twenty-five (25) questions related to sectoral impacts, and twenty-two (22) questions related to societal acceptance. These questions must be answered with yes, no, a specification, or n.a. (not applicable) and the answers are converted to a score. The Tool is designed to help innovators identify possible technical, environmental, sectoral, and societal concerns that their innovations may raise early on – and iteratively throughout the development – so that they may modify their designs and not become locked into those that are less likely to appeal to end users. The results and recommendations are summarized in a chart (Figure 1).

Many assessment question may serve as 'food for thought', or as topics to discuss with stakeholders or end-users. The TIF Tool does NOT provide a definitive assessment: it is a 'checklist' designed to help identify potential concerns so that innovators can then choose how - or whether - to respond to them.

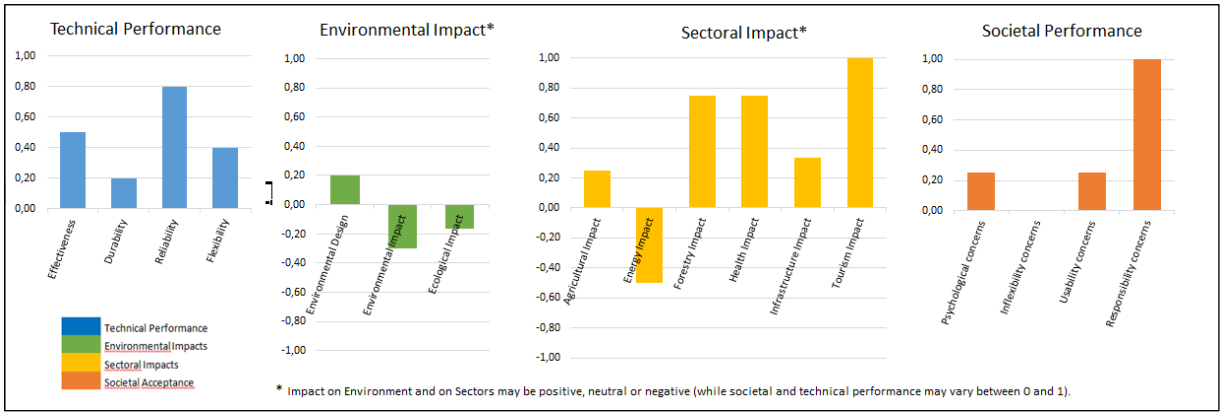


Figure B - 1 Summary of the results of the TIF-Tool

The Tool is meant to be applied by innovators at three 'stage-gates' – critical points in development at which innovators should pause to identify and address technical, environmental, sectoral and social, concerns. These 'stage-gates' refer to Technology Readiness Levels (TRLs) in the testing framework (see p. 10 and the TIF method document).

'Soft stage-gates' at which to apply the TIF Tool

Stage-gate 1: Apply the TIF Tool prior to validation in a laboratory setting

Stage-gate 2: Apply the TIF Tool prior to testing in an operational setting

Stage-gate 3: Apply the TIF Tool prior to deployment in the real world

The TIF Tool is an Excel spreadsheet with 6 tabs:

1. Navigation
2. Societal acceptance assessment
3. Technical performance assessment
4. Environmental impacts assessment
5. Sectoral impacts assessment
6. Summary of results

The initial navigation page introduces climate adaptation innovators to the layout of the TIF Tool before then presenting them with an innovation typology. This typology will help innovators to clearly identify the types of hazards their innovation is designed to protect against (be it directly or indirectly) and the type of adaptation their innovation is. Some environmental impacts assessment questions may not be applicable to 'social' forms of adaptation. However, all technical performance, sectoral impact assessment, and societal acceptance questions are applicable to all adaptations. Some (informational) innovations need to be combined with an additional measure that may have an impact (e.g. prescribed burning). Then the TIF Tool should be applied separately for this structural measure.

Note that the impact of an innovation on the environment and economic sectors can be positive, neutral or negative.

The TIF Tool and this TIF Tool Guidance document are accompaniments to the more detailed TIF Methodology document. Readers who are interested in the theoretical and methodological underpinnings of the Tool and Guidance should refer to the Methodology.

This document proceeds in the following sections by guiding innovators through the process of interpreting the results to their self-assessments of technical performance, environmental impacts, sectoral impacts, and societal acceptance.

2 Interpretation guidelines

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).

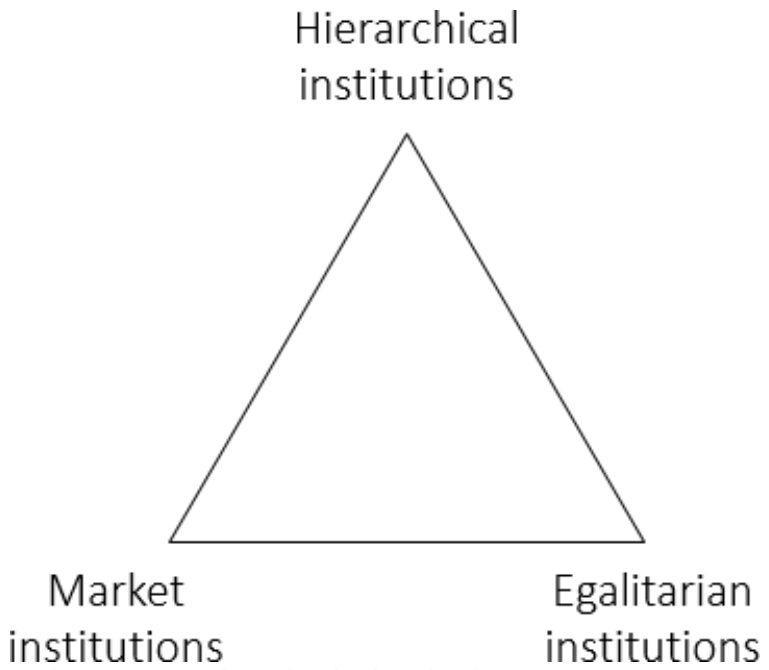


Figure B - 2: Three institutional cultures across Europe

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 favourable 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 Technical performance assessment

After completing the technical screening questions (Figure 2), innovators can refer to the interpretations provided in Table 1 below. Using the answers to the questions in the Excel (and the associated scores (range 0 to 1) per indicator), innovators should be able to determine whether adjustments to their design are needed or warranted.

1	**Technical Performance Assessment**	NB: all questions are applicable for all type of innovations (please fill in an answer for each question)!	
Answer the following questions by writing Yes or No in the corresponding cells.			**Yes or No?**
1	Does the innovation provide significant technical advantage(s) relative to traditional/conventional measures?		No
2	Does your innovation physically prevent a hazard from occurring?		No
3	Does your innovation require combination with other interventions and/or activities in order to reduce risk (e.g, flood warning system in combination with a flood barrier or a fire warning system in combination with controlled burning)?		No
4	Will the innovation require additional testing and/or substantial upgrades when considering future hazard conditions (i.e., considering climate change)?		No
5	Is the lifetime of the innovation limited by climate change? (i.e., will climate change affect the estimated life(time) of the innovation?)		Yes
6	Does the innovation require frequent inspection and maintainence to reach its intended lifetime?		No
7	Are the materials or software needed for maintanence and/or repair easily obtained and can they be integrated by the end-user?		No
8	Is the innovation designed to be used repetitively or continuously operated over its lifetime?		No
9	Can the innovation be operated without repair and/or replacement of components during a hazard event?		No
10	Does the innovation exhibit vulnerabilities during testing and/or demonstration (e.g., structural: sliding or rotation, or technological: errors)?		No
11	Is there a critical component in the innovation's structural or technological design that could lead to catastrophic failure?		No
12	Does your innovation rely on the delivery of services or materials (e.g., structural components, data) outside of your control to be successfully operated during a hazard event?		Yes
13	Does your innovation require the execution of tasks by humans to be successfully operated during a hazard event?		No
14	Can the vulnerability of your innovation to human error be easily reduced through improvements in operational protocols and/or end-user training?		Yes
15	Is the innovation modular (opposite: monolithic) and can it be easily installed or applied at different sites across Europe without adjustment?		No
16	Does the innovation require additional testing and/or substantial upgrades (e.g., new components) if used at different sites across Europe?		Yes
17	Will the size of the market for the innovation (in Europe) will significantly decrease (>50%) due to future hazard conditions (i.e., considering climate change)?		No
18	Have relevant end-users have been identified and involved in formulating design specifications?		Yes
19	Does the design of the innovation deliberately aim for advantages derived from multi-functionality (e.g., reduction of carbon emissions or enhanced recreational activities)?		No

Figure B - 3: Tab Technical performance

The questions are intended to assess sets of issues related to the indicators described in the TIF method document: effectiveness, durability, reliability, and exploitability. Depending on how the innovator responds to these questions, their innovation may be more marketable and have a more effective technical design or a design associated with some technical concerns. The table includes information and recommendations on how to alleviate those concerns and improve the performance of their innovation and its technical readiness.

Table 1: Responding to specific areas of technical concern (the numbers refer to the questions in the tab Technical Performance)

1	If your innovation does not provide significant technical advantage(s) relative to conventional measures, then it is likely to raise concerns about its technical design. Innovators should strive to generate designs which fill an existing gap or fulfil a perceived public (or private) need.
2	If your innovation does not physically prevent a hazard from occurring, it may not be able to fully mitigate risk by itself. Based on the definition of technical effectiveness used by BRIGAID, an innovation which completely reduces risk will always score higher in terms of its technical effectiveness. To determine the effectiveness of your innovation, compare your innovation against similar or conventional technologies to determine whether it provides significant advantages in terms of risk reduction.

3 If your innovation must be implemented or operated in combination with other interventions to reduce risk, this may raise some technical concerns. Innovations which are not stand-alone require that an end-user already have access to other interventions or the ability to acquire them. Furthermore, the ability of your innovation to reduce risk will be dependent on the successful operation and effectiveness of both interventions (see reliability concerns below).

4 If you have not considered future hazard conditions or anticipate that your innovation may require additional testing and/or substantial upgrades to be effective under future climate conditions, this may raise technical concerns. Innovators can refer to the current and future hazard maps provided in the TIF methods document to determine future conditions in their targeted end-user environment.

5 If the life of your innovation is determined by climate change, this may raise some technical concerns. An innovator should consider the implementation context of their innovation; if an innovation is designed to be a permanent solution, the innovator should strive to design their innovation to withstand the effects of climate change on the relevant hazard.

6 If your innovation requires frequent inspection and maintenance to reach its intended lifetime, this may raise concerns about the innovation's durability. Frequent inspection and maintenance is typically associated with higher costs over the innovations' lifetime and thus will lower its cost-benefit. It may also raise potential concerns about the innovation's reliability during an event.

7 If the materials or software needed for maintenance or repair of your innovation are difficult to obtain, this is likely to raise durability concerns. Innovators should consider incorporating materials that can be easily (and cost-effectively) obtained in case of emergency maintenance or repair.

8 If your innovation is not designed to be used repetitively and is only single-use, this may raise durability concerns. Innovations which can be used repetitively (or continuously) over their lifetime can be expected to have a higher cost-benefit over their lifetime.

9 If your innovation requires repair or replacement of components during the hazard event, this may raise some technical concerns. Innovations which are designed to fully withstand the hazard without replacement will score higher in terms of their reliability.

10 If your innovation exhibits vulnerabilities during testing, this could lead to low technical reliability. The innovation should be designed to withstand the hazard and the innovator should provide a level of safety (e.g., in the form of probability of failure or a safety factor) associated with the innovation.

11 If there is a critical component in the design of the innovation that could lead to catastrophic failure, this will raise reliability concerns. Innovators should consider how to minimize or remove the potential for catastrophic failure by optimizing the design of the innovation.

12 If your innovation relies on the delivery of services or materials to be successfully operated during a hazard event, this may raise reliability concerns. Innovators should consider this in the design of their innovation and work with end-users to reduce such vulnerabilities.

13 If your innovation requires on the execution of tasks by humans to be successfully operated during a hazard event, this may raise reliability concerns.

Innovators should strive to minimize the potential for failure due to human error (e.g., by optimizing the operation and maintenance protocols or requiring execution by trained experts).

14 If the innovation's vulnerability to human error cannot be easily reduced, this may raise reliability concerns. Innovators should consider how to remove potential for human error in the design of their innovation (e.g., by automating processes or removing human decision points).

15 A monolithic innovation raises some flexibility concerns as it may be difficult to deploy or build in other locations than the original implementation context. In contrast, modular innovations can be more easily be marketed at all locations where the hazard is present. Furthermore, as in the case of some mobile innovations, some modular innovations can be used by a single end-user at multiple locations during different hazard events, making them potentially more attractive than monolithic innovations.

16 An innovation's flexibility will increase, the more easily it can be adapted to different implementation contexts. If your innovation requires additional testing or substantial upgrades to be marketed or used at different sites in Europe, this may negatively affect its flexibility.

17 If the size of the market for your innovation will be substantially reduced by climate change, this may raise some flexibility concerns. Innovators should consider the impacts of climate change on the size of their market in the design of their innovations.

18 If relevant end-users or implementation contexts have not yet been identified, this may raise some flexibility concerns. Innovators should strive to identify implementation contexts and develop contact to potential end-users during the early stages of the design of their innovation.

19 Multi-functional innovations are arguably more flexibility. For example, innovations which have co- or secondary-benefits (e.g., innovations which increase energy production or decrease an end-user's reliance on fossil fuels) or perform a secondary function during non-hazard times (e.g., have recreational value or boost tourism) have higher exploitation potential than those which only perform a single function.

While not all of these issues require the innovator to take action (and some may not be relevant for a given implementation context), they are intended to help increase the innovator's awareness of potential technical concerns. By scoring themselves against conventional measures and other innovations which promise the same or similar benefits, the innovator will gain perspective of how their innovation may perform in the European market in the context of its technical design

3.1 Technical Readiness Level (TRL) scales

Based on the answers to the questions listed in Table 2 above, an innovator may choose to make changes to the original design of the innovation. An adjusted TRL Scale which lists key tasks related to the readiness of climate adaptation innovations has been included in a separate spreadsheet to help guide innovators through R&D. When testing, an innovator should refer to the checklist to assess the technical readiness of their innovation. Note that this TRL Scale assumes that when entering BRIGAID an innovator is at or has already achieved TRL 4 (prototype) and is striving to reach TRL 8 (demonstration).

Significant changes to the original design of the innovation, based on the answers to the societal, technical, or environmental questions, or because significant negative impacts are foreseen based on the questions related to sectoral impacts, may require that the innovator returns to TRL 1-3 or an earlier testing phase (e.g., laboratory testing). An innovator should be weary of proceeding too far in the TRL Scale and becoming entrenched before screening their innovation using the TIF Toolbox.

For more detailed guidance related to testing in each phase, innovators are encouraged to refer to the methods document and references included therein.

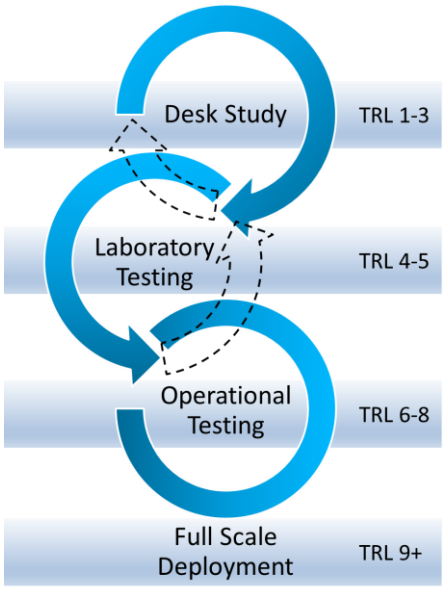


Figure B - 4: Conceptual model showing the four testing phases based on TRL definitions (see TIF method document)

4 Environmental impacts assessment

Climate adaptation innovations are designed to mitigate safety risks (for people, properties or infrastructure), but can also affect their environment (including nature and ecosystems). A positive impact of an innovation on the environment (such as an increase in nature area, or reduced energy demand) may lead to support for the development, speed up the market uptake and the implementation of your innovation. It may even help to find funding to further develop your innovation. In order to get insight in the potential impact of an innovation, the foreseen impacts has to be compared with the present situation (i.e., reference situation, which may already be altered by previous adaptation measures) 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 will be highly dependent on the geographic location.

