IMPETUS

Turning climate commitments into action

Deliverable Report

Design criteria and methodology for Regional Adaptation Pathways

30.09.2023

Deliverable Number: 5.1

Author:
Andrea Marinoni (UiT)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101037084.

Deliverable No.	D5.1
Deliverable nature	Report (R)
Work Package (WP) and Task	WP5, Task 5.1
Dissemination level	PU
Number of pages	20
Keywords	Adaptation pathways, functional framework, indicators, scenarios, tipping points
Authors	Andrea Marinoni (UIT)
Contributors	Dionysios Nikolopoulos, Nikos Pelekanos, Josep Pijuan Parra, Sebastiano Carrer, Elisa Andreoli, Chiara Castellani, Anastasia Fili, Anastastios, Athanasiou, Gonzalo Vilella Rojo, Queralt Plana Puig, Martine Rottink, Sandra Banusch, Daniel Wicke, Valentina D'Alonzo, Andreas Hagset, Ingrida Bremere, Daina Indriksone, Klio Monokrosou
Contractual submission date	30.09.2023
Actual submission date	29.09.2023
Document description	This document describes the activities undertaken in the IMPETUS project, including those carried out under WP5 Task 5.1.

[1] PU = Public
CO = Confidential, only for members of the consortium (including the Commission Services)
R = Report
ORDP = Open Research Data Pilot

Technical References

Project acronym	IMPETUS
Project full title	Dynamic Information Management Approach for the Implementation of Climate Resilient Adaptation Packages in European Regions
Call	H2020-LC-GD-2020-2
Grant number	101037084
Project website	http://climate-impetus.eu/
Coordinator	EUT

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101037084.

Document history

V	Date	Beneficiary	Author
V1	25.05.2023	UiT	Andrea Marinoni
V2	11.08.2023	UiT, EUT	Andrea Marinoni, Josep Pijuan Parra
V3	04.09.2023	UiT, EUT, NTUA, THETIS	Andrea Marinoni, Gonzalo Vilella Rojo, Dionysis Nikolopoulos, Chiara Castellani, Sebastiano Carrer
V4	20.09.2023	EUT	Josep Pijuan
Final	29.09.2023	EUT	Hannah Arpke

Disclaimer

Abbreviations

Abbreviation / Acronyms	Description
WEFE	Water-Energy-Food-Ecosystems

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 101037084.

Table of contents

List of tables

List of figures

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101037084.

Executive Summary

This deliverable is the first achievement of Work Package 5 and outcome of Task 5.1 *Adaptation Pathways* of the IMPETUS project. It describes the main functionalities and processes that are contained in the methodology for the development of regional adaptation pathways in the IMPETUS project.
Specifically, a thorough survey of the strategies for development of adaptation pathways that have been proposed in recent years in the technical literature is reported. Considering the results achieved by the consulted examples in technical literature, as well as the goals and objectives of the regional adaptation pathways in the IMPETUS project, a flexible and dynamic functional methodology for the development of adaptation pathways is introduced. The proposed methodology relies on the identification of objectives and vulnerabilities, that are then used to address future adaptation needs. This methodology implies employing a system of performance metrics to quantify the effect of adaptation measures on indicators and scenarios. In this way, the development of the adaptation pathways is flexible and versatile to address the evolution of the climate situation in every given region of interest. Also, by iteratively assessing the objectives and the vulnerabilities, this scheme addresses the changes and modifications that occurred, so to maximizing the impact of the adaptation interventions to be adopted.
This structure aims to provide a common grid and workflow for the identification of goals, vulnerabilities, tolerance, and effect of interventions on climate indicators that can be used by each DS to structure the portfolios of adaptation and mitigation measures to best address the effects of climate change in their region. At the same time, this scheme guarantees the possibility for stakeholders, communities, and authorities in each DS to provide their input and feedback to the development of adaptation interventions, so that the co-creation process of adaptation pathways at the core of the IMPETUS project can be fruitfully achieved.
This deliverable is closely linked to the activities of WP1, WP2, WP3, WP4, and WP6, and refers as initial baseline for the role of partners and steps taken towards the achievement of WP5 deployment of adaptation pathways at each demonstration site.

1 Objectives of task and deliverable

The IMPETUS project aims to support local stakeholders, communities, and authorities to co-create portfolios of measures and actions for climate change adaptation and resilience, so to enable the transition to a climate-neutral and sustainable society, as mentioned in the EU strategy for climate adaptation [24-26]. To achieve this goal, a coherent framework that can investigate and explore the effect of adaptation and mitigation measures in the diverse European biogeographical regions under different climate scenarios is developed in IMPETUS. This structure is versatile and flexible to properly account for the inputs and feedback from the Involved parts in the realm of a co-creation process of the portfolios of aforesaid measures.
This architecture will allow the diverse users of the IMPETUS project (i.e., Scientists, Climate modelers, Authorities, Environmentalists, Key Community Members and administrators, Policy Makers, Society at large) to accurately characterize the impact of factors and components (methodological, technological, governance, awareness, behavioural, economic, financial) on each demonstration site of the IMPETUS project. In this way, the portfolios of adaptation measures resulting from the IMPETUS framework will be:

- supported by knowledge and data analysis in the pursuit of resilience;
- resulting of the collaboration with quintuple helix stakeholders in the framework of a multi-governance co-design and co-creation process;
- maximizing their impact while minimizing the “regret” of communities to implement them;
- scalable and versatile as a function of the evolution of climate change and other drivers;
- supporting sustainable development at environmental, societal, and financial levels.

To this aim, the IMPETUS project allows stakeholders, communities and authorities to share experiences in the co-creation process of the adaptation measures in the framework of the Resilience Knowledge Boosters (RKBs), which digital component has been described in D2.1. The RKBs enable the diverse players in the IMPETUS project to co-create, demonstrate, monitor and assess the portfolios of adaptation measures for sustainable adaptation and resilience. Also, RKBs enable the thorough understanding of the actual impact of diverse sets of adaptation solutions and interventions (adaptation

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 101037084.

pathways) in each demonstration site under different climate scenarios. In this way, a reliable characterization of the possible options for adaptation and mitigation of the climate change effects in each DS can be achieved. Hence, this would allow the local authorities, stakeholders and communities in each DS to assess the impact of the solutions and interventions planned, and to retrieve information on the vulnerabilities of each region under diverse climate change scenarios. Ultimately, this co-creation process of the adaptation measures would lead to identifying the best adaptation pathway to be implemented in each DS to counteract the effects of climate change in the context of the diverse climatic risks that have been addressed in the IMPETUS project. At scale, this will thus guarantee the scalability and replicability of the adaptation and mitigation measures across the diverse biogeographical regions, also beyond the time extent the IMPETUS project.
Task 5.1 of the IMPETUS project aims primarily to set the guidelines for the design criteria and methodology for Regional Adaptation Pathways, with the following goals in mind:

- to enable the coordinated development of the regional adaptation pathways, taking into account the interaction between physical and digital worlds (by means of e.g., tools, models, visualization engines included in the RKBs);
- to enhance characterization of ecosystems and climate resilience status and the dynamic effect of measures for adaptation and mitigation in each DS;
- To enable co-creation and social innovation strategies, so that regional communities can be reinvigorated for their effort towards climate change adaptation;
- To provide knowledge sharing and information extraction across different regionalities at fine granularity and resolution scale by means of federated strategy.