> 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. The construction or the operation of an innovation may result in a temporary (short or long term) disturbance of the environment. Some impacts may be reversible with additional efforts when the innovation would be removed. Other impacts on the environment may be permanent (e.g. when some species disappear from a location, they may never return).

If it is clear that an innovation will have significant effects on the environment (e.g. the construction of a dike or a water retention area), or that implementation of innovation will need substantial space (that is for instance, currently designated as nature area), than there is likely a legal requirement for an Environmental Impact Assessment (EIA). In this EIA the impact of the plan or project must be compared with some alternative solutions. An EIA normally requires a substantial amount of detailed information on several topics (amongst other on species and habitats), supplied and analysed by experts. Information on EU's laws on Environmental Impact Assessment of major projects and of public plans and programs together with other related information can be found on www.ec.europa.eu/environment/eia. Furthermore, each EU country provides its own information on national EIA obligations (see national websites on Environmental Impact Assessment).

Regarding the impact on the environment, sustainability forms an important ambition for climate change innovation. Sustainable innovations are not harmful to the environment nor depleting natural resources, and support long-term ecological balance. Sustainability can be described as the endurance of systems and processes. Healthy ecosystems and environments are necessary to the survival of humans and other organisms.

After completing the environmental screening questions (Figure 4), innovators can refer to the interpretations provided in the next section.

3.1	Environmental Design	
3.1.1	Does the innovation deliberately use ecosystems and their services, or mimic or preserve natural processes? (A) Yes (B) No, and the innovation may hinder natural processes or services provided by ecosystems, (C) No, but the innovation does not affect the ecosystems present nor natural processes	A
3.1.2	How does the change in footprint (area) required for implementation on-site compare to conventional measures or the present situation? (A) Increase space required (B) Decrease space required (C) No Impact on space required	A
3.1.3	How does the construction or operation of the innovation affect the quantity of greenhouse gases in the environment (e.g., as CO_2 or CH_4)? (A) Increase (B) Decrease (C) No Impact	A
3.1.4	Is the innovation made from recycled or recycable materials? (A) Yes (B) No, it is made of non-recycable materials (C) Partly	A
3.1.5	Does the innovation include specific design features or components which preserve or enhance ecosystem services? (A) Yes (B) No, and the innovation may hinder natural processes or services provided by ecosystems (C) No, but the innovation does not affect the ecosystems present nor natural processes	A

3.2	Environmental Impact	
3.2.1	How does the innovation impact the quality of surface water? (A) Improve (B) Worsen (C) No Impact	A
3.2.2	How does the innovation impact the quantity of available surface water? (A) Increase (B) Decrease (C) No Impact	C
3.2.3	How does the innovation impact the quality of ground water? (A) Improve (B) Worsen (C) No Impact	A
3.2.4	How does the innovation impact the quantity of available ground water? (A) Increase (B) Decrease (C) No Impact	B
3.2.5	How does the innovation impact the quality of the sea water? (A) Improve (B) Worsen (C) No Impact	B
3.2.6	How does the innovation impact soil quality? (A) Improve (B) Worsen (C) No Impact	B
3.2.7	How does the innovation impact air quality? (A) Improve (B) Worsen (C) No Impact	B
3.2.8	Does the implementation (or construction) of the innovation generate debris? (A) Yes (B) Debris can even be stored or captured by the innovation (C) No	A
3.2.9	Does the implementation (or construction) of the innovation generate noise or vibration? (A) Yes (B) It even dampens noise (C) No	A
3.2.10	How does the innovation impact landscape quality? (A) Improve (B) Worsen (C) No Impact	A

3.3	Ecological Impact	
3.3.1	How does the innovation impact the spatial extent of protected nature area? (A) Increase (B) Decrease (C) No Impact	B
3.3.2	How does the innovation impact the quality of protected habitats? (A) Improve (B) Worsen (C) No Impact	A
3.3.3	How does the innovation impact the number protected species (e.g., birds, vegetation, fish, mammals)? (A) Increase (B) Decrease (C) No Impact	A
3.3.4	How does the innovation impact the spatial extent of non-protected nature area? (A) Increase (B) Decrease (C) No Impact	B
3.3.5	How does the innovation impact the quality of non-protected habitats? (A) Improve (B) Worsen (C) No Impact	B
3.3.6	How does the innovation impact the number non-protected species (e.g., birds, vegetation, fish, mammals)? (A) Increase (B) Decrease (C) No Impact	C

Figure B - 5: Tab Environmental impact

Explanation questions on environmental impacts

4.1 Environmental Design

1.1.1 Nature-based Solutions: A special type of innovative adaptation measures (with an increasing interest of e.g. the European Commission) are Nature-based Solutions. They deliberately use ecosystems and the services they provide, and/or natural processes (like water retention, water storage, buffering of floods, wave damping, changing wildfire conditions (e.g. by removing burnable material), changing soil conditions, providing shade etc.) to address societal challenges such as climate change or natural disasters. Nature-based Solutions are often used in conjunction with other types of interventions.

4.1.1 Areal Footprint: the physical implementation of the innovation may require space at its implementation location that is currently used for other purposes. This may result in resistance.

4.1.2 Carbon Footprint: the construction, transportation to its implementation location, and/or application of the innovation may result in additional CO2 emissions compared with the current situation. The use of local materials may reduce transportation, and subsequently the amount of carbon dioxide released. Implementation may be favoured if an innovations forms a sink for carbon dioxide (e.g. because the innovation increases permanent vegetation development that could store carbon dioxide).

4.1.3 Resource Footprint: recycling and recyclability fits in the Circular Economy concept and in the Cradle to Cradle concept. A Circular Economy is a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling. Cradle to Cradle pertains a "closed loop" approach to production processes, where waste forms a resource for production. The innovation is made of recyclable materials.

4.1.4 Footprint on the Services provided by the natural Ecosystem: The natural environment offers besides its intrinsic value, a broad range of benefits for human beings, such as the provision of products (e.g. food, fibres, wood, fresh water,

medicines), regulation of temperature, nutrients, waste, water, and greenhouse gasses, supporting services, such as nutrient cycles and crop pollinations, and providing cultural and amenity values (e.g. recreation, tourism, inspiration, spiritual). These benefits are called ecosystem services. An innovation may affect these ecosystem services provided by the natural environment.

4.2 Environmental Impact

Environmental quality is a set of properties and characteristics of the environment (water, soil and air). It forms a measure of the condition of the environment. In the EU the environmental quality is protected from pollution by several EU and national regulations and standards and it is monitored by governmental agencies. Pollution can be defined as the addition of any substance (solid, liquid, or gas) or any form of energy (such as heat, sound, or radioactivity) to the environment at a rate faster than it can be dispersed, diluted, decomposed, recycled, or stored in some harmless form.

4.2.1 Surface Water Quality: the construction, implementation, and/or application of the innovation may affect aquatic ecosystems, drink water production, health situation, availability of water for irrigation, fish production, tourism, etc. by producing pollutants like nutrients, oil spilling, chemicals, salt, plastics, or an increase in water temperature, etc.

4.2.2 Surface Water Quantity: the construction, implementation, and/or application of the innovation may also affect the water quantity by using water, streamlining extreme discharges, buffer and/or store extreme discharges.

4.2.3 Ground Water Quality: an innovation may affect ground water quality by producing pollutants like nutrients, oil spilling, chemicals, salt, etc.

4.2.4 Ground Water Quantity: an innovation may also affect ground water quantity by using water, affecting the ground water level, retention of freshwater, etc.

4.2.5 Sea Water Quality: the construction, implementation, and application of an innovation may affect sea water quality by releasing pollutants like nutrients, oil spilling, chemicals, plastics,which in return may result in an impact on marine ecosystems, fish production, tourism, health situation, etc.

4.2.6 Soil Quality: an innovation may affect soil properties such as nutrient status, salinity, and water holding capacity. These are important for terrestrial ecosystems, agricultural and forestry production, health situation, etc. Furthermore, soil support buildings and roads.

4.2.7 Air Quality: air quality is important for the health situation, and air pollution can result in diseases, allergic reactions and even deaths. Furthermore, air pollution may affect buildings. An innovation may (temporarily or permanently) produce air pollutants like chemicals, particulates (e.g. dust), biological molecules, etc. (NB Carbon Dioxide is already included in the Carbon Footprint question).

4.2.8 Debris: an innovation may result in debris. Some debris is easily recyclable, while other debris may need further processing or must be stored.

4.2.9 Noise: during construction or implementation, the innovation may result in temporarily noise. However, some innovations may result in permanent noise during application.

1.1.2 Landscape Quality: An innovation may affect the visible features (like hydrological or

ecological aspects, settlement patterns, cultural history, scenic characteristics, or land use patterns) of an area of land, its landforms, and how they integrate with natural or other man-made features.

4.3 Ecological Impact

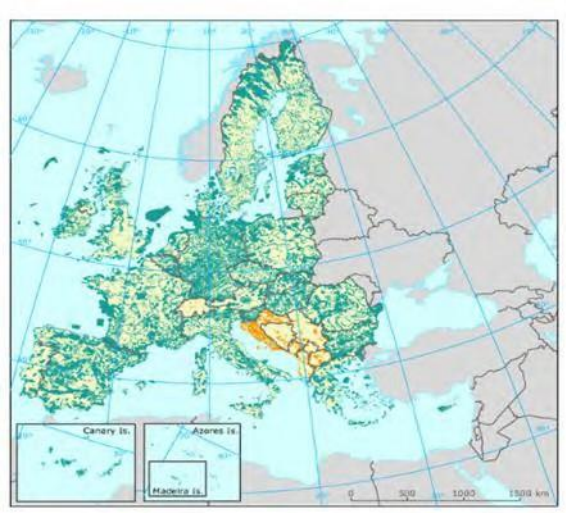
The conservation of biodiversity, restoration of nature, and greening the economy and the society as a whole to make them more sustainable are important ambitions of the EU. 'Green' aspects will certainly favour implementation of the innovation.

4.3.1 Nature Conservation: innovations may result in an impact on the size of protected nature area. Such an innovation will certainly encounter legal resistance, and probably lead to the requirement of detailed ecological analysis and the obligation to compensate the affected nature values by developing a new nature area.

Due to its physical geography and the long history of cultural development, Europe harbours 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).

Several of these 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.

Maps and information available on e.g. http://natura2000.eea.europa.eu/# provide a first impression of the nature values present.



4.3.2 Nature Conservation: innovations may result in an impact on the quality of habitats in the protected nature area, and cause a shift from one habitat towards another habitat.

4.3.3 Protected species: Many European wildlife species (birds, vegetation, fish, mammals, other animals) are increasingly in danger. Therefore, the EU aims to protect all species facing particular threats by e.g. the EU Habitats (Habitats Directive 92/43/EEC) and Birds Directive (Directive 2009/147/EC), in which over 1.000 animal and plant species are mentioned. NB: Because of the diversity and complexity of ecosystems, the help of experts may be needed to identify if and which protected species are present at a certain location, and to assess how the innovation may affect these species.

4.3.4 Non-protected nature (size): Not all nature in Europe is protected by international (Natura 2000 area) or national legislation (e.g.as designated nature area, nature reserve, national park, or protected landscape). Implementation of innovations in these areas may expect no legal hurdles forthcoming from nature conservation agreement and less resistance than in protected nature areas. If an innovation would result in an increase of nature, then it will probably meet societal support.

4.3.5 Quality of the non-protected habitats: Ex-ante identified positive co-benefits of the innovations for non-protected habitats could result in a swift implementation of the innovation.

4.3.6 Impact on the number of non-protected species: an increase in the number or the variety of species could result in support from the general public and the government.

5 Sectoral impacts assessment

Climate Adaptation Innovations are designed to directly offset the effects of climate change in socio-economic sectors like agriculture, energy, forestry, health, infrastructure or tourism.

However, they may also have (unintended or unforeseen) co-benefits or trade-offs in others. All impacts must be compared with the present situation (i.e., reference situation) and to the business as usual approach over the short and long-term.

> 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. The construction or the operation of an innovation may result in a temporary (short or long term) disturbance of socio-economic sector. Some impacts may be reversible with additional efforts when the innovation would be removed, while other impacts may be permanent.

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 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.

4.1	**Agriculture**	
4.1.1	How does the innovation impact the total area available for agricultural production? (A) Increase (B) Decrease (C) No Impact	A
4.1.2	How does the innovation impact agricultural production conditions (e.g., by increasing soil quality or water availability)? (A) Improve (B) Worsen (C) No Impact	A
4.1.3	How does the innovation impact the variety of agricultural products (e.g., crops, dairy, meat, fruit, fish, aquaculture) that can be produced or are available? (A) Increase (B) Decrease (C) No Impact	B
4.1.4	How does the innovation impact the total yield of one or more agricultural products? (A) Increase (B) Decrease (C) No Impact	C
4.2	**Energy**	
4.2.1	How does the innovation impact the energy production capacity (e.g., by generating energy or increasing energy distribution)? (A) Increase (B) Decrease (C) No Impact	B
4.2.2	How does the innovation impact the reliability of energy production (e.g. by improving cooling water conditions for energy plants)? (A) Increase (B) Decrease (C) No Impact	B
4.2.3	How does the innovation impact the efficiency of energy production? (A) Increase (B) Decrease (C) No Impact	B
4.2.4	How does the innovation impact the carbon footprint of the end-user? (A) Increase (B) Decrease (C) No Impact	B
4.3	**Forestry**	
4.3.1	How does the innovation impact the total area available for wood production (including timber and biomass)? (A) Increase (B) Decrease (C) No Impact	A
4.3.2	How does the innovation impact wood production conditions (e.g., by increasing forest resilience or water availability)? (A) Improve (B) Worsen (C) No Impact	A
4.3.3	How does the innovation impact the total area available for non-wood production (including cork, fruit, honey, mushrooms, pastures, game and fishing)? (A) Increase (B) Decrease (C) No Impact	A
4.3.4	How does the innovation impact non-wood production conditions (e.g., by increasing forest resilience or water availability)? (A) Improve (B) Worsen (C) No Impact	C
4.4	**Health**	
4.4.1	How does the innovation impact the number of fatalities in the area exposed to the hazard? (A) Increase (B) Decrease (C) No Impact	B
4.4.2	How does the innovation impact the number of people affected by the hazard in their physical health (i.e., number of people injured)? (A) Increase (B) Decrease (C) No Impact	B
4.4.3	How does the innovation impact the number of people affected by the hazard in their mental/psycho-social health? (A) Increase (B) Decrease (C) No Impact	B
4.4.4	Does the innovation emit or release chemicals or products that are harmful to humans? (A) Yes (B) It can even capture harmful substances (like small particles) (C) No impact on concentration of chemicals or harmful products	C
4.5	**Infrastructure**	
4.5.1	How does the innovation impact the quality of the built environment (I.e., residential, commercial, and industrial)? (A) Improve (B) Worsen (C) No Impact	B
4.5.2	How does the innovation impact the total area available for urban development? (A) Increase (B) Decrease (C) No Impact	A
4.5.3	How does the innovation impact the capacity of existing transportation systems (e.g., roads, railways, waterways, and airports) or create new capacities? (A) Increase (B) Decrease (C) No Impact	A
4.5.4	How does the innovation impact the reliability of existing transportation systems (e.g., roads, railways, waterways, and airports)? (A) Increase (B) Decrease (C) No Impact	B
4.5.5	How does the innovation impact the transport capacity of critical infrastructure networks (e.g., power, water, waste management)? (A) Increase (B) Decrease (C) No Impact	A
4.5.6	How does the innovation impact the reliability of critical infrastructure networks (e.g., power, water, waste management)? (A) Increase (B) Decrease (C) No Impact	A
4.6	**Tourism**	
4.6.1	How does the innovation impact the total area available for recreational activities? (A) Increase (B) Decrease (C) No Impact	A
4.6.2	How does the innovation impact the attractiveness of the area for recreational activities? (A) Increase (B) Decrease (C) No Impact	A
4.6.3	How does the innovation impact the length of the tourist season? (A) Increase (B) Decrease (C) No Impact	A

Figure B - 6: Tab Sectoral Impact

After completing the sectoral screening questions (Figure 5), innovators can refer to the interpretations provided in the next sections.