To this aim, this deliverable provides details on the design criteria and methodology for the development of adaptation pathways that can be used in each DS. Starting from a thorough literature review of the schemes for the development of regional adaptation pathways that have been implemented in the last years, this deliverable addresses the benefits and drawbacks of the proposed strategies. As a result, this deliverable identifies a structure that is versatile and flexible to address the needs, expectations and operational requirements of the development of adaptation pathways in each DS. In this way, we can set up a dynamic workflow to identify the objectives, vulnerabilities, critical points and achievable results of adaptation solutions and interventions in the IMPETUS project, so that the community systems can appreciate the impact of climate change in their region (according to the activities of WP2, 3, and 4 in the IMPETUS project).
The functional dynamic framework for the development of adaptation pathways identifies points that can be connected, managed, and refined across each DS to take into account the specific goals and characteristics of each DS. This allows the stakeholders, communities and local authorities to characterize the impact of adaptation measures.
This deliverable also provides an introduction to the specific properties and definitions of the adaptation measures in each DS, focusing on the objectives for climate resilience of each DS, and on the effects on climate indicators that each intervention might have under diverse climate scenarios in each DS.
This shows how the proposed dynamic adaptation pathways framework can be integrated and interacting with the RKBs, so to boost the advancement of climate resilience in the diverse DSs.
This report is organized as follows. Section 2 introduces a survey of the examples of frameworks for adaptation pathways that have been proposed in technical literature. In particular, following the approach proposed in [1], Section 2.1 provides a categorization of the approaches that have been recently introduced. It also draws the motivation for the design choices that have been made in the context of the IMPETUS project for the design of the methodology for dynamic adaptation pathways (that are described in Section 2.2). Section 3 describes the main features of the adaptation pathways that will be developed in each DS of IMPETUS. Finally, Section 4 reports the final remarks and outlook of the proposed methodology in the context of the IMPETUS project.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101037084.

2 Design of a methodology for the development of adaptation pathways

In this Section, the background and motivations of the methodology for the development of adaptation pathways are introduced. In particular, Section 2.1 reports the main examples of schemes for adaptation pathways in technical literature. Section 2.2 discusses the main motivations and design criteria for the methodology that is proposed in the IMPETUS project, and the main features that its functional framework shows.

2.1 Adaptation pathways in the technical literature

Given the complexity and the uncertain nature of social-environmental challenges, especially under the lens of climate change, planning approaches that promote adaptability are required to accommodate changing conditions over time. 'Adaptation pathways' have been proposed as a promising decision-focused approach to incorporate flexibility into decision-making and account for future uncertainties.
In particular, adaptation pathways have experienced growing popularity as a decision-focused approach in climate adaptation research and planning. Adaptation pathways started to be conceptualized in 2010 [1]. They have become recognized as sequences of actions, which can be implemented progressively, depending on how the future unfolds and the development of knowledge [1]. Moreover, in an adaptive plan, adaptation pathways capture the implementation process by specifying which measure(s) are to be taken at each given time. As such, adaptation pathways rely on the definition of uncertainty and on the development of flexible planning schemes. Also, by means of adaptation pathways, decision makers, stakeholders and communities can identify 'no or low regrets' interventions, hence avoiding undesired effects such as inadequate thresholding and effects of maladaptation practices.
Historically, the first instances of adaptation pathways were assuming a constant planning horizon, thus modelling the goals of the stakeholders as static and relying on the inputs from decision makers [1-5]. This original strategy has been recently amended in order to enable the use of adaptation pathways in uncertain and resource-constrained environments, where multiple decision-makers are involved and adaptation outcomes and goals are more complex.

The diversity of the approaches and uses of frameworks for the development of adaptation pathways make a survey of all these strategies quite cumbersome. To provide a robust understanding of the schemes that have been implemented in recent years, a research on the technical literature has been carried out, taking advantage of recent surveys that have been recently published [1,4,9]. This research is instrumental to provide material to choose a functional framework to address the operational needs and requirements of the adaptation portfolios in each DS. Also, it enables to match the expectations of the key players (i.e., stakeholders, communities and local authorities) in each DS.
The key component of adaptation pathways is the sequencing of decisions and measures in time to achieve future goals according to relevant climate scenarios. In this respect, technical literature seems to agree on considering adaptation pathways as adaptation responses that admit path dependency, decision sequencing, and timeframes.
Uncertain and changing conditions require more adaptive planning which enables flexibility in decision-making over time to account for changing conditions. However, the conceptualizations differ in the extent to which pathways are understood as alternative sequences of discrete actions to perform/introduce/incorporate/identify a well-defined adaptation need, or as a metaphor for broad directions of change and transformation.
In this context, in [1], nineteen case examples have been thoroughly identified, and characterised, by (i) decision context, (ii) method, and (iii) representation or visualisation of the output, [1-23]. Table 1 reports these examples, discussing also whether the proposed methodologies for development of adaptation pathways have been implemented.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101037084.

Table 1 - Main examples of adaptation pathways frameworks as reported in technical literature [1].

Case study	***Context***	***Method***	***Visualization***	***Implemented***
Climate uncertainty in the Thames Estuary 2100 Project [2], [3]	Planning long-lived infrastructure under the Thames Estuary 2100 Project, London	Identifies and discusses sets of options for lowering risk under different climate conditions	Maps what measures satisfy performance criteria under rising sea levels	Yes
Dynamic adaptive policy pathways. A method for crafting robust decisions for a deeply uncertain world. [4]	Planning for long-term water safety in the Dutch Delta Programme (Delta Commissioner, 2013).	Connects actions to achieve goals under climate uncertainties. Discusses no regret actions, lock-ins and stakeholder preferences	A route-map illustrating actions to be taken with increasing impact over time	No
Local coastal adaptation pathway [5]	Exploring adaptation for a coastal community in Australia	Assesses 'things of value' at risk of sea-level rise and associated adaptations. Next constructs pathways in workshops with residents	Geographical map overlaid with a timeline, thresholds and trigger points for actions	Yes
Hurricane Sandy and adaptation pathways in New York: Lessons from a first-responder city. [6]	New York City Climate Action Strategy after Hurricane Sandy	Reviews measures triggered by perceived risk levels. Qualitative evaluation of future plans	Timeline of selected measures and risk levels	Yes
Regional climate change adaptation plan for the Eyre Peninsula. [7]	Adaptation planning for the Eyre Peninsula in South-Western Australia for eight areas of decision making	Regional planning process involving conversations and workshops with key regional leaders and influencers	Graphics of best current practices and transformational options over time with decision switch points	Yes
Vulnerability and resilience for adaptation pathways in remote disadvantaged communities. [8]	Responding to increasing stressors (flooding and heat waves) in remote disadvantaged regions	Puts together vulnerability and resilience narratives in linked system diagrams and pathways	Sketches short-term responses and longer term actions under stressors	No
Adaptation pathways of global wheat production [9]	Wheat yields in nine major wheat producing countries	Models intensity and timing of adaptation to maintain yields for two adaptation	Graphs of timing and intensity of adaptations necessary to maintain current wheat yields	Yes

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101037084.

		options (irrigation, change crop variety)		
Adaptation services and pathways for the management of temperate montane forests under transformational climate change [10]	Managing changes in fire events caused by a warming, drying climate in montane forests in south-eastern Australia	Constructs pathways from 1) ecosystem adaptation services, 2) decision points between ecosystem states, 3) values, knowledge, rules to reframe decision context	Qualitatively visualises alternative states and decision points to switch between states over time	Yes
Mapping options and trade-offs for London's water resources [11]	Adaptation planning for London's urban water supply system, to link current risk-based planning with long term pathways	Risk assessment, with a quantification of risk of water shortages under different pathways and population and climate scenarios through to 2100	Timeline of measures against 1) volume of water saved / gained; 2) probability of water shortage	Yes
Scenario planning to leapfrog the Sustainable Development Goals: An adaptation pathways approach. [12], [13]	Poverty alleviation under climate change in developing countries, Indonesia case.	Uses a normative back-casting process to identify pathways towards an aspirational future vision, with emphasis on building adaptive capacity	Abstract representation of scenario lines (what could be) and a vision (what should be) over time	No
Flexible adaptation planning: Cockburn sound coastal alliance experience. [14]	Addressing coastal vulnerability along Cockburn Sound, Perth, Australia.	Defines and appraises pathways for different strategic aims	Decision trigger points on risk / time axis	Yes
Development and valuation of adaptation pathways for storm water management infrastructure [15]	Design of urban storm water management infrastructure, based on Kent Ridge catchment, Singapore	Cost-benefit analysis of pathways, generated as incremental combinations of three pre-defined solutions	Maps adaptation actions and tipping points with respect to increase in annual rainfall	Yes
Climate adaptation pathways in multiuse woodland landscapes [16]	Management of grassy eucalypt woodland landscapes, south-eastern Australia	Outlines pathways for three future landscapes. Discusses decision context and	Sketches decision points and resulting	No

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101037084.

		implementation constraints, using the values-rules-knowledge framework	trajectory in (mal)adaptation space	
Pathways to resilience: adapting to sea level rise in Los Angeles [17], [18]	Reduction flood risk and damage from sea level rise in Los Angeles County, US	Analyses combinations of measures with respect to flood risk and damage costs	Tree diagram with measures and switch points at different stages of sea level rise	Yes
Water Resource Planning in the Cauvery River Basin, Karnataka, India [19]	Planning under climate and socioeconomic uncertainties in the Cauvery River Basin, India.	Iterates climate and socio-economic scenario assessment, appraisal of measures with stakeholders, and modelling	Timeline of measures as proposed by four stakeholder groups	Yes
Adaptation pathways for conservation law and policy [20]	Managing climate-induced change with Australian conservation law and policy	Outlines three possible pathways for changes in law with the legal mechanisms needed	Sketches pathways for expanding the focus of conservation law	No
Paving the way to coastal adaptation pathways [21]	Adaptation to sea level rise in French coastal areas	Constructs pathway narratives for coastal archetypes from under two scenarios of sea level rise	Narratives built from change variables, including governance	No
Designing adaptation pathways for flood-affected households in Bangladesh [22]	Building livelihood resilience in north-west Bangladesh	Adaptation options are identified from correlation to resilience indicators and ordered from the short-term to long-term options	Visualisation as in Case 5, with respect to a general trend of flooding	Yes
Strategic planning of the integrated urban wastewater system using adaptation pathways [23]	Management of a semi-hypothetical urban wastewater system	Multi-criteria approach to evaluate strategies for i) compliance with adaptation thresholds and ii) levels of regret under transient scenarios	Compliance and regrets for strategies over time, for decision makers to select pathways	No

By looking at the methods summarized in Table 1, it is worth noting that the methods to develop adaptation pathways introduced in technical literature have been mainly implemented in the context of

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101037084.

land and water management [1-23]. In addition, we can also observe, getting inspired by the approach proposed in [1], how the reported strategies can be clustered into three main groups of approaches for adaptation pathways development. These groups are [1]:

1. **Performance-threshold oriented pathways development**: the strategies in this group aim at providing alternative sequences of discrete adaptation measures in response to different future scenarios. This group of strategies rely on a well-defined system of interest which is used to address future adaptation needs. A performance metric is employed to quantify the effect of the actions in support of an existing value set. The methodologies in this group were designed in data-rich contexts where the goals can be clearly quantified. Also, these goals are typically iteratively re-assessed, thus assuming a clear mandate and agency of the decision makers (see for instance [2-4,11,17]).
2. **Multi-stakeholder-oriented pathways development**: these strategies stress the social and institutional components of pathways development. The methodologies in this group assume that adaptation plays out in a multi-stakeholder setting. Pathways methods attempt to include multiple drivers and multiple stakeholders with conflicting goals, interests, and contested values. Hence, in this approach, adaptation pathways are more oriented to strengthen social engagement and represent different social needs rather than to achieve a pre-defined and quantitative adaptation result. (see for instance [5,19])
3. **Transformation-oriented pathways development**: the strategies in this group do not assume current system performance to be satisfactory. Instead, these methodologies assume that adaptation can be achieved by means of governmental measures. As such, these schemes take into account a need for adjustment of values and policies in the framework of the adaptation pathways. (see for instance [12,16]).

With this in mind, it is possible to dig deeper into the properties and features that each group of strategies is characterized by. Specifically, the methods for performance-threshold oriented pathways development (Group 1) assume that the adaptation goal is clearly defined, and the results are policy and government-actor oriented. Adaptation is motivated by system performance dropping below a decisive level. This condition is called an adaptation tipping point. Measures are organized incrementally into pathways to maintain performance under different climate scenarios. Pathways are evaluated quantitatively and are represented in terms of “route-maps” [4], [11].
The methods for multi-stakeholder-oriented pathways development (Group 2) are mainly focused on the use of participatory methods, and attention to multi-stakeholder interests and ambiguities. Their approach to knowledge development is mainly designed to provide space for recognition and inclusion of non-scientific knowledge. As such, they aim to promote collaborative learning and to build capacity for adaptive planning. Pathways maps reflect the output of a stakeholder process and qualitatively visualize selected pathways [5], [19].
Finally, the methods for transformation-oriented pathways development (Group 3) focus on the development for a future goal, assuming that no planned intervention or policy would be appropriate to reach it unless deep transformation in the socioeconomic system and in the cultural dimension is performed. These methods work following three steps: *i)* identification of drivers of change; *ii)* participatory development of an aspirational vision and future scenarios of what could be; and *iii)* a normative back-casting process to identify and explore no-regrets strategies. These methods rely on the need for transformation and the use of visioning and back-casting methods. As such, they can be ideal in situations where adaptation measures have not been thought, planned, and designed before, i.e., where an implementation deficit and the potential need for transformational change have been identified [10], [12], [16].
Considering these points and the objectives of the IMPETUS project to provide an actual impact on climate change adaptation in the European biogeographical regions, a dynamic methodology to develop adaptation pathways in the considered demonstration sites has been designed, mainly relying on the functional framework characterizing schemes in the aforementioned Group 1. The next Section provides the main motivations and characteristics of this architecture.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 101037084.

2.2 A functional framework for dynamic adaptation pathways development

2.2.1 Motivations and design criteria

To accomplish the aims and objectives of the IMPETUS project, a functional framework for the development of adaptation pathways in each DS should consider the following goals:

1. Meet short and long-term adaptation needs;
2. Promote collaborative learning, adaptive planning, and adaptive capacity;
3. Account for complexity and long-term change, including a potential need for transformation.