5.1 Agriculture

5.1.1 If an innovation needs area that is currently used for agricultural production, then its implementation may lead to resistance among farmers, and implementation could lead to an obligation to compensate the affected landowners.

5.1.2 If your innovation could improve local agricultural production conditions e.g. by increasing freshwater availability, improving the groundwater table, preventing damage by temporal flooding, or increasing the soil quality, then your innovation will probably meet support from farmers.

5.1.3 If your innovation could lead to an increase in the variety of agricultural products that could be produced, then this may result in interest of farmers or consumers for your innovation. However, when new products do require new expertise or additional investments, such interest may be very modest, or result in a demand for agricultural innovation.

5.1.4 If your innovation results in increased yield, e.g. by improving local production conditions, or improving harvest conditions or methods, then your innovation probably will meet support from local farmers.

5.2 Energy

5.2.1 If your innovation generates energy (e.g. a device that harvest wave energy) or sources for energy production (e.g. biofuel), or offers space for energy production (e.g. wind turbines or solar panels), then it probably meet support from the energy sector, the government, and the general public.

5.2.2 Research has shown that climate change may affect power generation by decreasing water availability and increasing ambient air and water temperature, which reduces the efficiency in cooling. If your innovation improves cooling water conditions for energy plants, then it will probably meet support from the energy sector and the government.

5.2.3 If your innovation improves the efficiency of energy production, then it will probably meet support from the energy sector and the government.

5.2.4 The energy sector is the largest contributor to global GHG emissions. If the innovation results in less greenhouse gas emission by the energy sector than in the current situation, or forms a sink for carbon dioxide, then it probably will be meets societal support and support from the energy sector.

5.3 Forestry

5.3.1 If an innovation needs area that is currently used for wood production, then its implementation may lead to concern from the forestry sector, and implementation could lead to an obligation to compensate the affected wood producers.

5.3.2 If your innovation would lead to improved resilience of a forest against climate change (e.g. by improving surface water management conditions, improving the groundwater table, preventing damage by temporal flooding, or increasing the soil

quality) then your innovation probably result in support from the forestry sector.

5.3.3 If your innovation cost area that is currently in use for non-wood productions such as cork, fruit, hone, mushrooms, pastures, game, or fish, then it will meet concern from forest owners and users, and implementation could lead to an obligation to compensate the affected non-wood producers.

5.3.4 If your innovation would result in improved production conditions for non-wood products such as cork, fruit, hone, mushrooms, pastures, game, or fish, then your innovation probably result in low resistance or even in support from forest owners and users.

5.4 Health

5.4.1 If your innovation could decrease the potential numbers of fatalities of climate change related hazards (e.g. by reducing the risk of drowning during a flood, by a cooling effect during heat waves, by improving air and or water quality during heat waves), then it will probably be supported by the health sector, the government, and the general public.

5.4.2 If your innovation could reduce the impact of hazards on the physical health of affected people (e.g. by reducing the impacts of floods, by a cooling effect during heat waves, by improving air and or water quality during heat waves), then it will it will probably be supported by the health sector and the general public.

5.4.3 Climate change related hazard may result in stressful conditions for human beings, such as a high night temperature during heat waves (which may impact sleep). If your innovation could reduce the impact of climate related hazards (e.g. by reducing the urban heat effect due to the cooling effect of vegetation, the urban wind pattern, or water bodies) on the mental/psycho-social health of affected people, then it will it will probably not meet resistance by the health sector or the general public.

5.4.4 If your innovation emits or release chemicals or products that are harmful, then this may result in resistance, and it is recommended to adjust the design in order to prevent or reduce the emittance of these chemicals.

5.5 Infrastructure

5.5.1 If the innovation improves the quality of the built environment (e.g. by a urban design that deliberately uses trees to provide shade, or green roofs or walls to cool buildings or to store rainwater, or to develop green water retention areas), then it will probably meet less resistance, or even support from local residents or the local government.

5.5.2 If the innovation needs area that is currently in use for urban development, then it will probably meet resistance from the infrastructural sector, and implementation could lead to the appointment of another area for urban development, or an obligation to compensate the affected stakeholders.

5.5.3 If the innovation does increase existing transportation capacity or create new transportation possibilities (e.g. roads, railways or energy transportation networks integrated in flood defences), then it is likely to meet less resistance, and even receive support from the transportation sector and the government.

5.5.4 If the innovation results in a higher reliability of the existing transportation systems (e.g. by reducing the time that a road or railway is flooded, or by reducing the potential

damage by erosion due to flooding to roads and railways), then it will probably meet few resistance, or even support from the general public and the transportation sector.

5.5.5 If an innovation results in a decrease in the power, water or waste management infrastructure, then it may not be accepted, and the innovator is advised to adjust the design.

5.5.6 If an innovation results in a less reliable infrastructure, then the innovator is advised to adjust the design.

5.6 Tourism

5.6.1 If an innovation needs area that is currently used for recreational activities, then it will probably meet resistance, while an innovation that results in more recreational area (e.g. a green water retention area, or water square in the urban area), will probably meet support.

5.6.2 If an innovation improves the recreational attractiveness of an area, e.g. by creating nature area or walking paths, then it will probably not lead to public resistance, and could create opportunities to strengthen or to develop the tourist sector.

5.6.3 If an innovation would lead to an extended tourist season (e.g. by offering new recreation possibilities outside the normal tourist season) then it will probably generate support among the general public and the tourist sector

6 Societal acceptance assessment

After completing the societal acceptance questions innovators can use this guidance to interpret their results and identify possible societal acceptance concerns for their innovations.

The questions in Section 1 are yes or no questions. They test particular issues or sets of issues associated with the themes of issues described in the TIF method document: psychological concerns, inflexibility concerns, usability concerns and responsibility concerns. 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.

	Societal Acceptance assessment NB: all questions are applicable for all type of innovations (please fill in an answer for each question)!	
Answer the following 16 questions by writing Yes or No in the corresponding cells. These questions apply to ALL types of adaptations.		**Yes or No?**
1	Does your innovation use any materials that might be considered unfamiliar (such as nanomaterials or genetically modified materials)?	Yes
2	Will members of the public affected by your innovation be the ones to decide whether or when to use it?	Yes
3	Does your innovation involve visible infrastructure (such as physical barriers) or visible land use changes (such as woodland removal)?	Yes
4	Could the use/deployment of your innovation disrupt daily activities, for example through road closures?	Yes
5	Does your innovation require large amounts of capital investment relative to other adaptations in the sector?	Yes
6	Does your innovation require a long lead time between users placing an order and it becoming operational?	Yes
7	Does your innovation require new infrastructure or significant changes to existing infrastructure?	Yes
8	Does your innovation involve releasing any materials into the environment (such as sprays or coatings)?	Yes
9	Are your potential users likely to have a single mission, for example to protect ecosystems?	Yes
10	Does your innovation take less time to use/deploy than incumbent alternatives (such as sand bags for floods or fire nozzles for wildfires)?	No
11	Would everyday users of your innovation require special training in how to use it?	No
12	Will your organisation provide help and support to users of your innovation?	No
13	Innovations can either reinforce or change users' existing ways of working. Does your innovation reinforce existing ways of working?	No
14	Are the effects of your innovation directly publicly tangible (such as seeing flood defences working or hearing a warning alert system)?	No
15	Adaptations can either be used/deployed permanently or temporarily. Is your innovation deployed permanently?	No
16	Is any personal data associated with the adaptation shared with others, for example other companies? If your innovation uses no personal data, select 'No'	No
17	Is any personal data associated with the adaptation held securely, for example in an encrypted database? If your innovation uses no personal data, select 'Yes'	No
18	Are members of the general public involved in shaping the research, development, demonstration and deployment of your innovation?	Yes
Answer the following 4 questions by writing A, B or C in the corresponding cells.		**A, B or C?**
19	What would your innovation primarily protect (either directly or indirectly)? (A) public infrastructure, (B) private properties and assets, or (C) the environment	A
20	Who would pay for your innovation? (A) government authorities, (B) private companies or (C) local communities	B
21	Who would implement your innovation? (A) government authorities, (B) private companies or (C) local communities	A
22	How would compensation be made in the event of your innovation failing? Through (A) government compensation, (B) project insurance or (C) responsible parties	C

Figure B - 7: Tab Societal Acceptance

Innovators can now explore specific areas of societal concern by consulting the guidance on answers to each question associated with higher public concern given in Table 1 below. The table includes material and organisational recommendations on how to alleviate those concerns and improve the performance of their innovation and its societal readiness.

Table 2: Responding to specific areas of societal concern

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 minimising 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 minimise 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 defences 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 is 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.

The questions in Section 2 are multiple choice questions. They test particular issues associated with the sociocultural theme of issues described in the TIF method document. Depending on how an innovator responds to these questions they will have given a response that indicates their innovation is best suited to ‘technocratic’, ‘techno-optimistic’ or ‘techno-sceptical’ implementation contexts.

Innovators might now locate the intended implementation context of their innovation in a triangular space to help them think about where they are likely to meet societal support and where they are likely to meet societal resistance (see Figure 1).

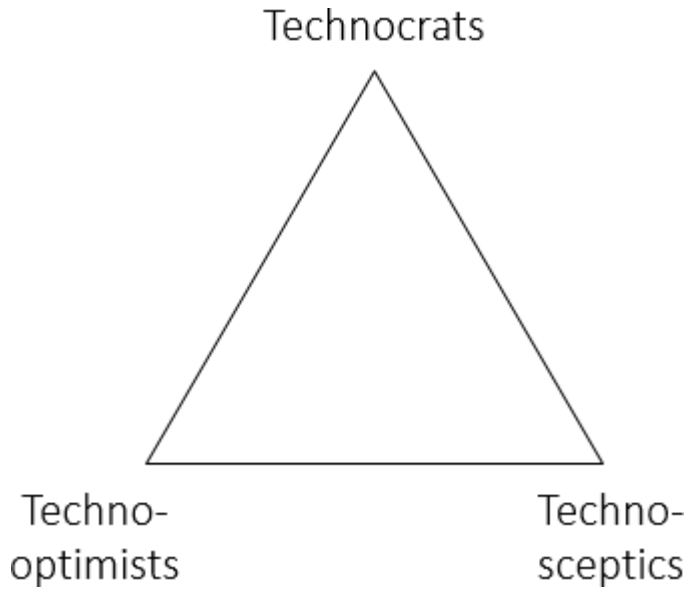


Figure B - 8: A space for matching technology characteristics with implementation contexts

Technocratic, techno-optimistic and techno-sceptical implementation contexts each hold unique preferences for 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-maximising 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-maximising 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 implementation context may be technocratic, but the technology characteristics are preferred by techno-optimists. Innovators should consider changing either their implementation context or set of technology characteristics to make sure they match. If the 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.

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 are described in the TIF method document, together with their typical strengths and weaknesses.

BRIGAID For more information on BRIGAID, see http://brigaid.eu/

TIF-Tool: A Testing and Implementation Framework (TIF) for Climate Adaptation Innovations

The BRIGAID Test and Implementation Framework Tool (TIF Tool) is designed to help climate adaptation innovators identify possible societal, technical, environmental and sectoral concerns that their innovations may raise early on – and iteratively throughout the development – so that they may modify their designs and not become locked into those that are less likely to appeal to end users. The TIF Tool is a self-assessment tool and should be applied in the least at three 'stage-gates' – critical points in development at which innovators should pause to identify and address social, technical, environmental and sectoral concerns. By raising a range of societal, technical, environmental and sectoral issues known to be of concern (but which might not all be applicable for your innovation) the TIF Tool supports interaction and communication between innovators and end-users about these concerns and subsequently helps to identify how those concerns might be addressed.

Many assessment question may serve as 'food for thought', or as topics to discuss with stakeholders or end-users. The TIF Tool does NOT provide a definitive assessment: it is a 'checklist' designed to help identify potential concerns so that innovators can then choose how - or whether - to respond to them.

- Stage-gate 1: Apply the TIF Tool prior to validation in a laboratory setting
- Stage-gate 2: Apply the TIF Tool prior to testing in an operational setting
- Stage-gate 3: Apply the TIF Tool prior to deployment in the real world

The TIF Tool consists of 6 tabs (+current tab), each dedicated to assessing a different aspect of climate adaptation innovations' overall performance and readiness:
- General questions about the type of innovation
- Technical performance – questions designed to identify areas of possible technical concern over an innovation
- Environmental impacts – questions designed to identify areas of possible environmental concern over an innovation
- Sectoral impacts – questions designed to identify areas of possible sectoral concern over an innovation
- Societal acceptance – questions designed to identify areas of possible societal concern over an innovation
- Summary of results – the overall performance of an innovation and a break-down of performance against societal, technical, environmental and sectoral questions and specific issues

The TIF Tool Guidance document provides information on how innovators should interpret the results of their self-assessment (TIF Tool results) and suggestions how to modify their designs.
The TIF Tool and the TIF Tool Guidance document are accompaniments to the more detailed TIF Methodology document. Readers who are interested in the theoretical and methodological underpinnings of the Tool and Guidance should refer to the Methodology.

For help on the separate issues of business development and market readiness, readers should refer to the BRIGAID Market Analysis Framework (MAF+).

Tab: General Questions:

Please fill in the name of your innovation:			
Developed by (fill in your name):			
Please fill in the date:			
Adaptation Innovation are designed to reduce climate related hazards. This could be:			
	Type of Hazard		***Description***
	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.
		Flash Flood	A flash flood is a rapid flooding of low-lying areas (e.g. rivers, dry lakes), and often the result of rapid run-off due to heavy precipitation on saturated soil or dry soil that has poor absorption ability; the collected run-off then forms a larger volume, or even a fast flowing waterfront.
	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.
			Type of Hazard / Fill in Subtype (if any)
1	Please indicate, which type of climate related hazard would be reduced by your innovation?		**……** / **…..**

There are different types of adaptations, including:			
	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
2	Which type of adaptation is your innovation?		Please select Type **Technological**

Tab: Technical Performance

2	Technical Design	
	Answer the following questions by writing Yes or No in the corresponding cells.	**Yes or No?**
1	Does the innovation provide significant technical advantage(s) relative to a traditional/conventional measures?	
2	Does your innovation physically prevent a hazard from occurring?	
3	Does your innovation require combination with other interventions and/or activities in order to reduce risk (e.g, flood warning system in combination with a flood barrier or a fire warning system in combination with controlled burning)?	
4	Will the innovation require additional testing and/or substantial upgrades when considering future hazard conditions (i.e., considering climate change)?	
5	Is the lifetime of the innovation limited by climate change? (i.e., will climate change affect the estimated life(time) of the innovation?)	
6	Does the innovation require frequent inspection and maintenance to reach its intended lifetime?	
7	Are the materials or software needed for maintenance and/or repair easily obtained and can they be integrated by the end-user?	
8	Is the innovation designed to be used repetitively or continuously operated over its lifetime?	
9	Can the innovation be operated without repair and/or replacement of components during a hazard event?	
10	Does the innovation exhibit vulnerabilities during testing and/or demonstration (e.g., structural: sliding or rotation, or technological: errors)?	
11	Is there a critical component in the innovation's structural or technological design that could lead to catastrophic failure?	
12	Does your innovation rely on the delivery of services or materials (e.g., structural components, data) outside of your control to be successfully operated during a hazard event?	
13	Does your innovation require the execution of tasks by humans to be successfully operated during a hazard event?	
14	Can the vulnerability of your innovation to human error be easily reduced through improvements in operational protocols and/or end-user training?	
15	Is the innovation modular (opposite: monolithic) and can it be easily installed or applied at different sites across Europe without adjustment?	
16	Does the innovation require additional testing and/or substantial upgrades (e.g., new components) if used at different sites across Europe?	
17	Will the size of the market for the innovation (in Europe) will significantly decrease (>50%) due to future hazard conditions (i.e., considering climate change)?	
18	Have relevant end-users have been identified and contacted and has a need for this innovation observed?	
19	Are the advantages of the innovation derived from its multi-functionality (e.g., reduction of carbon emissions or enhanced recreational activities)?	