To meet these goals, the methodology for the development of regional adaptation pathways must be designed according to the following criteria, originally identified in [1]:

- *The development of adaptation pathways focuses on specific decisions or decision-makers to meet short and long-term adaptation needs*. This criterion entails the capacity of the proposed methodology to allow the objectives to be selected so that short and long-term adaptation needs are met. Also, the assessment of the fulfilment of adaptation needs must be flexible easily rearranged according to the identification and selection of decision makers(s) and their corresponding goals. This is to maximize the actual impact of adaptation interventions and policies in the adaptation pathways on local key players;
- *The development of adaptation pathways allocates actions to meet short and long-term adaptation needs on a temporal scale under uncertainty*. This makes the sequencing of activities and interventions factor in several components of dynamic adaptation measures, such as lead-time, trade-offs, interdependencies, flexibility, reversibility, and robustness;
- *Visual communication of adaptation pathways promotes collaborative learning on the adaptation process*. As such, the proposed methodology must effectively synthesise actions required to meet adaptation needs. The visualisation of pathways can be used to promote collaborative learning and adaptive capacity with key players in the definition of adaptation measure portfolios;
- *Monitoring and evaluation enable learning from and informing pathways implementation*, i.e., the effect of actions must be monitored so to inform their re-adjustment and / or follow-up interventions and activities;
- *Engaging stakeholders with different values, goals, and knowledge across levels and sectors facilitates collaborative learning on the potential need for transformation.* Involving stakeholders in the definition of adaptation pathways is instrumental to dealing with ambiguity and uncertainty. Thus, a common agenda for the generation of adaptation pathways, and an adaptive functional framework, must be established.
- *The development of adaptation pathways must account for complexity and a need for transformation:* the proposed methodology must enable the mapping of causes of vulnerability and controlling variables, particularly across scales. This can be achieved by addressing both symptoms and root causes of vulnerability resulting from the use of activities ranging from physical interventions to capacity-building and governance arrangements. Various types of intervention can be combined in pathways to generate and sustain the transformational changes needed;
- *Adaptation pathways are a necessary integral component of long-term sustainable development.* Therefore, the proposed methodology must allow the adaptation pathways to address and guarantee the long-term sustainability of development choices. As such, the proposed methodology must allow the pathways to promote coherent responses for long-term sustainable development.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101037084.

2.2.2 Methodology for dynamic adaptation pathways

To accomplish the aims and objectives of the IMPETUS project, a functional framework for the methodology used to develop adaptation pathways is proposed. This architecture is inspired by the work in [4] and provides an analytical approach for exploring and sequencing a set of possible actions based on alternative external developments over time. Central to adaptation pathways are adaptation tipping points, i.e., the conditions under which an action no longer meets clearly specified objectives. The timing of an adaptation tipping point is scenario-dependent. Also, it relies on the quantification and assessment of the effects of each intervention on the considered climate indicators under different climate scenarios. Pathways are designed to address future adaptation needs. Possible actions are sequenced in the form of adaptation decision trees or a 'roadmap', which definition relies on the properties of the adaptation tipping points. Any given route through the tree is an adaptation pathway. The analysis of pathways provides insight into potential lock-ins and path dependency [1,4].
The proposed approach offers an overview of the typical iterative assessment steps [1,4,27]:

- the decision context;
- the vulnerabilities and opportunities;
- the identification and analysis of actions;
- the development and evaluation of pathways;
- the design of an adaptive plan;
- the plan implementation;
- the monitoring;
- the periodical revision of the plan.

As such, the proposed methodology can be categorized in the Group 1 of strategies for the development of adaptation pathways that has been previously introduced in Section 2.1. This enables to apply the performance-threshold orientated pathways approach in a multitude of adaptation contexts, such as those represented by the demonstration sites of IMPETUS.

This integrated approach includes: transient scenarios representing a variety of relevant uncertainties and their development over time; different types of actions to handle vulnerabilities and opportunities; Adaptation Pathways describing sequences of promising actions; and a monitoring system with related contingency actions to keep the plan on the track of a preferred pathway.

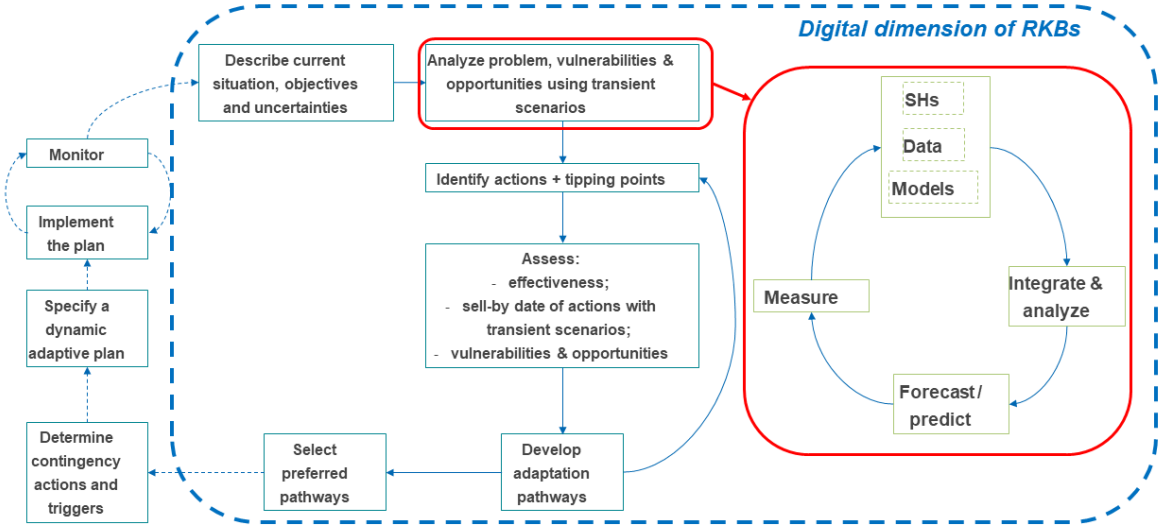


Figure 1 - Functional framework of the proposed dynamic adaptation pathways methodology.

The main steps of the proposed methodology (whose functional framework is displayed in Figure 1 are as follows:

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101037084.

1. *Describe the study area*. This step includes defining: a) the system's characteristics, b) the objectives of the adaptation process, c) the constraints in the current situation and d) potential constraints in future situations. This step provides a definition of success of a given adaptation pathway. This definition depends on the specifics of the desired outcomes and on the assessment of 'sell-by dates' of the actions. As such, it is important to specify the indicators and targets that are used in subsequent steps. The description of the study area includes a specification of the major uncertainties that play a role in the decision-making problem. These uncertainties are not restricted to uncertainties about the future, but can also cover uncertainties related to the data or models that are used;
2. *Problem analysis*. In this step, the current and possible future situations are compared to the specified objectives to identify potential gaps. In particular, the possible future situations are considered as references under the assumption of absence of new policies to be implemented. Thus, this step considers transient scenarios that span the uncertainties identified in step one. Also, this step entails the definition of opportunities and vulnerabilities in the analysis, ideally performed by means of computational models (e.g., digital twins of the considered region of interest [4]). Specifically, opportunities are developments that can help in achieving the objectives, while vulnerabilities are developments that can harm the extent to which the objectives can be achieved [4].
3. *Identification of possible actions* that can be taken to meet the expected objectives. The opportunities and vulnerabilities identified at the previous step are instrumental to specify the characteristics of these actions. These actions can be further described in terms of the policies that can be implemented in the region of interest under the different relevant climate scenarios. Therefore, this step ultimately aims to put together a rich pool of possible actions able to describe the diverse conditions that the development of the adaptation pathways might have to face;
4. *Evaluate the actions*. In this step, the assessment of the effects of each considered action under different scenario conditions is performed. The outcome of this process is used to retrieve information on the sell-by date for each of the actions. This step implies the re-evaluation of vulnerabilities and opportunities that have been previously defined. This process can take place under diverse criteria, focusing, e.g., on the ability of a given action to reduce vulnerabilities; on the capacity of a given action to benefit from a specified opportunity; on the ability of each action to generate new opportunities; on the temporal validity and sustainability (short term vs long term) of each action; on the ability of each action to avoid maladaptation situations. As a result of this quantification, only the actions that are deemed promising are considered for the following steps;
5. *Assembly of pathways* using the information generated in the previous steps. First, it is worth noting that the re-assessment of the opportunities and vulnerabilities (step 4) would lead to the identification of new or additional actions, hence resulting in an iterative process starting from step 3. At this stage, the actions could be considered as sets of actions if they must be taken all together in the definition of the pathways. The adaptation pathways are then designed taking into account only the actions that are considered appropriate. Specifically, a pathway identifies a sequence of actions that are arranged over a temporal timeline: an action becomes active if the previous action does not fulfil the objectives that are pertinent to the given scenario. The concatenation of these actions can be performed according to diverse criteria and performance scores. These criteria could consist, e.g., on the impact of the actions, their operational needs and requirements, the uncertainty they entail, and their versatility. Analyzing all these components in a system perspective would lead to identify all the valid pathways that could fulfil the objectives defined in step 1.
6. *Develop a manageable number of preferred pathways*. In this step, a selection of the valid pathways is performed, so to reduce the space of the possible concatenations of actions. This reduction should consider the diversity of the perspectives and scenarios the valid pathways can entail. The ultimate goal of this step is to identify valid pathways that can maximize the robustness (i.e., the ability of the pathways to achieve the expected goals without being

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101037084.

perturbed by non idealities). The robustness can be also assessed in terms of technological readiness, as well as of societal readiness, so to increase the impact of the adaptation pathways on the life of the communities of the region of interest. Given the iterative structure of the process that has been discussed in the previous points, the pathways selected at this step would determine the benchmark for the dynamic adaptive methodology.

7. *Improve the solidity* of the preferred pathways through contingency planning. In this step, the set of actions that have been resulting from the previous steps are further evaluated in order to minimize their need for contingency actions in case of perturbations of the scenarios that have been originally foreseen. Thus, the contingency actions can be grouped in three categories: corrective (i.e., when it is paramount to find a way to change the scenario to achieve the expected objectives for adaptation), defensive (to be used when the dynamic assessment of the effect of the actions tend to diverge from the achievement of the expected objectives in the considered temporal horizon), and capitalizing (to be used to improve the robustness of the pathways). This results in the identification of actions that are more promising to keep each of the pathways on track for success. It is worth noting that the contingency actions are associated with a monitoring system, which in turn implies the quantification of trigger values to be estimated. This system must be used to decide whether a contingency action should be activated or not.
8. *Translate the results* from all the previous steps into a dynamic adaptive plan. The result of this step is a summary of targets, problems, and potential and preferred pathways identified in the previous steps. The ultimate goal of this plan is to identify what set of actions should be activated at a given time (in a given adaptation pathway and under specific uncertainties), and which actions should instead be postponed. A plan able to keep the preferred pathways open as long as possible should be preferred.

The actions to be taken immediately are implemented and the monitoring system is established. Then, time starts running, signpost information related to the triggers is collected, and actions are started, altered, stopped, or expanded in response to this information. After implementation of the initial actions, activation of other actions is suspended until a trigger event occurs.
It is worth noting that the Resilience Knowledge Boosters (RKBs) developed in the framework of the IMPETUS project will be integral to the development of the adaptation pathways and innovation packages. In fact, local communities and stakeholders will retrieve useful information to design and implement actions for adaptation in the corresponding demonstration sites using the RKBs. Consequently, the RKBs will allow the demonstration sites and their stakeholders to obtain a more detailed understanding of the current adaptation and mitigation vulnerabilities, hence producing up-to-date and impactful adaptation pathways and innovation packages.

3 Specifics of adaptation pathways in IMPETUS demonstrations sites

To ensure an effective implementation of the aforementioned framework, while supporting the diversity of climate change adaptation and mitigation solutions entailed by the IMPETUS project, the specific characteristics of the adaptation pathways at each demonstration site must be gathered. To this aim, the parameters and variables that are needed to define the properties of the dynamic adaptation pathways framework at each DS have been grouped in five main sections:

- Description of each DS, comprising:
    - *Type of climate risk*: identified according to the categories that have been used to classify the most relevant climate change effects and hazards to be investigated at each DS (as for GA Section 1.3.2.2), i.e., Sea level rise, Flooding risk, Water scarcity, Marine storms, Fires, Biodiversity loss, Health diseases, Temperature increase, Avalanche increase, Extreme storms;

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101037084.

  - *Indicators and metrics (*I&M) to be used at each DS (defined according to the nomenclature and terminology used in D3.2). Specifically, Indicators are related to climate change vulnerability, resilience assessment and climate adaptation. Indicators are “a quality or trait that suggests effectiveness, progress or success” of a given policy or intervention. Preferably they should be normative and goal oriented. Metrics are defined as “a variable that can be measured (if quantifiable) or tracked (if qualitative) that represents the indicator”. Chosen I&M must be related to (i.e. affected by) adaptation measures proposed in DSs;
  - *Indicator’s key reference system,* i.e., transversal, cross-cutting environmental themes, and common reference point for different climate risks (e.g., Water management, Ecosystem and Nature Based Solution, Health and wellbeing, Land use and food system, Critical infrastructure);
  - *Modelling capacity,* to assess the experience and expertise that each DS can take advantage of in quantifying with rigorous scientific approach the characteristics of scenarios, indicators, metrics and impact of interventions in the DS for each climate risk;
- Scenarios identification, which includes:
  - *Climate scenarios* used to describe a set of alternative plausible trajectories of societal development, which are based on hypotheses about which societal elements are the most important determinants of challenges to climate change mitigation and adaptation;
  - *Climate and socioeconomic variables*, i.e., climate variables and the socioeconomic variables;
  - *Tipping points/alarm thresholds:* An adaptation tipping point specifies the conditions under which the status quo, a policy action or a portfolio of actions will fail. An adaptation tipping point is reached when the magnitude of external change is such that a policy no longer can meet its objectives, and new actions are needed to achieve the objectives. The timing of an adaptation tipping point (the sell-by year of actions) is scenario dependent;
- Characteristics of the adaptation pathways: sequences of interventions, which can be implemented progressively, depending on future dynamics, where interventions are defined as processes, practices and structures to moderate potential damages or to benefit from opportunities associated with climate change. In an adaptive plan, adaptation pathways capture the implementation process by specifying which measure(s) are to be taken now and which are planned to be implemented once certain conditions occur. Therefore, they can be categorized and described in terms of several properties of each selected intervention, such as:
  - Cost;
  - Technology readiness level;
  - Societal readiness level;
  - Time to implementation;
  - Modelling tools;
  - Hidden risks – disadvantages of intervention;
  - Feasibility.
- Quantification of the effect of each intervention in terms of adaptation (based on the indicators that have been identified).

During the reporting period, several one-to-one meetings have been conducted to assess the ability of the proposed dynamic adaptation pathways structure to grasp the main characteristics of the portfolios of climate change adaptation and mitigation measures to be implemented in each DS, and in particular their effect on indicators and climate scenarios in the context of the decision making and planning processes in place at each local community and government under exam. This information has been gathered by means of spreadsheet that were summarizing the aforesaid information (see Appendix A). During these meetings, the aforesaid information has been discussed and feedback have been taken into account to evaluate the robustness of the proposed approach for dynamic adaptation pathways characterization in capturing the key components of the adaptation plans at each DS.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 101037084.