Tab: Environmental Impact

2 Environmental Impact Assessment

Answer the following questions by choosing A, B, C, or n/a in the corresponding cells. Please fill in 'no impact' when an (informational) innovation has no ***direct*** *impact.*
some (informational) innovations need to be combined with a structural measure that may have an impact (then apply seperately the TIF Tool for this structural measure).

NB*:* **A, B, C,** or n/a (not applicable) **?**

3.1	**Environmental Design**
3.1.1	Does the innovation deliberately use ecosystems and their services, or mimic or preserve natural processes? (A) Yes (B) No, and the innovation may hinder natural processes or services provided by ecosystems, (C) No, but the innovation does not affect the ecosystems present nor natural processes
3.1.2	How does the change in footprint (area) required for implementation on-site compare to conventional measures or the present situation? (A) Increase space required (B) Decrease space required (C) No Impact on space required
3.1.3	How does the construction or operation of the innovation affect the quantity of greenhouse gases in the environment (e.g., as CO_2 or CH_4)? (A) Increase (B) Decrease (C) No Impact
3.1.4	Is the innovation made from recycled or recycable materials? (A) Yes (B) No, it is made of non-recycable materials (C) Partly
3.1.5	Does the innovation include specific design features or components which preserve or enhance ecosystem services? (A) Yes (B) No, and the innovation may hinder natural processes or services provided by ecosystems (C) No, but the innovation does not affect the ecosystems present nor natural processes

3.2	**Environmental Impact**
3.2.1	How does the innovation impact the quality of surface water? (A) Improve (B) Worsen (C) No Impact
3.2.2	How does the innovation impact the quantity of available surface water? (A) Increase (B) Decrease (C) No Impact
3.2.3	How does the innovation impact the quality of ground water? (A) Improve (B) Worsen (C) No Impact
3.2.4	How does the innovation impact the quantity of available ground water? (A) Increase (B) Decrease (C) No Impact
3.2.5	How does the innovation impact the quality of the sea water? (A) Improve (B) Worsen (C) No Impact
3.2.6	How does the innovation impact soil quality? (A) Improve (B) Worsen (C) No Impact
3.2.7	How does the innovation impact air quality? (A) Improve (B) Worsen (C) No Impact
3.2.8	Does the implementation (or construction) of the innovation generate debris? (A) Yes (B) Debris can even be stored or captured by the innovation (C) No
3.2.9	Does the implementation (or construction) of the innovation generate noise or vibration? (A) Yes (B) It even dampens noise (C) No
3.2.10	How does the innovation impact landscape quality? (A) Improve (B) Worsen (C) No Impact

3.3	**Ecological Impact**
3.3.1	How does the innovation impact the spatial extent of protected nature area? (A) Increase (B) Decrease (C) No Impact
3.3.2	How does the innovation impact the quality of protected habitats? (A) Improve (B) Worsen (C) No Impact
3.3.3	How does the innovation impact the number protected species (e.g., birds, vegetation, fish, mammals)? (A) Increase (B) Decrease (C) No Impact
3.3.4	How does the innovation impact the spatial extent of non-protected nature area? (A) Increase (B) Decrease (C) No Impact
3.3.5	How does the innovation impact the quality of non-protected habitats? (A) Improve (B) Worsen (C) No Impact
3.3.6	How does the innovation impact the number non-protected species (e.g., birds, vegetation, fish, mammals)? (A) Increase (B) Decrease (C) No Impact

Refer to the accompanying TIF Tool guidance document for detailed help on interpretating your results from these environmental design questions and to the TIF method document for detailed background on the theory and method that underpins them.

Tab: Sectoral Impact

3 Sectoral Impact Assessment

Answer the following questions by choosing A, B, or C in the corresponding cells. Please fill in 'no impact' when e.g. an (informational) innovation has no ***direct*** *impact.* **A, B or C?**

NB*: some (informational) innovations need to be combined with a structural measure that may have an impact (then apply seperately the TIF Tool for this structural measure).*

4.1	**Agriculture**	
4.1.1	How does the innovation impact the total area available for agricultural production? (A) Increase (B) Decrease (C) No Impact	
4.1.2	How does the innovation impact agricultural production conditions (e.g., by increasing soil quality or water availability)? (A) Improve (B) Worsen (C) No Impact	
4.1.3	How does the innovation impact the variety of agricultural products (e.g., crops, dairy, meat, fruit, fish, aquaculture) that can be produced or are available? (A) Increase (B) Decrease (C) No Impact	
4.1.4	How does the innovation impact the total yield of one or more agricultural products? (A) Increase (B) Decrease (C) No Impact	
4.2	**Energy**	
4.2.1	How does the innovation impact the energy production capacity (e.g., by generating energy or increasing energy distribution)? (A) Increase (B) Decrease (C) No Impact	
4.2.2	How does the innovation impact the reliability of energy production (e.g. by improving cooling water conditions for energy plants)? (A) Increase (B) Decrease (C) No Impact	
4.2.3	How does the innovation impact the efficiency of energy production? (A) Increase (B) Decrease (C) No Impact	
4.2.4	How does the innovation impact the carbon footprint of the end-user? (A) Increase (B) Decrease (C) No Impact	
4.3	**Forestry**	
4.3.1	How does the innovation impact the total area available for wood production (including timber and biomass)? (A) Increase (B) Decrease (C) No Impact	
4.3.2	How does the innovation impact wood production conditions (e.g., by increasing forest resilience or water availability)? (A) Improve (B) Worsen (C) No Impact	
4.3.3	How does the innovation impact the total area available for non-wood production (including cork, fruit, honey, mushrooms, pastures, game and fishing)? (A) Increase (B) Decrease (C) No Impact	
4.3.4	How does the innovation impact non-wood production conditions (e.g., by increasing forest resilience or water availability)? (A) Improve (B) Worsen (C) No Impact	
4.4	**Health**	
4.4.1	How does the innovation impact the number of fatalities in the area exposed to the hazard? (A) Increase (B) Decrease (C) No Impact	
4.4.2	How does the innovation impact the number of people affected by the hazard in their physical health (i.e., number of people injured)? (A) Increase (B) Decrease (C) No Impact	
4.4.3	How does the innovation impact the number of people affected by the hazard in their mental/psycho-social health? (A) Increase (B) Decrease (C) No Impact	
4.4.4	Does the innovation emit or release chemicals or products that are harmful to humans? (A) Yes (B) It can even capture harmful substances (like small particles) (C) No impact on concentration of chemicals or harmful products	

4.5	Infrastructure
4.5.1	How does the innovation impact the quality of the built environment (I.e., residential, commercial, and industrial)? (A) Improve (B) Worsen (C) No Impact
4.5.2	How does the innovation impact the total area available for urban development? (A) Increase (B) Decrease (C) No Impact
4.5.3	How does the innovation impact the capacity of existing transportation systems (e.g., roads, railways, waterways, and airports) or create new capacities? (A) Increase (B) Decrease (C) No Impact
4.5.4	How does the innovation impact the reliability of existing transportation systems (e.g., roads, railways, waterways, and airports)? (A) Increase (B) Decrease (C) No Impact
4.5.5	How does the innovation impact the transport capacity of critical infrastructure networks (e.g., power, water, waste management)? (A) Increase (B) Decrease (C) No Impact
4.5.6	How does the innovation impact the reliability of critical infrastructure networks (e.g., power, water, waste management)? (A) Increase (B) Decrease (C) No Impact

4.6	Tourism
4.6.1	How does the innovation impact the total area available for recreational activities? (A) Increase (B) Decrease (C) No Impact
4.6.2	How does the innovation impact the attractiveness of the area for recreational activities? (A) Increase (B) Decrease (C) No Impact
4.6.3	How does the innovation impact the length of the tourist season? (A) Increase (B) Decrease (C) No Impact

Refer to the TIF method document for detailed background on the theory and method that underpins the questions related to sectoral impacts.

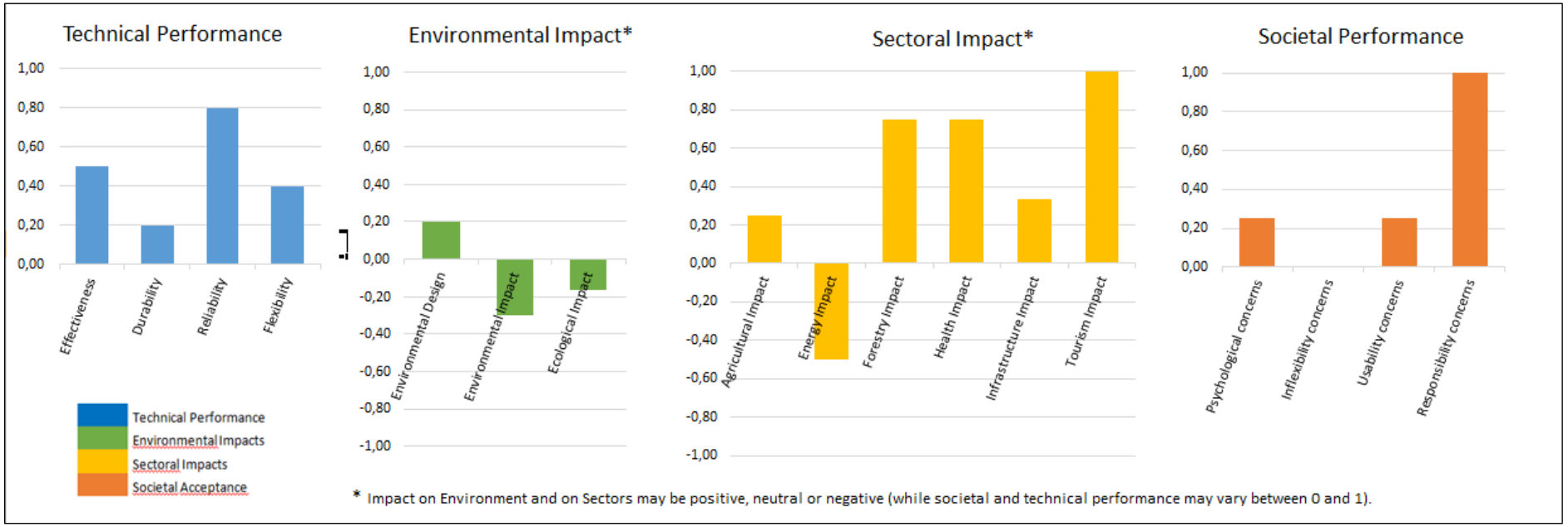
Tab: Societal Acceptance

4	**Societal Acceptance assessment** NB: all questions are applicable for all type of innovations (please fill in an answer for each question)!	
Answer the following 16 questions by writing Yes or No in the corresponding cells. These questions apply to ALL types of adaptations.		**Yes or No?**
1	Does your innovation use any materials that might be considered unfamiliar (such as nanomaterials or genetically modified materials)?	
2	Will members of the public affected by your innovation be the ones to decide whether or when to use it?	
3	Does your innovation involve visible infrastructure (such as physical barriers) or visible land use changes (such as woodland removal)?	
4	Could the use/deployment of your innovation disrupt daily activities, for example through road closures?	
5	Does your innovation require large amounts of capital investment relative to other adaptations in the sector?	
6	Does your innovation require a long lead time between users placing an order and it becoming operational?	
7	Does your innovation require new infrastructure or significant changes to existing infrastructure?	
8	Does your innovation involve releasing any materials into the environment (such as sprays or coatings)?	
9	Are your potential users likely to have a single mission, for example to protect ecosystems?	
10	Does your innovation take less time to use/deploy than incumbent alternatives (such as sand bags for floods or fire nozzles for wildfires)?	
11	Would everyday users of your innovation require special training in how to use it?	
12	Will your organisation provide help and support to users of your innovation?	
13	Innovations can either reinforce or change users' existing ways of working. Does your innovation reinforce existing ways of working?	
14	Are the effects of your innovation directly publicly tangible (such as seeing flood defences working or hearing a warning alert system)?	
15	Adaptations can either be used/deployed permanently or temporarily. Is your innovation deployed permanently?	
16	Is any personal data associated with the adaptation shared with others, for example other companies? If your innovation uses no personal data, select 'No'	
17	Is any personal data associated with the adaptation held securely, for example in an encrypted database? If your innovation uses no personal data, select 'Yes'	
18	Are members of the general public involved in shaping the research, development, demonstration and deployment of your innovation?	

Answer the following 4 questions by writing A, B or C in the corresponding cells.		**A, B or C?**
19	What would your innovation primarily protect (either directly or indirectly)? (A) public infrastructure, (B) private properties and assets, or (C) the environment	
20	Who would pay for your innovation? (A) government authorities, (B) private companies or (C) local communities	
21	Who would implement your innovation? (A) government authorities, (B) private companies or (C) local communities	
22	How would compensation be made in the event of your innovation failing? Through (A) government compensation, (B) project insurance or (C) responsible parties	

Refer to the accompanying TIF Tool guidance document for detailed help on interpretating your results from these societal testing questions and to the TIF method document for detailed background on the theory and method that underpins them.

Tab: Summary of Results



The table below summarizes the results of the TIF screening.

1	**Your innovation raises**	**many**	**technical concerns overall, having scored**	**9**	**out of a possible**	**19**	**and is**	**far**	**from/to being ready in terms of its technical design.**
1	Your innovation raises	some	concerns related to its technical effectiveness, having scored	3	out of a possible	4	and is	close	from/to being ready/effective in terms of its technical design.
1	Your innovation raises	many	concerns related to its durability, having scored	1	out of a possible	5	and is	far	from/to being ready/effective in terms of its technical design.
1	Your innovation raises	some	concerns related to its reliability, having scored	3	out of a possible	5	and is	close	from/to being ready/effective in terms of its technical design.
1	Your innovation raises	many	concerns related to its flexibility, having scored	2	out of a possible	5	and is	far	from/to being ready/effective in terms of its technical design.
2	**Your innovation raises**	**several**	**environmental concerns overall, having scored**	**-3**	**on**	**21**	**criteria,**	**and is far from being ready**	**in terms of its environmental design.**
2	Your innovation raises	some concerns,	related to its Environmental Design having scored	1	on	5	criteria. Your innovation may have	a positive impact	on the environment.
2	Your innovation raises	several concerns,	related to its Environmental Impact, having scored	-3	on	10	criteria. Your innovation is may have a	a negative impact	on the environment.
2	Your innovation raises	several concerns,	related to its Ecological Impact, having scored	-1	on	6	criteria. Your innovation is may have a	a negative impact	on the environment.
3	**Sectoral Impacts**								
3	Your innovation raises	few concerns,	related to **Agricultural Impacts**, having scored a total of	1	on	4	criteria. Your innovation may have	a positive impact	impact on the **Agricultural Sector**.
3	Your innovation raises	few concerns,	related to **Energy Impacts**, having scored a total of	2	on	4	criteria. Your innovation may have	a positive impact	impact on the **Energy Sector**.
3	Your innovation raises	few concerns,	related to **Forestry Impacts**, having scored a total of	3	on	4	criteria. Your innovation may have	a positive impact	impact on the **Forestry Sector**.
3	Your innovation raises	few concerns,	related to **Health Impacts**, having scored a total of	3	on	4	criteria. Your innovation may have	a positive impact	impact on the **Health Sector**.
4	Your innovation raises	few concerns,	related to **Infrastructure Impacts**, having scored a total of	2	on	6	criteria. Your innovation may have	a positive impact	impact on the **Infrastructure Sector**.
4	Your innovation raises	no concerns,	related to **Tourism Impacts**, having scored a total of	3	on	3	criteria. Your innovation may have	a positive impact	impact on the **Tourism Sector**.
4	**Your innovation raises**	**many**	**societal concerns overall, having scored**	**4**	**out of a possible**	**18**	**and is**	**far**	**from/to societal readiness.**
4	Your innovation raises	many	psychological concerns, having scored	1	out of a possible	4	and is	far	from/to societal readiness.
4	Your innovation raises	many	inflexibility concerns, having scored	0	out of a possible	5	and is	far	from/to societal readiness.
4	Your innovation raises	many	usability concerns, having scored	2	out of a possible	8	and is	far	from/to societal readiness.
4	Your innovation raises	few	responsibility concerns, having scored	1	out of a possible	1	and is	close	from/to societal readiness.

Refer to the accompanying TIF Tool guidance document for detailed help on interpretating your results from these testing questions and to the TIF method document for detailed background on the theory and method that underpins them.

Appendix C. Results of the Frontrunner Workshop Additional Guidelines for Impact Assessment

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.

1 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.)*

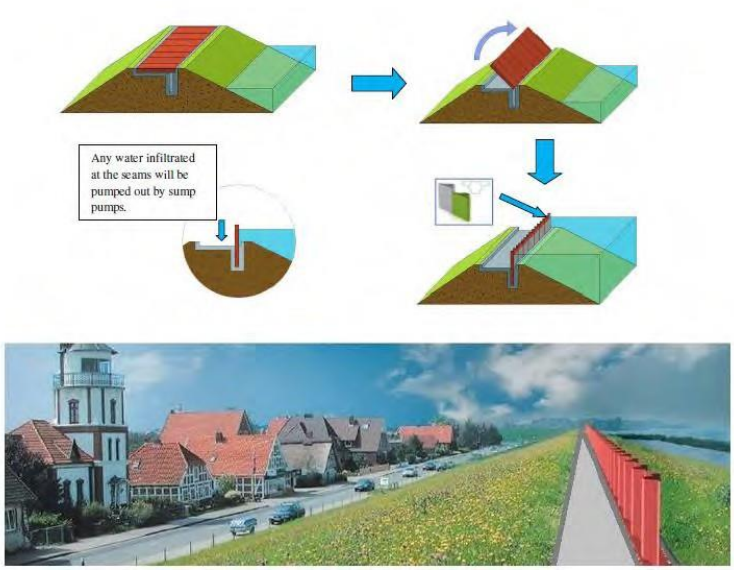


Figure C-1. Visualization of the Flip-Flap Cofferdam.

- **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).*

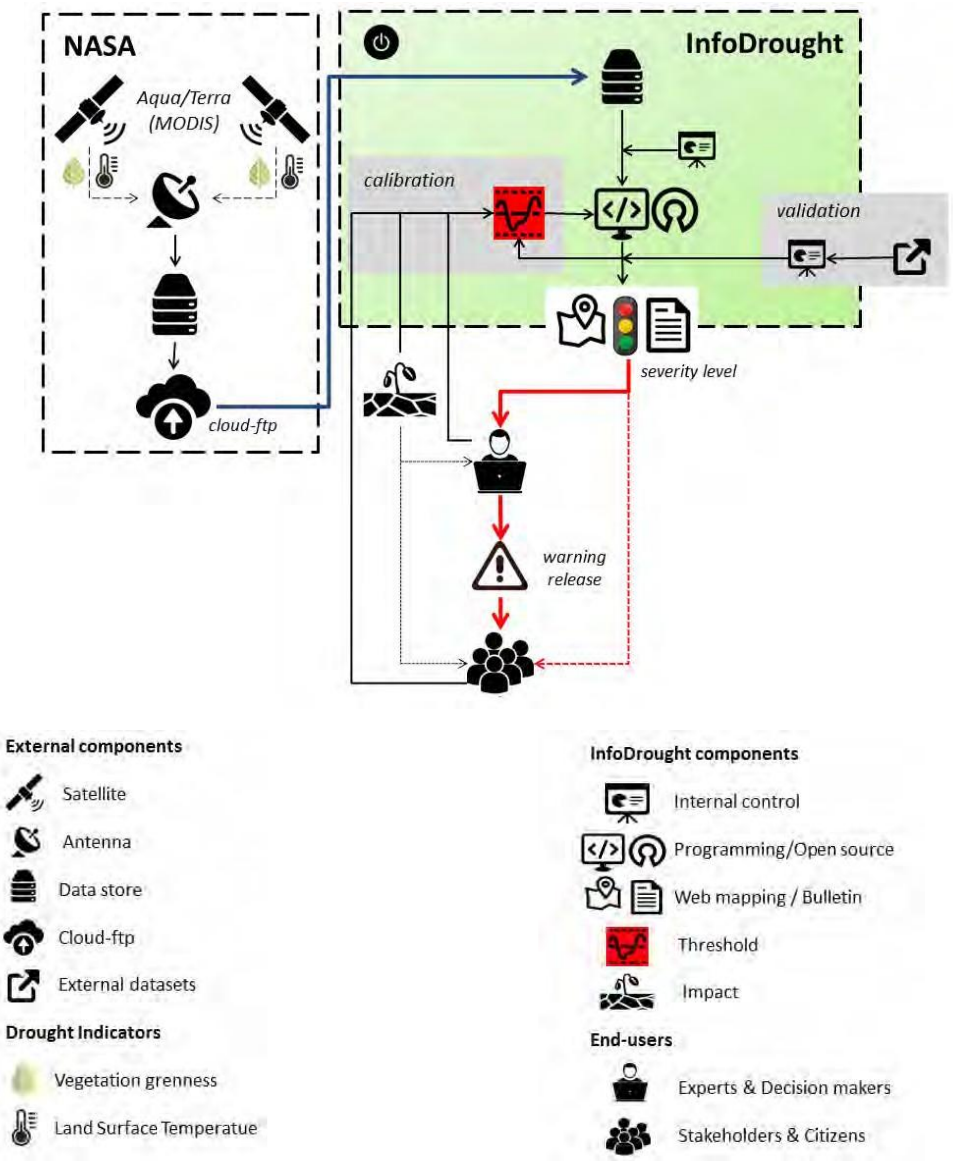


Figure C-2. Sketch of the InfoDROUGHT monitoring system.

- **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 continuously 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 indices, 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)

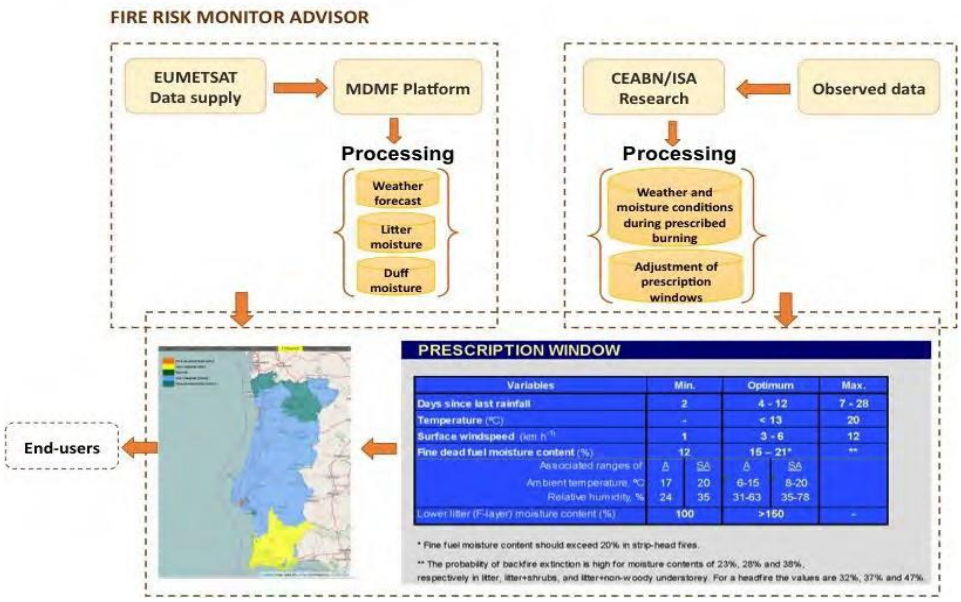


Figure C-4. Schematic showing the process used in Fire Risk Monitor Advisor

2 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 language” 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 structural 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 limitations 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 questionnaires that build off of one another and guide the innovator through the testing phases instead of a single long questionnaire and multiple phone calls.*

    a. We propose that BRIGAID develops a series of questionnaires (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 questionnaires (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 questionnaires would help reduce these overlaps by allowing the answers from one questionnaire to feed the next.

Appendix D. Innovator and decision-maker Feedback Report

A report on innovator and decision maker feedback on the full version of the BRIGAID Test and Implementation Framework (TIF)

1 Background

This document reports on innovator and decision maker feedback on the full version of the BRIGAID Test and Implementation Framework (TIF) (Deliverable 5.2). In part fulfilment of Task 5.3 it draws on a series of telephone interviews and written remarks to inform the fine-tuning of the first concept of the TIF method. The purpose of the TIF is to help innovators to make sure that their climate adaptation innovations are addressing the sorts of societal, technical, environmental and sectoral concerns that potential decision and policy makers might have when making decisions about which innovations to adopt. It is composed of two elements: a practical tool for innovators to assess their innovations against with guidance for interpreting their results, and a method document that gives detailed background on the theories and methods that underpin the tool. The purpose of gathering feedback is to ensure that (1) the tool is usable by different innovators (who will use the TIF to identify concerns and develop test plans) without expert assistance and (2) it addresses the sorts of concerns that different decision makers (including policy makers) may have when choosing innovations.

2 Interviews

Ten innovators and decision makers were selected to participate in a series of one-to-one telephone interviews to provide detailed feedback on the TIF tool and guidance. Some participants also chose to provide feedback on the detailed TIF method document, and an additional tool designed to help innovators accurately identify the technical readiness level (TRL) of their innovations. The participants were selected to represent a diversity of innovator and decision maker perspectives (see Table 1). These included a diversity of types of climate adaptation innovation (structural/physical and social, engineered and built environment, informational, behavioural and ecosystem-based) focusing on a diversity of climate risks (river and coastal floods, droughts, extreme rainfall and wildfires) a diversity of public sector, private sector and third sector decision makers, and a diversity of national and supranational perspectives, including the European Union, Germany, Israel, the Netherlands, Portugal, Spain and the United Kingdom. As prompts, the participants were invited to think about whether the TIF was easy to understand and navigate, the phrasing of the questions, whether the tool was helpful in developing a BRIGAID test plan and whether there was anything missing that decision and policy makers might like to know when making decisions about which climate adaptations to adopt. The scope of feedback was unrestricted.

Table D - 1: A list of innovator and decision maker participants involved in providing feedback on the full version of the BRIGAID Test and Implementation Framework

Participant(s) and organisation type	Innovation	Country
Public sector decision makers – local government (1)	N/A, but tested with green roof innovations in mind (an extreme rainfall and droughts-focused structural/physical, ecosystem-based adaptation innovations)	Netherlands
Public sector decision makers – supranational government (1)	N/A, but tested with green roof innovations in mind (an extreme rainfall and droughts-focused structural/physical, ecosystem-based adaptation innovations)	European Union
Innovators (2)	A droughts-focused structural/physical, engineered and built environment adaptation innovation	Israel
Innovators (1)	A droughts-focused social, informational adaptation innovation	Spain
Private sector decision makers	N/A	Germany
Innovators (1)	A wildfires-focused social, informational adaptation innovation	Portugal
Public sector decision makers – local government (1)	N/A, but tested with green roof innovations in mind (an extreme rainfall and droughts-focused structural/physical, ecosystem-based adaptation innovations)	Netherlands
Public sector decision makers – supranational government (1)	N/A, but tested with green roof innovations in mind (an extreme rainfall and droughts-focused structural/physical, ecosystem-based adaptation innovations)	European Union
Third sector decision makers	N/A	United Kingdom

3 Feedback

A wide range of feedback on the TIF was elicited from the participants which has been distilled into 39 unique detailed remarks and 14 overall feedback themes (see Table 2). In turn, these might further be aggregated into five clusters. The first of these clusters relates to usability, and in particular suggestions to make the TIF process clearer, more consistent across sections, easier to navigate and more manageable in scope. The second cluster relates to intentional or unintentional subjectivities in the TIF, and in particular the possibility for deliberately weighting certain issues and attending to subjectivities when answering questions. The third cluster relates to inputs to and outputs from the TIF, and in particular suggestions to make recommendations arising from concerns raised by the TIF more positive and systemic. The fourth cluster relates to issue-specific suggestions for the societal, technical, environmental and sectoral aspects of the TIF and, separately, the TRL tool. The final cluster relates to possible wider uses of the TIF, and in particular its potential as a tool for decision makers. The full list of 14 feedback themes and 39 unique detailed remarks can be consulted in the Table below.

Table D - 2: Feedback themes and detailed remarks from innovators and decision makers

Feedback theme	Detailed remarks
Clarity of process	• The welcome tab of the tool could provide space for respondents to add details of their innovations (e.g. name, innovation, date of completion), which could in turn be duplicated on the summary of results tab to generate a complete report • The order in which the tool and its guidance are meant to be (i.e. tool followed by guidance) used could be made clearer on the welcome and summary of results tabs of the tool • The applicability of the questions in the tool to all types of innovations could be made clearer • Whether or not an innovation has "scored well" could be communicated more clearly in the summary of results tab of the tool • Conclusions and next steps could be added to welcome and summary of results tabs of the tool as well as the guidance for interpreting results
Consistency throughout	• Questions with a yes/no response should be responded to with a "yes/no" and multiple choice questions should be responded to with an "A", "B" or "C" throughout the tool (environment and sectoral tabs to change) • High scores should mean a good score and low scores should mean a bad score throughout the summary of results tab of the tool (environment and sectoral wording to change) • Reference to "few", "some" and "many" concerns raised should be consistent throughout the in the summary of results tab
Ease of use	• "Yes/no" responses to questions in the tool could be given with a simple "y/n" • Text that asks respondents to "proceed to next tab" when all questions on a tab have been completed could be added to the tool • Questions in the tool could be repeated in the guidance for interpreting results to avoid having to look back and forth between them • The scope of the tool could be seen as intimidating and time consuming and might better be operationalised as a simple checklist
Scope of the tool	• The environment tab of the tool could be included under the technical tab to streamline the process • There is some confusion about the relationship between the TIF and a proliferation of other BRIGAID questionnaires and processes
Question weighting	• Questions or areas of assessment could be weighted by the developers of the tool or the respondents themselves to give an indication of the relative importance of particular societal, technical, environmental or sectoral issues
Information and	• Some information might not be known by respondents when answering questions in the tool and a "not yet known" response option could be added. Societal question 1,

subjectivity	technical questions 10 and 16 and environmental questions 2.4 and 3.4 are given as examples • Innovators have been seen to downplay negative aspects of their innovations and overstate positive aspects of their innovations. Questions in the tool should be phrased in such a way that they do not realise they are giving an answer that could be negative, particularly environmental and sectoral questions • Three respondents working on the same innovation can give different answers to the same questions in the tool, highlighting possible subjectivities. This could be because different 'aspects' or modules of an innovation are emphasised during the assessment. The specific questions are: societal questions 1, 2, 3, 5, 6, 7, 9, 10, 14, 16, 18, 19, 20; technical questions 1, 2, 5, 7, 9, 10, 11, 14, 15; environmental questions 1.1, 1.2, 1.3, 1.4, 2.3, 2.4, 2.5, 2.7, 2.9, 3.2, 3.3, 3.4, 3.5, 3.7; and sectoral questions 1.1, 1.3, 1.4, 2.1, 2.3, 3.1, 3.2, 3.3, 3.4, 4.1, 4.2, 4.4, 5.1, 5.2, 5.5, 5.6, 6.1, 6.2, 6.3. 65% of societal questions raised such ambiguities, 47% of technical questions, 67% of environmental questions and 79% of sectoral questions
Positive advice	• The recommendations made in the guidance for responding to concerns raised in the tool are based around not doing things that raise concerns, but this might encourage innovators to be less innovative. Recommendations could instead be positively oriented around dealing with those concerns, for example through communications strategies. Societal question 1 is given as an example
Systems-thinking	• Concerns in the tool are addressed one by one which might discourage 'systems-thinking' and the consideration of synergistic opportunities and threats that might manifest from the interactions between multiple factors • Recommendations in the guidance might also operate in this synergistic way, with things that innovators could do that address multiple issues at the same time
Societal-specific	• The terms "large", "frequent", "long" and "fail" in some of the questions in the tool could be defined relative to other things • Question 3 in the tool considers land-use changes to be negative but some could be seen as positive (e.g. forest-planting) • Questions 16 – 20 in the tool compel a single response "A", "B" or "C" but might have multiple responses, for example "A, B and C" which could be accounted for. This might particularly be the case for multifunctional innovations • Questions of privacy and the handling of personal data are currently absent from the tool and could be important questions for innovations that make use of information technologies • Forum for the Future has produced a report on societal questions for synthetic biology innovations which could be useful
Technical-specific	• Question 4 in the tool could emphasise that respondents consider the full range of climate change projections and not just central estimates