In summary, the discussions with the DSs have highlighted that the proposed approach is flexible and versatile enough to allow a full appreciation of the adaptation pathways in each DS, while pairing the diversity of solutions and measures that each DS can put in place. The inputs and feedback from DSs were collected by workshops, direct conversations, stands at local events, organized by DS leaderships. In particular, it is worth noting that the proposed dynamic adaptation framework allows to:

- Integrate the description of the risks, scenarios, indicators and adaptation measures in plans at multiple governmental scales (local, regional, national) (e.g., the actions to be implemented in DS4 will have impact on other regions of the country of Netherlands);
- Capture different characteristics of climate change although in the same class of risks and hazards, hence enabling each DSs to pin out the most relevant features for their local and regional ecosystems, without compromising the quality and granularity of the analysis (e.g., the causes and effects of flooding risks for DS6 are different from those of DS2 and DS5, but the proposed framework still allows us to build a specific narrative for these properties at each DS);
- Identify the main properties of feasibility and implementability of the adaptation and mitigation solutions, while providing a preliminary quantification of the impact of the proposed measures in terms of societal acceptance (e.g., with respect to the interventions to be implemented to address water scarcity and the effect of storm water on infrastructures for DS1, and the construction of sand dunes to counteract sea level rise and extreme storms in DS2);
- Understand the level of transferability of the proposed analysis, in terms of solutions' design as well as impact on communities (e.g., DS4);
- Appreciate multiple levels of impact of the proposed solutions and portfolios of measures on multiple climate scenarios (e.g., DS1, DS6), thus allowing us to finely track the characteristics of the adaptation pathways that could be implemented at each DS.

The detailed report of these one-to-one meetings, as well as of all the activities that will take place after M24 for the definition and characterization of the regional adaptation pathways in each biogeographical region considered in the IMPETUS project, will be provided in D5.2.

4 Conclusions and outlook

This deliverable provides the guidelines for the design of the dynamic adaptation pathways in the IMPETUS project. The motivations, operational requirements and needs that the dynamic adaptation pathways must accomplish are presented. The main motivations behind the choice of the main structures of the functional framework are provided along with a thorough discussion on the related works in technical literature. The proposed architecture of the dynamic adaptation pathways (based on an iterative analysis of goals, objectives, vulnerabilities and opportunities) allows to support the stakeholders, communities and authorities to co-create, demonstrate, monitor and assess the climate adaptation pathways for sustainable adaptation and resilience. The proposed dynamic adaptation pathways scheme allows the RKBs to be integrated into the procedure to define and determine the characteristics of the portfolios of adaptation interventions for each demonstration site. This enables the eventual institutionalization of the adaptation pathways and innovation packages into the administrative decision processes of the IMPETUS regions. The dynamic adaptation pathways structure has been discussed with the DSs: the specifics of the adaptation pathways properties for each DS will be further discussed in D5.2. Additionally, the structure discussed in this report is directly connected to the activities of other WPs, e.g., interventions hidden risks and cost analysis will be performed under T3.5; the model that generates/optimizes adaptation pathways following these guidelines will be developed under T3.6; the resilience assessment methodology of the pathways under T3.4; the implementation of the framework will be supported by each DS of WP4; WP2 RKBs will host the results. Also, the discussion on the impact of each intervention on the socioeconomic variable of relevance for each DS will be further discussed in WP6.

5 References

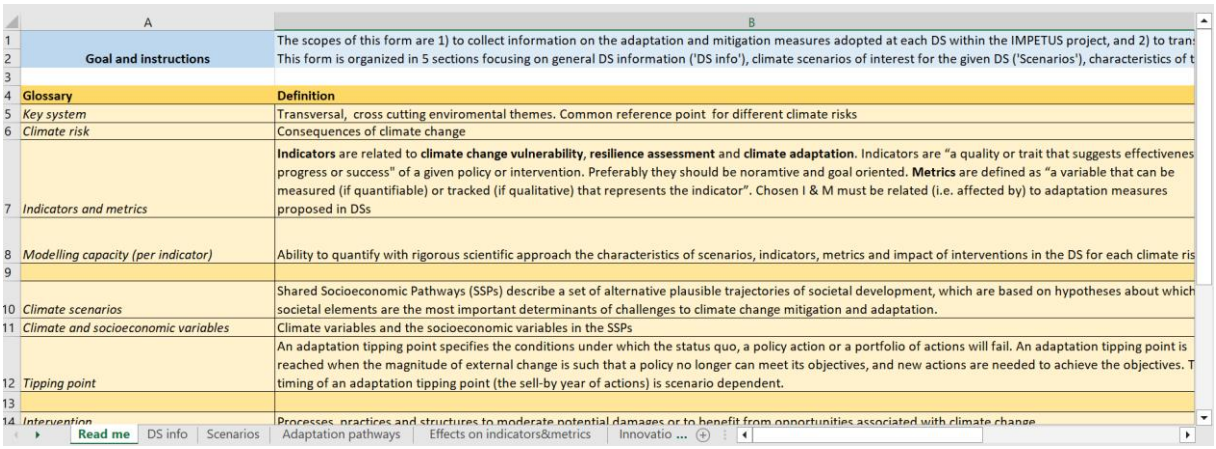
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101037084.

[1] S. Werners et al., “Adaptation pathways: A review of approaches and a learning framework,” Environmental Science and Policy 116:266–275, 2021
[2] Ranger, N., Reeder, T., Lowe, J., “Addressing “deep” uncertainty over long-term climate in major infrastructure projects: four innovations of the Thames Estuary 2100 Project,” Euro J. Decis. Process. 1, 233–262, 2013
[3] Reeder, T., Ranger, N., “How Do You Adapt in an Uncertain World? Lessons From the Thames Estuary 2100 Project,” World Resources Report. USAresili, Washington DC, 2011
[4] Haasnoot, M., Kwakkel, J.H., Walker, W.E., Maat, Jt., “Dynamic adaptive policy pathways: a method for crafting robust decisions for a deeply Uncertain world,” Glob. Environ. Chang. Part A 23, 485–498, 2013
[5] Barnett, J., Graham, S., Mortreux, C., Fincher, R., Waters, E., Hurlimann, A., “A local coastal adaptation pathway,” Nat. Clim. Chang. 4, 1103–1108, 2014
[6] Rosenzweig, C., Solecki, W., “Hurricane Sandy and adaptation pathways in New York: lessons from a first-responder city,” Glob. Environ. Chang. 28, 395–408, 2014
[7] Siebentritt, M., Halsey, N., Smith, M.S., “Regional Climate Change Adaptation Plan for the Eyre Peninsula,” EPICCA Eyre Peninsula Integrated Climate Change Agreement Committee, Eyre, Australia, 2014
[8] Maru, Y.T., Stafford Smith, M., Sparrow, A., Pinho, P.F., Dube, O.P., “A linked vulnerability and resilience framework for adaptation pathways in remote disadvantaged communities,” Glob. Environ. Chang. 28, 337–350, 2014
[9] A. Tanaka et al., “Adaptation pathways of global wheat production: Importance of strategic adaptation to climate change,” Scientific Reports, 5: 14312, 2015
[10] Colloff, M.J., Doherty, M.D., Lavorel, S., Dunlop, M., Wise, R.M., Prober, S.M., “Adaptation services and pathways for the management of temperate montane forests under transformational climate change,” Clim. Change 138, 267–282, 2016
[11] Kingsborough, A., Borgomeo, E., Hall, J.W., “Adaptation pathways in practice: mapping options and trade-offs for London’s water resources,” Sustain. Cities Soc. 27, 386–397, 2016
[12] Butler, J.R.A., et al., “Scenario planning to leap-frog the sustainable development goals: an adaptation pathways approach,” Clim. Risk Manag. 12, 83–99, 2016
[13] Butler, J.R.A., et al., “Framing the application of adaptation pathways for rural livelihoods and global change in eastern Indonesian islands. Glob. Environ. Chang. 28, 368–382, 2014
[14] J. Garcia-Webb et al., “Flexible adaptation planning: The Cockburn Sound Coastal Alliance experience,” in proc. Australasian Port and Harbour Conference, Cairns, Australia, 2017
[15] N. Manocha and V. Babovic, “Development and valuation of adaptation pathways for storm water management infrastructure,” Environmental Science & Policy, 77: 86-97, 2017
[16] Prober, S.M., et al., “Informing climate adaptation pathways in multi-use woodland landscapes using the values-rules-knowledge framework,” Agric. Ecosyst. Environ. 241, 39–53, 2017
[17] Aerts, J., et al., “Pathways to resilience: adapting to sea level rise in Los Angeles,” Ann. N. Y. Acad. Sci. 1427, 1–90, 2018
[18] de Ruig, L.T., et al., “An economic evaluation of adaptation pathways in coastal mega cities: an illustration for Los Angeles,” Sci. Total Environ. 678, 647–659, 2019
[19] Bhave, A.G., et al., “Water resource planning under future climate and socioeconomic uncertainty in the Cauvery River Basin in Karnataka, India,” Water Res. Res. 54, 708–728, 2018
[20] J. McDonald et al., “Adaptation pathways for conservation law and policy,” WIREs Climate Change, 10, (1) Article e555, 2019
[21] Rocle, N., et al., “Paving the way to coastal adaptation pathways: an interdisciplinary approach based on territorial archetypes,” Environ. Sci. Policy 110, 34–45, 2020
[22] R. Roy et al., “Designing adaptation pathways for flood-affected households in Bangladesh,” Environment, Development and Sustainability, 23: 5386–5410, 2021
[23] Sadr, S.M.K., et al., “Strategic planning of the integrated urban wastewater system using adaptation pathways,”Water Res. 182, 2020
[24] Fetting, C.. “The European Green Deal”, ESDN Report, December 2020, ESDN Office, Vienna, 2020
[25] https://ec.europa.eu/info/publications/climate-resilient-europe_en
[26] https://ec.europa.eu/info/horizon-europe/missions-horizon-europe_en
[27] https://climate-adapt.eea.europa.eu/en/knowledge/tools/adaptation-support-tool/index_html