Environmental-specific	• ‘Exploitability’ questions in the tool seem out of place in the TIF and could be better placed in the MAF+ • Questions in the tool do not seem to recognise innovations whose purpose is not to reduce physical risk but to provide information • Questions in the tool could consider supply chains and other systems upon which the innovation depends. There might be things that an innovation is reliant on elsewhere in the supply chain that is at risk of climate change • The response to question 1.2 in the tool would seem to always be “yes” and therefore may not be needed • Many questions in the tool could have a “D” response option for “dependent upon location” • The environmental impacts under consideration could be more explicitly linked to EU legislation in the guidance document
Sectoral-specific	• A ‘decision making’ sector could be added to the sectors considered in the tool • Questions 1.1 and 3.1 in the tool might not necessarily be negative as farmers or other land owners might be paid and therefore be in favour of the innovation
TRL tool-specific	• The TRL tool could be used as a means of screening and selecting future BRIGAID innovations • Some innovators do not do laboratory work and skip several levels of the scale. Certain levels might therefore not be applicable to some innovations and the progression along the scale may not be linear • Societal aspects should be removed from the TRL tool as, unlike technical aspects, they do not translate into ‘levels’ and are therefore only be included in the separate, ‘STRL’ scale
A tool for decision makers	• The tool could also be helpful to decision makers in making decisions about which innovations to adopt, but much more work would be needed in thinking about how it relates to other decision tools that are already available and in use

Appendix E. 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.

1 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.

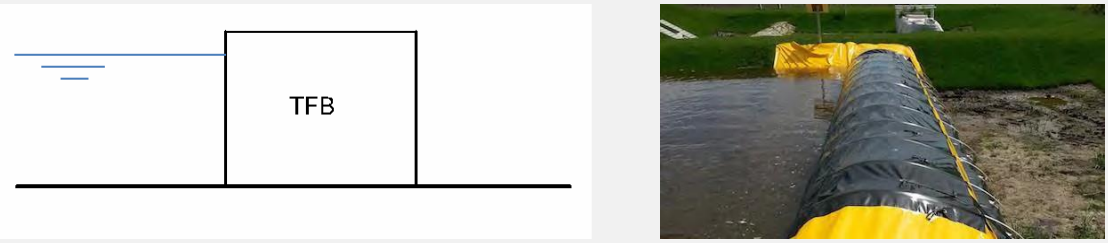


Figure 1 Schematic cross section of a Temporary Flood Barrier (left) and an example TFB (right) (source: www.tubebarrier.com)

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 fulfil 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 fulfil 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 4). 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 4 or Appendix A).

Water filled tubes are very modular, they consist of separate tubes of a finite length (approximately 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.

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:

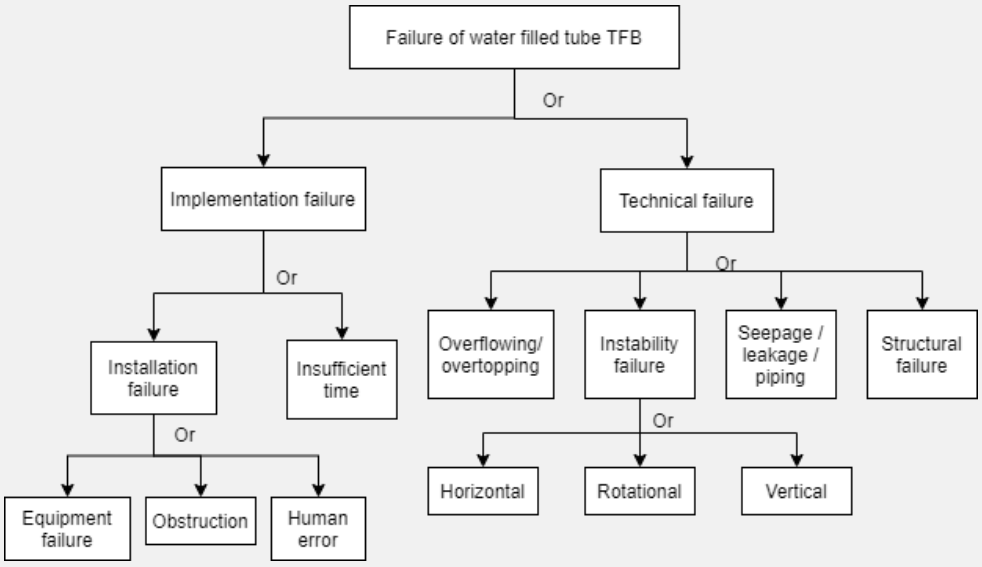


Figure 2 Fault tree example of a water filled tube (TFB)

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.

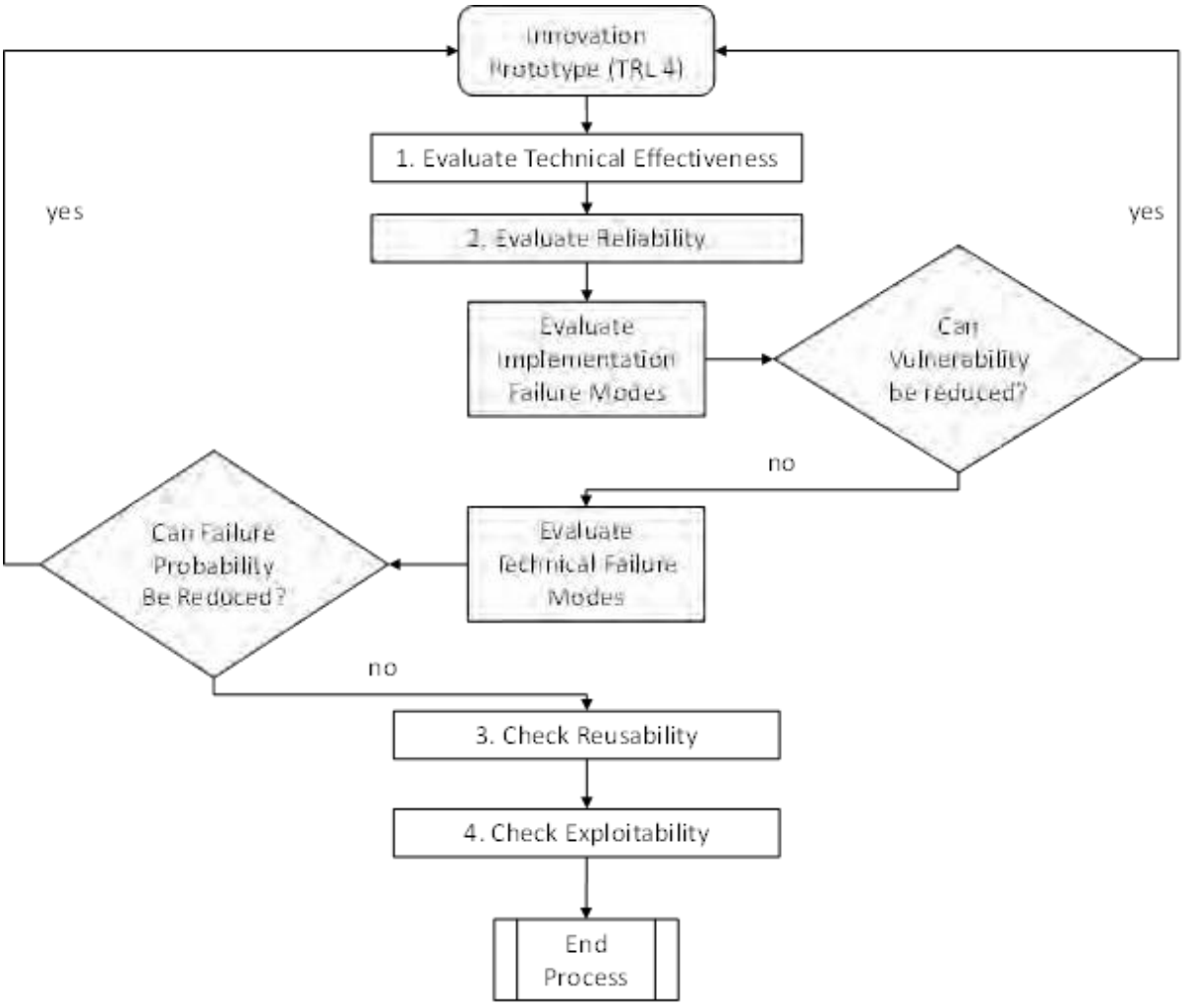


Figure 4 Overview of laboratory testing for an engineered/built (structural) innovation.

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]).

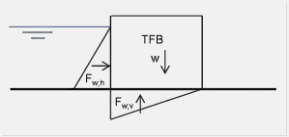


Figure 5: Typical loads on a schematized temporary water-retaining structure consisting of layers of sand bags.

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).

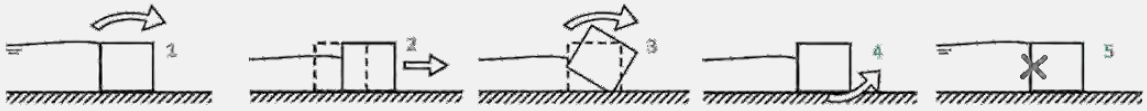


Figure 6 Typical structural failure mechanisms of temporary water retaining structures: Overflow (1), Sliding (2), Rotation (3), Seepage (4) and (5) Structural failure (Boon 2007)

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):

$$Fs_{sliding} = \frac{f(W - F_{W;V})}{F_{w;h}} \quad (1)$$

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 ·H_r ·L	0.42	m^3
$F_{w;v}$	Upward water pressure		0	kN/m
W	Weight of structure	V · y_w	4.2	kN/m
H_w	Water level		0.58	m
$F_{w;h}$	Horizontal force	0,5 ·y_w·H_r^2	1.25	kN/m
FS	Safety factor	W · 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 F - 1 Example Testing Protocol for Laboratory Testing (Wibowo and Ward, 2016)

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

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 4.2.

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 exploitability holds under the design criteria

Evaluate whether the exploitability estimated during the Desk Study (Table 4-1) 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).

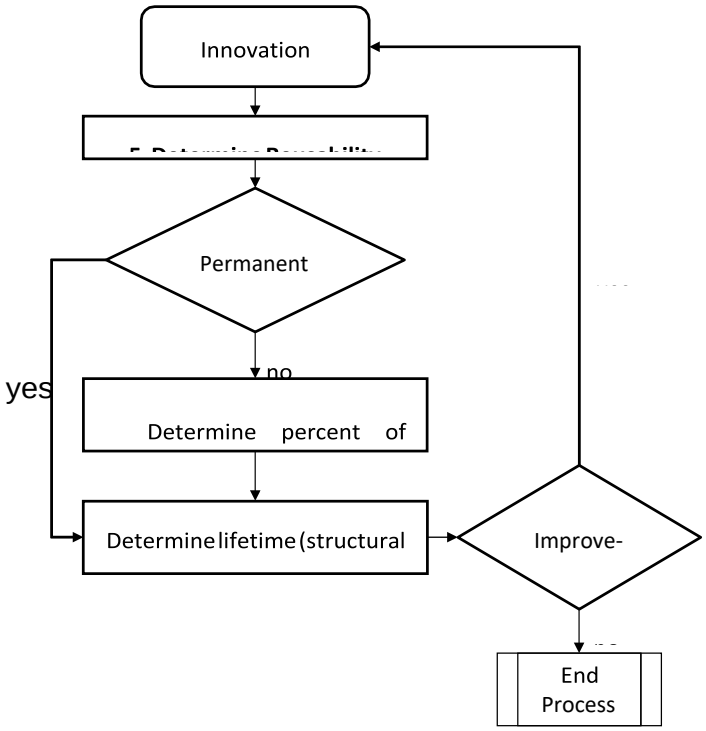


Figure 8 Evaluating the reusability of an engineered/built (structural) innovation.

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.

2 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.

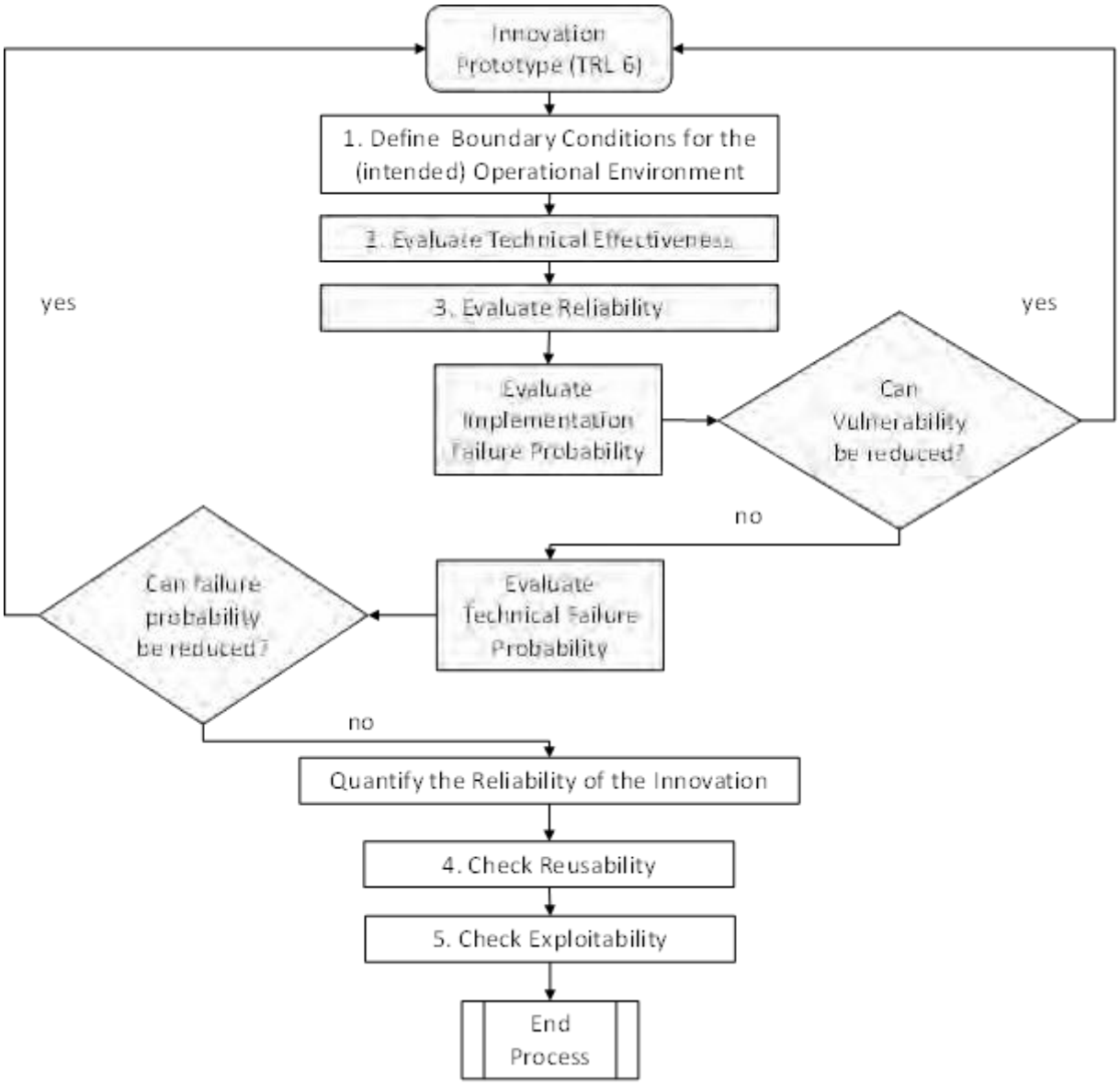


Figure 9 Overview of operational testing for an engineered/built (structural) innovation.