6 Appendix A

In this section, the main components of the spreadsheet form to collect information for the development of adaptation pathways in each DS are displayed in the following Figures.

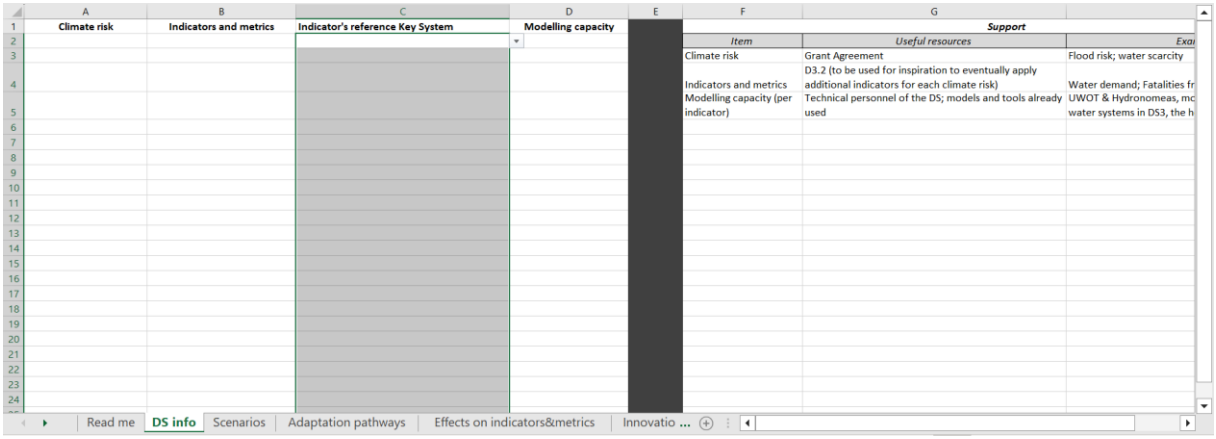
This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 101037084.



	A	B
1		The scopes of this form are 1) to collect information on the adaptation and mitigation measures adopted at each DS within the IMPETUS project, and 2) to tran
2	**Goal and instructions**	This form is organized in 5 sections focusing on general DS information ('DS info'), climate scenarios of interest for the given DS ('Scenarios'), characteristics of t
3		
4	**Glossary**	**Definition**
5	*Key system*	Transversal, cross cutting enviromental themes. Common reference point for different climate risks
6	*Climate risk*	Consequences of climate change
7	*Indicators and metrics*	**Indicators** are related to **climate change vulnerability**, **resilience assessment** and **climate adaptation**. Indicators are "a quality or trait that suggests effectivenes progress or success" of a given policy or intervention. Preferably they should be noramtive and goal oriented. **Metrics** are defined as "a variable that can be measured (if quantifiable) or tracked (if qualitative) that represents the indicator". Chosen I & M must be related (i.e. affected by) to adaptation measures proposed in DSs
8	*Modelling capacity (per indicator)*	Ability to quantify with rigorous scientific approach the characteristics of scenarios, indicators, metrics and impact of interventions in the DS for each climate ris
9		
10	*Climate scenarios*	Shared Socioeconomic Pathways (SSPs) describe a set of alternative plausible trajectories of societal development, which are based on hypotheses about which societal elements are the most important determinants of challenges to climate change mitigation and adaptation.
11	*Climate and socioeconomic variables*	Climate variables and the socioeconomic variables in the SSPs
12	*Tipping point*	An adaptation tipping point specifies the conditions under which the status quo, a policy action or a portfolio of actions will fail. An adaptation tipping point is reached when the magnitude of external change is such that a policy no longer can meet its objectives, and new actions are needed to achieve the objectives. T timing of an adaptation tipping point (the sell-by year of actions) is scenario dependent.
13		
14	*Intervention*	Processes, practices and structures to moderate potential damages or to benefit from opportunities associated with climate change

Read me | DS info | Scenarios | Adaptation pathways | Effects on indicators&metrics | Innovatio ...

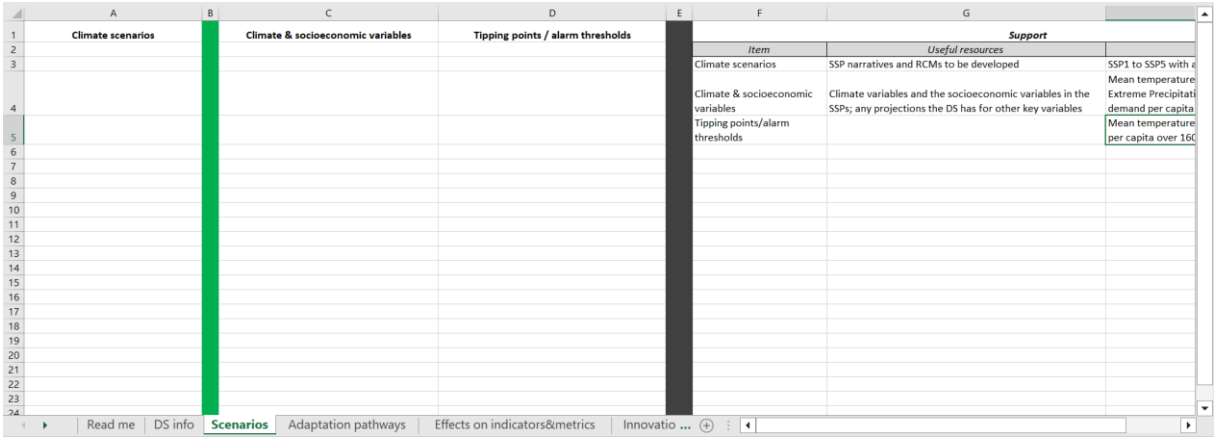
Figure 2 - Description of goals and glossary



	A	B	C	D	E	F	G	
1	**Climate risk**	**Indicators and metrics**	**Indicator's reference Key System**	**Modelling capacity**			***Support***	
2						*Item*	*Useful resources*	*Exa*
3						Climate risk	Grant Agreement	Flood risk; water scarcity
4						Indicators and metrics	D3.2 (to be used for inspiration to eventually apply additional indicators for each climate risk)	Water demand; Fatalities fr
5						Modelling capacity (per indicator)	Technical personnel of the DS; models and tools already used	UWOT & Hydronomeas, mc water systems in DS3, the h

Read me | DS info | Scenarios | Adaptation pathways | Effects on indicators&metrics | Innovatio ...

Figure 3 - Information to desribe the main characteristics of each DS



	A	B	C	D	E	F	G	
1	**Climate scenarios**		**Climate & socioeconomic variables**	**Tipping points / alarm thresholds**			***Support***	
2						*Item*	*Useful resources*	
3						Climate scenarios	SSP narratives and RCMs to be developed	SSP1 to SSP5 with a
4						Climate & socioeconomic variables	Climate variables and the socioeconomic variables in the SSPs; any projections the DS has for other key variables	Mean temperature Extreme Precipitati demand per capita
5						Tipping points/alarm thresholds		Mean temperature per capita over 16

Read me | DS info | Scenarios | Adaptation pathways | Effects on indicators&metrics | Innovatio ...

Figure 4 - Description of climate scenarios relevant for each DS.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101037084.

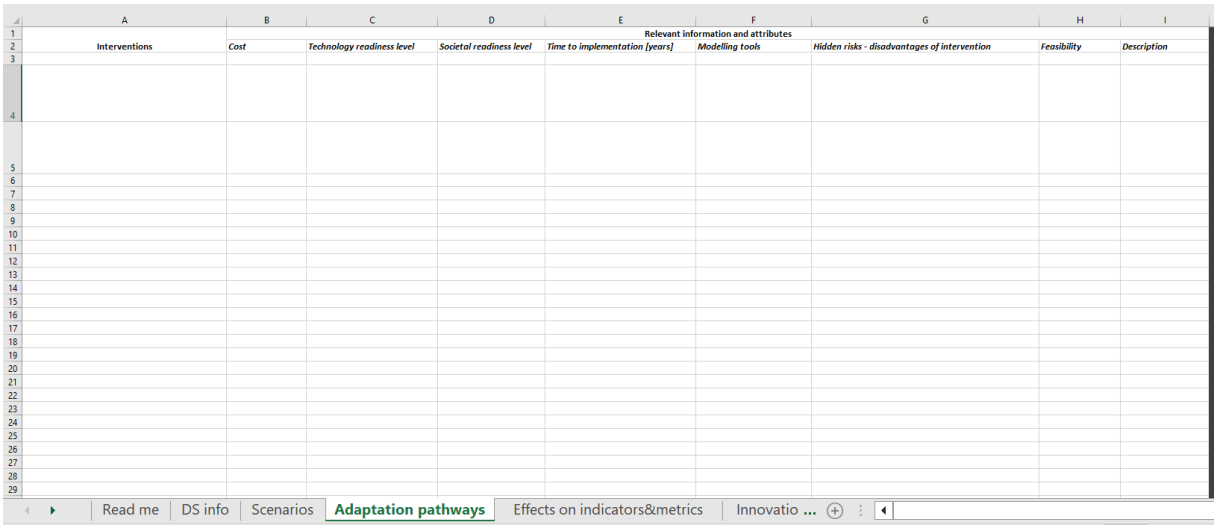


Figure 5 - Main features of adaptation pathways for each DS

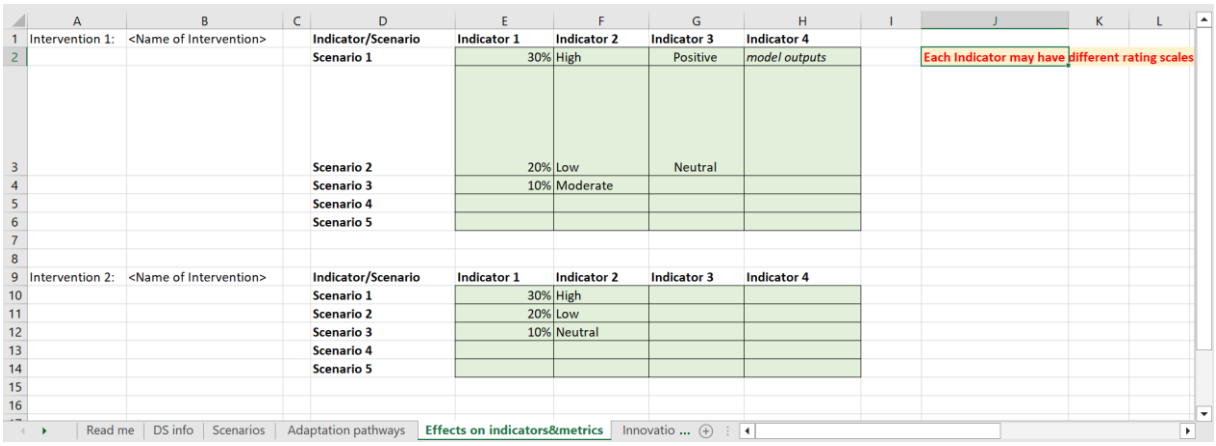


Figure 6 - Evaluation of effects of each intervention on indicators and scenarios

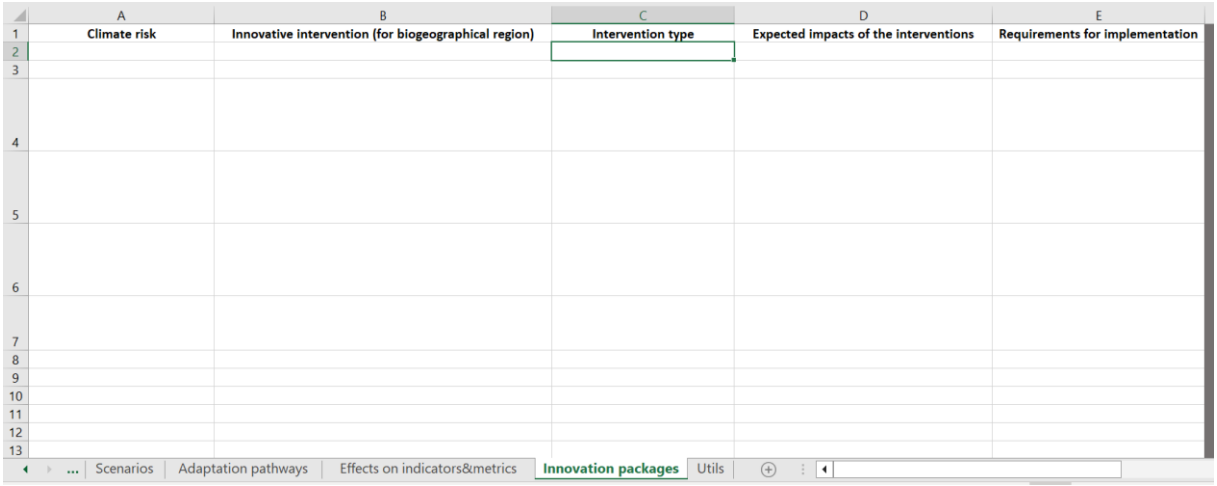


Figure 7 - Information on innovation packages for each DS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101037084.