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.

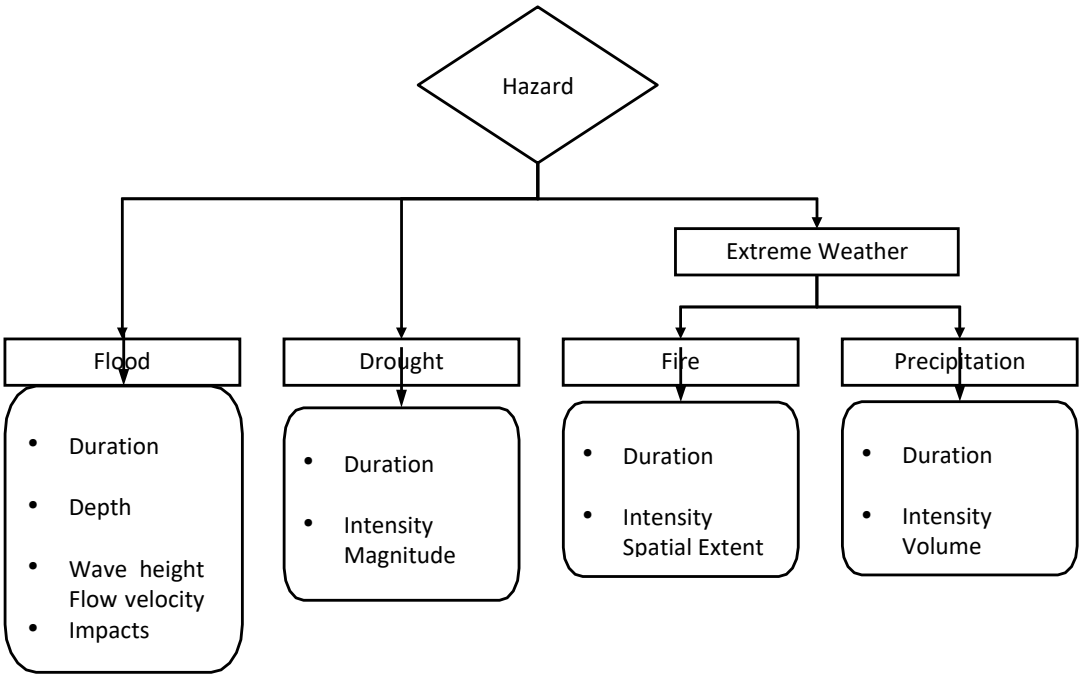


Figure 10 Establishing physical boundary conditions for testing of structural/built environment innovations based on hazard type (minimum requirements).

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 operators[18] 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.
- **Rule-based** performance is the next cognitive level; this level involves responding to a

[18] 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.

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:

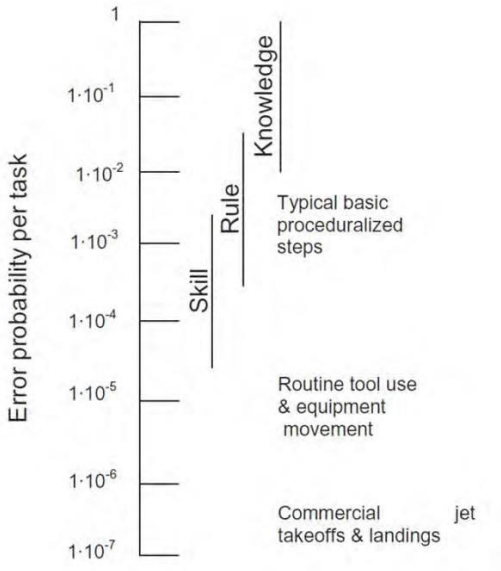


Figure 11: Human error probabilities and performance levels by Watson and Collins (Bea 2010)

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[19] needed for 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:

[19] 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

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

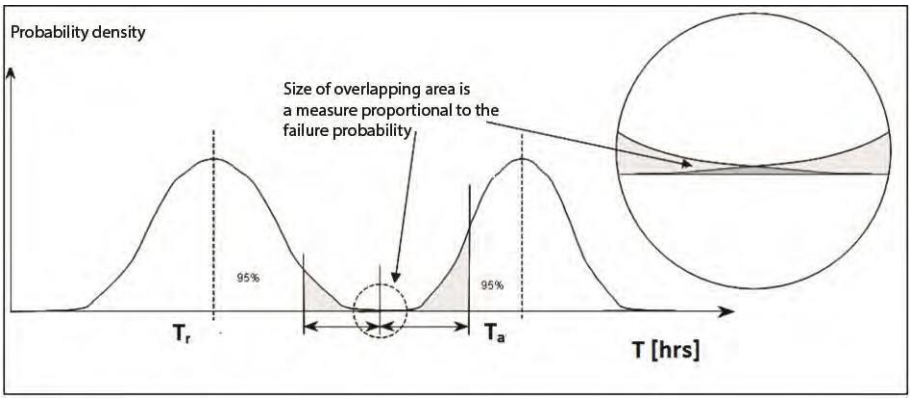


Figure 12 Probability density of the required time (T_r) versus the available time (T_a) (Lendering et al. 2015)

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 σ = 2	°
y_w	Volumetric weight water	Deterministic		10	kN/m
H	Water level inside structure	Normal	-	μ = 0.6 σ = 0.05	^{2} 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;

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

$P_f = 1-(1-P_{f\,implementation})\cdot(1-P_{f;technical}) = 1/31$ *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 fulfil 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 F. Staged development of the TIF tool

1 Background

BRIGAID Test and Implementation Framework Tool (TIF-Tool) is based on a broad range of scientific knowledge and is developed in close collaboration with climate adaptation innovators and end-users. The purpose of the TIF-Tool (the Excel based self-assessment tool and the accompanying guidance document) is to help innovators to make sure that climate adaptation innovations are addressing early on all sorts of technical, environmental, sectoral, and societal concerns that their innovations may raise– and iteratively throughout the development – so that they may modify their design and not become locked into those that are less likely to appeal to end users. This document reports on the practice-oriented validation of the BRIGAID Test and Implementation Framework Tool (TIF-Tool). It describes the steps in the development of the TIF-Tool and how the collected feedback from the application of the TIF-Tool in stocktaking cycle 1 and 2 and from the workshop on the application of the TIF-Tool was used to adjust the TIF-Tool to support the innovators.

2 Preparation phase - TIF-Tool V0 (version 0)

During the so-called 'Frontrunner-Workshop' at BRIGAID's projectmeeting in November 2016 pre-liminary ideas about the various tools to support the implementation of adaptation innovations were discussed with a selected group of BRIGAID's consortium innovators.

Here it was expressed that climate adaptation innovators especially need a tool that is easy to use without expert assistance and that provides an impression of all sorts of concerns that different decions makers (including policy makers) may have when choosing innovations. The information about the innovation's performance and impact must be clear and also useful for communication about the innovation. Furthermore the tool had to be usable for different types of innovations and not time-consuming.

Based on these requirements the initial version of BRIGAID's TIF-Tool (the Excel based self-assessment tool and the accompanying guidance document) was developed (version 0). Before this initial version was launched and presented to innovators in cycle 1, we asked feedback from a selected group of some 10 innovators (BRIGAID 'Frontrunners' consortium partners) and decision makers (potential end-users) for the fine-tuning of the first concept. The purpose of gathering feedback was to ensure that (1) the tool is usable by different innovators (who will use the TIF-Tool to identify concerns and develop test plans) without expert assistance and (2) it addresses the sorts of concerns that different decisions makers (including policy makers) may have when choosing innovations. We invited the participants to inform us whether the TIF-Tool was easy to understand and navigate, on the phrasing of the questions, whether the tool was helpful in developing a BRIGAID test plan and whether there was anything missing that decision and policy makers might like to know when making decisions about which climate adaptations to adopt.

We received this feedback on the Excel based self-assessment tool and the accompanying guidance document via a series of telephone interviews and written responses (see Appendix E in Deliverable 5.2). This feedback was used to improve the initial version (version 0), resulting

in TIF-Tool version 1 (BRIGAID's Deliverable 5.1, April 2017 and BRIGAID's Deliverable 5.2, October 2017).

3 TIF-Tool V1 (version 1)

3.1 Stocktaking Cycle 1

BRIGAID's TIF-Tool Version 1 was introduced in cycle 1 of the stock-taking process by the leaders of WP 2 (Floods), 3 (Droughts) and 4 (Extreme Weather) to the innovations of consortium partners (see Table 3-1). These consortium partners were invited by the leaders of WP 2, 3 and 4 to apply the TIF-Tool (version 1) on their innovation and to report on their experiences and to include the results of the application of the TIF-Tool (version 1) in their testplan. BRIGAID's 'Frontrunner' innovators had already experience with the application of TIF-Tool version 0.

Table F - 1: Innovations from stock-taking cycle 1

	Innovation	Innovator
Innovations from Consortium Partners		
1	eEM-DAT	UCL
2	OBREC	University of Bologna
3	MyFloodRiskProfile	HKV Consultants
4	Flip-Flap Dam	Spectrum Construct SRL
5	ThirdEye: Flying Sensors for Drought and Disease	FutureWater
6	Water + Furrow Diker	S.Q. AQUAPROIECT S.A.
7	InfoSequia	FutureWater
8	GM4W: Water vapour GNSS monitoring & heavy rain nowcasting	GReD srl
9	AEWMS: Active Eco-Wildfire Management System	GIFF Lda
10	FireAd _ Fire Risk Monitor Advisor	Centro de Ecologia Aplicada "prof. Baeta Neves"
Innovations from non-consortium partners (stocktaking)		
1	SCAN	Sumaqua
2	EVAPO-CONTROL	ARANA WM
3	Water from Heaven	Water Innovation Consulting
4	ARIEL	BALAM Ingenieria de Sistemas
5	HYDROVENTIV	Le PRIEURE
6	TubeBarrier	TubeBarrier

This rendered very useful feedback from real-life innovators, via the leaders of WP 2-4. The remarks related to:

- Applicability of some question to all types of innovations. In particular for so-called 'Informational' innovations (such as hazard and vulnerability mapping and systematic monitoring and remote sensing) some questions seem at first sight less applicable.
- The TIF Tool seems a bit biased to structural innovations.

- Many ‘Informational’ innovations are no direct intervention in reducing impact, and they need to be combined with a structural measure that may have a direct impact.
- Some answers in the societal part of the TIF Tool seem not to match the characteristics of the innovation. E.g. Land use changes necessary to implement a particular structure could have co-benefits (and not only trade-offs).
- In some cases there are more answers possible, depending on the situation. E.g. what the innovation protects, depends on the location (e.g. is there public infrastructure or are private properties present).
- The technology characteristics (in the ‘Societal’ sheet) depend on the context.
- Presentation of the summary of the results: are negative values possible for ‘Environmental’ and ‘Sectoral’ impacts?
- Quantification of the results of the self-assessment (errors in the Excel formulas).
- A drop down menu would be helpful to fill in the answers.

3.2 Workshop on the application of the TIF Tool and feedback from WP2-4 breakout session, BRIGAID’s Lisbon meeting (April 2018)

As a next step, during BRIGAID’s project meeting in Lisbon, a dedicated workshop (19/04/2018) was organized as a pilot with the aim to learn from the application of the TIF-Tool on an innovation (which was in this case the Prescribed Burning Tool). This workshop was attendant by some 30 of BRIGAID’s participants (both innovators and end-users). Furthermore, during the WP2-4 breakout session it was discussed how the TIF-Tool has helped innovators. This yielded important insights:

- A joint application of the TIF-Tool on an innovation facilitates a lively discussion on the benefits, co-benefits and trade-offs of the innovation.
- Different people may come with different answers, so there is some subjectivity (however the aim of the TIF-Tool is to help sharpen the ideas about the own innovation).
- The value of the TIF-Tool is that it serves as ‘food for thought’ for both innovators and end-users.
- Although, the TIF-Tool is meant as a self-assessment, some questions may be difficult to answer without help of experts.
- Innovators may tend to give favourable answers, and try to avoid outcomes that indicate that their innovation may raise some concerns (or are far from readiness).
- An indication by the TIF-Tool that an innovation may raise (some) concern, or is far from readiness, could result in some resistance of innovators against the outcome of the TIF-Tool assessment.
- The TIF-Tool does NOT provide a definitive assessment: it is a 'checklist' designed to help identify potential concerns so that innovators can then choose how - or whether - to respond to them.

- Several question could help to identify import topics for further discussion with stakeholders or end-users.
- The sectoral questions could recognise the ‘decision maker sector’ as a distinct sector with its own set of questions.
- Several questions in the technical and societal part seem at first sight not applicable for all innovations, and the TIF-Tool could invite the innovator to explain why a question is not applicable (and re-consider the applicability of the question).
- The TIF-Tool presents a summary of the assessment result, and it would be helpful to provide an explanation on the scoring and suggestions how to proceed.
- TIF-Tool should refer for help on the separate issues of business development and market readiness, to the BRIGAID Market Analysis Framework (MAF+).
- The TIF-Tool could form a part of a broader ‘BRIGAID toolkit’, which includes the TRL Tool, TIF-Tool, MAF+, other tools (e.g. a sheet that could calculate costs and benefits).
- How to reach innovators outside the BRIGAID project? (Within BRIGAID the TIF-Tool is presented within the stocktaking process).
- It would be useful to provide some examples of application of the TIF-Tool.

3.3 Adjustments to the TIF-Tool V1 (resulting in version 1.2)

The feedback from Stocktaking Cycle 1 and the workshop on the TIF Tool was used to improve the version 1 of the TIF-Tool, resulting in TIF-Tool version 1.2. In particular a ‘General’ sheet was included which asks information about the innovator, type of hazard as well as the type of innovation, and provides at the same time (necessary) background information about BRIGAID’s categorisation of hazards and innovations.

In the ‘Welcome’ sheet is stressed that many assessment question may serve as 'food for thought', or as topics to discuss with stakeholders or end-users. The TIF Tool does NOT provide a definitive assessment: it is a 'checklist' designed to help identify potential concerns so that innovators can then choose how - or whether - to respond to them.

The ‘Welcome’ sheet now also refers to BRIGAID’s website, and to BRIGAID Market Analysis Framework (MAF+) for help on the separate issues of business development and market readiness.

In all sheets a drop down menu was inserted for the answers, and the answers were marked in red (to make it more clear).

Several questions were rephrased, some Excel formulas adjusted, and n.a. (not applicable) was added as an answer to several questions.

Furthermore, the ‘Environmental’ and ‘Sectoral’ impact sheets now inform innovators to opt for 'no impact' when an (informational) innovation has no direct impact, and that some (informational) innovations need to be combined with a structural measure that may have an impact (for which the TIF Tool should be applied separately).

Finally, now it is indicated (in relation to the graphical summary of the 'Innovation Design Assessment') that the impact on 'Environment' and on 'Sectors' may be positive, neutral or negative (while societal and technical performance may vary between 0 and 1).

4 TIF-Tool V1.2 (version 1.2)

4.1 Stocktaking cycle 1 and 2

TIF-Tool V1.2 was then re-presented to consortium innovators and introduced to non-consortium innovators in cycle 1 (see Table 3-1) of the stock-taking process by the leaders of WP 2-5. All innovators were asked to include the results of the TIF-Tool in their test reports. These results are presented in (the appendices of) Deliverable 2.2 'Test results of cycle 1; Report on initial test results'.

Furthermore the TIF-Tool V1.2 was introduced to all selected innovations in cycle 2 (see Table 3-2) by the leaders of WP2-5. All innovators were asked to include the results of the TIF-Tool V1.2 in their test results (see Deliveable 2.4, 'Test results of cycle 2 innovations').

Table F - 2: Selected Innovations cycle 2

	Innovation	Innovator
Innovations from Consortium Partners		
1	Application Framework with Drone system	RINA Consulting
2	Action plan in case of dike failure	Aquaproiect S.A.
3	Toolkit Method	Thetis S.p.A.
4	MyFloodRisk (for business)	HKV Consultants
5	URBRAIN	UTCB
6	Nature-sourced desalination using halophyte-zeolite wetlands	MIGAL - Galilee Research Institute
7	New growing system for food vertical farming	RINA Consulting
Innovations from non-consortium partners (stocktaking)		
1	BlueBloq / Micro Urban Wetlands (MUW)	Field Factors
2	Paint your city green!	Jan Lauwers & partners
3	Multiflexmeter	Waterschap Scheldestromen
4a	Recycle - Porous and Permeable Pavement Block	Favaro1
5	The Mobile Natural Biological System	Ayala Water & Ecology
6	Self-erecting flood protection system	University of Kaiserslautern
7a	Ecological Water Management	Ecological Water Management (consortium)
8	Mole - An underground soil moisture sensor connected to the cloud	IDESIO

We asked feedback from the innovators in cycle 1 and 2, and received feedback via a series of (skype) interviews (6 innovators), via meetings during the Cartagena project meeting (2 innovators and 3 WP leaders) and via email (1 innovator).

This also yielded some additional valuable feedback from innovators:

- The TIF-Tool helps to consider a broad range of aspects in the further development and decisions about steps towards implementation.
- The TIF Tool is easy to understand, even without the guidance document at hand.
- Some minor textual issues.
- Especially the graphical summary is very helpful for innovators, because it provides an easy to understand indication of the technical performance, environmental and sectoral impacts, and societal performance and relates to the techical-scientific background of most innovators.
- The results of the TIF-Tool are helpful in composing a brief report about important performance indicators and impacts of th innovation.
- The graphical summary could be presented more prominently.
- Although it is clearly indicated in the graphical summary, the difference between the range of technical and societal performance (0 ... 1) and environmental and sectoral impact (-1 ,,, +1) is confusing.
- Several indicators match with the ambitions (design criteria) of the NBS innovation, and it is good to notice that the results of the TIF-Tool perfectly reflect these design criteria.
- The TIF-Tool (the Excel-based self-assessment of the performance of climate adaptation innovations) is especially helpful for innovations in TRL 1-3. If there is already a pilot of an innovation (TRL-6), then more detailed background information is required (provided by experts).
- In cycle 2 the TIF-Tool was presented to the (non-BRIGAID partners) innovators in the final stage of testing. However, it might be more beneficial for innovators to apply the TIF-Tool in an earlier stage of the testing process.

4.2 Adjustments to the TIF-Tool V1.2 (resulting in version 1.3)

The feedback on TIF-Tool V1.2 from Stocktaking Cycle 1 and 2 was used to improve version 1.2 of the TIF-Tool, resulting in TIF-Tool version 1.3.

Next to a few minor textual adjustments, the main adjustment is a central position of the graphical summary in the sumary tab.

Furthermore the graphical results of the technical performance, environmental impact, sectoral impact and societal performance are now presented with their own scale bar to indicate more clear the difference in range.

5 TIF-Tool V1.3 (version 1.3)

5.1 Stocktaking cycle 3

TIF-Tool V1.3 was presented to all innovators in cycle 3 (see Table 3-3) of the stock-taking process by the leaders of WP 2-5.

Table F - 3: Selected innovations cycle 3

	Innovation	Innovator
Innovations from Consortium Partners		
1	AUDIMOD	ICATALIST
2	Irriframe - Acquacampus	UNIBO & Consorzio CER
3	PAS-WATER	ICATALIST
4	FlooDrought	Technical University of Civil Engineering Bucharest
Innovations from non-consortium partners (stocktaking)		
1.	Leaf.skin	Singulargreen
2.	ALMA raingarden	Storm Aqua AS
3.	Natural water retention through restoration of the sponge function of drained soils	Wetlands International
4.	Fire Free Fibres Blankets	AI-Geosystem
5.	RichWater	BioAzul
6.	Flood, planting at Erzeni river	POLIS UNIVERSITY

All innovators were asked to include the results of the TIF-Tool V1.3 in their test reports, and feedback from the innovators in cycle 3 was used for the final version of the TIF-Tool.

Furthermore TIF-Tool V1.3 will be tested in amongst others a dedicated workshop for water managers (scheduled in February 2019 in Delft). The experiences from this workshop will be used for the final version of the TIF-Tool.

5.2 Adjustments to the TIF-Tool V1.3 (resulting in final version)

The feedback on TIF-Tool V1.2 from Stocktaking Cycle 3 was used to improve version 1.3 of the TIF-Tool, resulting in the final TIF-Tool version 1.3.

The main adjustment was the inclusion of potential negative impacts for the Environmant and Sectoral tabs, as well as the inclusion of a CyberSecurity tab that is presented to the users only if such concerns are relevant to their innovation.

Appendix G. TIF Tool: Impact and Outlook

1 Introduction

Because the TIF-Tool was recognized by BRIGAID's board members as well as by the EU reviewers as a promising tool to support climate adaptation innovators, it was agreed to explore avenues to further develop an open-access web-based version of the TIF-Tool.

Following the suggestion of the EU reviewers to consider the TIF-Tool as an adaptation innovation itself, the idea was raised to apply BRIGAID's MAF+ Tool (the Business Development Exercise) on the TIF-Tool.

In September 2018 a meeting was organized between one of the co-developers of the TIF-Tool (Jantsje van Loon-Steensma, TU Delft) and the developers of the MAF+ (Gerardo Anzaldua and Hugh McDonald, Ecologic Institute). In preparation for this meeting, an account was set up for the TIF-Tool. The initial questions of the MAF+ exercise immediately revealed the differences in goal between BRIGAID's TIF-Tool and other climate adaptation innovations. The TIF-Tool was developed as a free, and easily accessible tool, and not to make profit. Therefore, many questions of the MAF+ seemed not applicable. Moreover, the application of the MAF+ exercise would require a substantial investment of time (e.g. to elaborate a comprehensive bench-mark analysis).

During BRIGAID's meeting in October 2018 the present co-developers of the TIF-Tool (TU Delft, University of Oxford, Universite Catholique de Louvain, Instituto Superior Agronomia, Icre8, Bureau Veritas) agreed that the TIF-Tool was developed as a free, and easy accessible tool, and that TU Delft should took the lead in the further development of an open-access web-based version of the TIF-Tool. This could possible imply the application of the MAF+ Tool.

As a next step, the web-based version of the TIF-Tool could form a part of a broader 'BRIGAID Toolkit', which includes the TRL-Tool, TIF-Tool, MAF+, other tools (e.g. a sheet that could calculate costs and benefits). Further agreements have to be made about hosting and maintenance of such a BRIGAID Toolkit.

The potential of BRIGAID's tools (including the TIF-Tool) is currently explored with various stakeholders, such as water boards and Climate KIC.

2 Impact for innovators

2.1 Overall Survey

A survey titled ‘Your experience with BRIGAID’ was conducted to directly assess the impact of the project on innovators and was sent to all innovators who had received particular support types from BRIGAID. This constituted a group of about 45 innovators who had received one or more of the following forms of support;

- Business development support
- Support through the use of the TIF tool (Technical Implementation Framework)
- Support through the use of the MAF+ tool (Market Analysis Framework)

The survey included a separate section on the TIF tool, from which 60% of respondents described the use of the tool as ‘easy or very easy’ with only 7 % finding it difficult. Over 90% would recommend it to other innovators.

The components (represented as tabs in the excel tool) considered most relevant are shown in **Fout! Verwijzingsbron niet gevonden.**. It is encouraging that all components were considered the most important to at some innovators, as it vindicates the inclusion of these components. For example, the sectoral component is seen as the least relevant to many of the innovators, but as the most important to a select few.

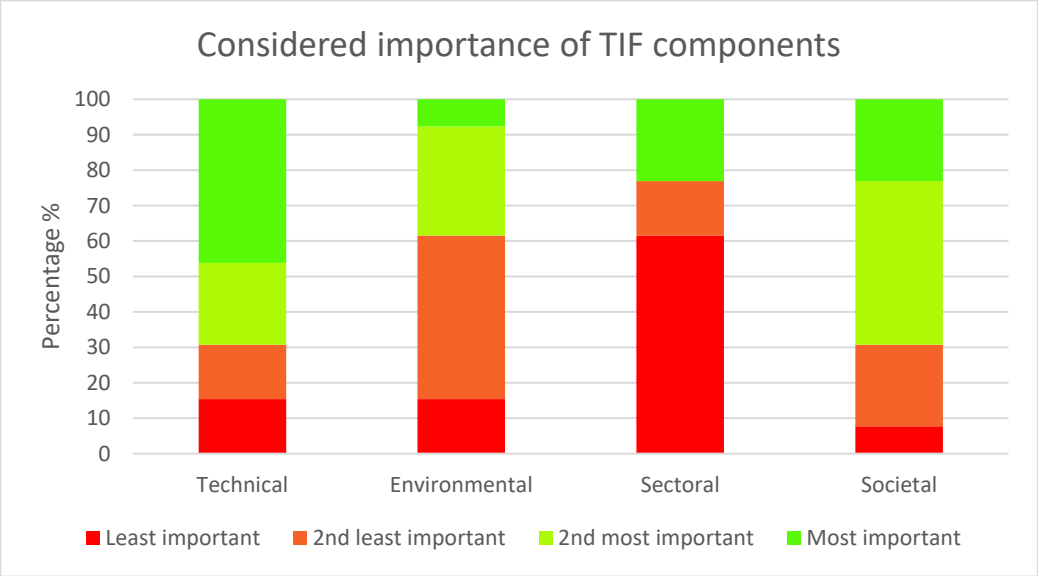


Figure G - 1: Survey results for considered importance of the TIF components.

More generally, the TIF tool was seen by innovators to be useful, and simple to use, but the multiple choice format did not allow for more detail to be provided. Given that the tool is simply meant to help innovators identify potential issues related to their products, this concern does not to be addressed in the tool itself, but perhaps better explanation is needed to accompany the tool. Other comments and suggestions given by the innovators include;

- Seeing how different answers would result in a better score is currently not clear
- Examples could be given to see how it works
- Including a life-cycle aspect to the assessment

3 Cyber security assessment

3.1 MSc Research

As part of the development of the TIF tool, an MSc was undertaken at TU Delft on the topic of 'Assessing Cyber Security of Innovations in Climate Disaster Resilience'[20].The impacts of cyber security threats applicable to climate change innovations was categorized under the following headings;

- Confidentiality; The level of confidentiality determines how the system discloses information and services. Unauthorized entities should not have access to the asset, as these entities can use the asset for other, potentially harmful, purposes.
- Integrity; The level of integrity is a safeguard of the accuracy and completeness of the information and services provided. Modified or malicious information and services damages processes or the system in its entirety.
- Availability; The level of availability is the continuous access for authorized entities

[20] Sharwan Adjodha MSc. Thesis available at TU Delft repository; http://resolver.tudelft.nl/uuid:f728a854-d34a-4197-af12-3034fab1b3ce

upon demand. Limited availability may harm the continuation of the system and its processes

The MSc research the conducted cyber security risk assessments on two specific innovations from BRIGAID, selected for their relevance to the topic. These were GM4W; a heavy precipitation forecasting service system for local entities, and QoAir; a blockchain network of weather measuring sensors. Based on the research and results of these assessments, an experimental version of the TIF tool with a fifth assessment tab – 'Cyber Security' was developed. As with the other tabs, the assessment was based on a series of questions for the innovators, and the results were expressed in the summary tab as a score between 0 (cyber security threats can have a large impact) and 1 (cyber security threats have no impact) for the categories given above.

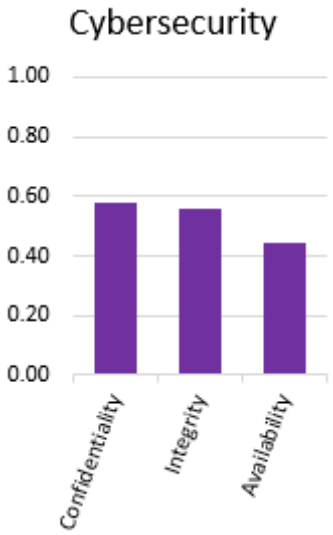


Figure G - 2: Example results of the cyber security assessment in the prototype TIF tool

3.2 Implementation in TIF tool

The topic of cyber security is a very relevant one for future climate change innovations, and it was agreed that future iterations the TIF tool should somehow include cyber security aspects. However, in order not to over-complicate the tool, the questions (and therefore) relating to cyber-security are 'hidden' from innovators unless they answer the following question positively;

Could your innovation be subject to cyber security threats?
Choosing 'Yes' causes the 'cyber security' tab to appear below with specific cyber security information to be filled out.
Please refer to the cyber security threat guidance document if unsure.

Following on from a positive response, the following questions are asked of the innovator, providing the scores for confidentiality, integrity and availability;

1	**Service**
1.1	Does any part of your innovation's system require electricity?
1.2	Is there a protocol in place in case of power outage or other disruption of service?
1.3	Does your innovation prioritize critical assets in case of limited power supply?
1.4	Is the innovation able to operate offline?

2	**Data Transmission**
2.1	Does any part of your innovation's system require the transmission of data?
2.2	Does your innovation have servers sending and/or receiving data?
2.3	Does your innovation have firewalls for the protection of your servers?
2.4	Does your innovation store data?
2.5	Is stored data in the innovation's system protected from unauthorized access?
2.6	Does the data used by the innovation contain sensitive data (privacy, legal, ethical)?
2.7	Is the data within your innovation encrypted?
2.8	Is the validity of the data in your innovation monitored?
2.9	Is there a backup protocol in case of loss of data?

3	**Hardware**
3.1	Does any part of your innovation's system require hardware?
3.2	Is any hardware belonging to your innovation placed in an on-site location?
3.3	Is the site location of your innovation secured?
3.4	Is any hardware belonging to your innovation placed out in the open?
3.5	Is there a protection for the hardware elements of the system?

4	**Identity & Access**
4.1	Does any part of your innovation's system require staff members' access?
4.2	Does your innovation have a control for identification of accessing entities?
4.3	Does your innovation have a clear distinction in the authorization of different entities?
4.4	Is the data within your innovation accessible for the entities who need that data?
4.5	Do users have access to the innovation at all times?
4.6	Are entities with access to the innovation's system trained to limit human errors?
4.7	Does any part of your innovation's system require outside parties' access?
4.8	Is every part of your innovator's system is built within your own company?

4 Web-based application

A web-based version of the TIF tool is available at www.brigaid.eu .