CoCliCo

Research and Innovation Action (RIA)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003598

Start date : 2021-09-01 Duration : 48 Months

Report on Integrated Scenarios and data specifications for use in WP3-6

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CoCliCo - Contract Number: 101003598

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Document title	Report on Integrated Scenarios and data specifications for use in WP3-6
Author(s)	Mr. Bart VAN DEN HURK
Number of pages	17
Document type	Deliverable
Work Package	WP2
Document number	D2.2
Issued by	DELTARES
Date of completion	2022-12-02 09:35:09
Dissemination level	Public

Summary

The goal of this document is to present a refined set of Integrated Scenarios and to provide specifications to be used as guidance in the production of these scenarios in WP3-6. The document discusses the selected parameter and scenario space that spans the set of Integrated Scenarios. A total number of 96 Integrated Scenarios will be considered giving a substantial set of scenarios to select from when developing the Rich User Narratives and its associated functionalities in the platform.

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Report on Integrated Scenarios and data specifications for use in WP3-6

[D2.2]

Release Status: DRAFT

Dissemination level: Public

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Date: 27/11/2022

Filename and version: D2.2 Report on Integrated Scenarios and data specifications for use in WP3-6_v01.docx

Project ID NUMBER 101003598

Call: H2020-LC-CLA-2020-2

DG/Agency: CINEA

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Document History

Location

This document is stored in the following location:

Filename	D2.2 Report on Integrated Scenarios and data specifications for use in WP3-6_v01.docx
Location	Teams LGI CoCliCo/WP2

Revision History

This document has been through the following revisions:

Version No.	Revision Date	Filename/Location stored:	Brief Summary of Changes
V01	27/11/2022	D2.2 Report on Integrated Scenarios and data specifications for use in WP3-6_v01.pdf	

Authorisation

This document requires the following approvals:

Authorisation	Name	Signature	Date
Project Coordinator	Gonéri Le Cozannet		

Distribution

This document has been distributed to:

Name	Title	Version Issued	Date of Issue
Consortium & EC	D2.2 Report on Integrated Scenarios and data specifications for use in WP3-6	V01	01/12/2022

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Executive summary

This deliverable is part of the Task 2.2.1" Development of Integrated Scenarios" based on user's priorities (D1.2, M8) as described in the DoA. These Integrated Scenarios form the main requirement from WP2 to WP3-6 (D2.2, M12), and form the basis for geospatial data layers to be included in the Full-Track core web-platform.

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1 Introduction

One of the objectives of CoCliCo is to develop a web-based, open European coastal risk data and mapping web-platform, allowing user-driven exploration and visualization of coastal risks and their drivers and a range of user-defined Integrated Scenarios. Such Integrated Scenarios typically combine likely and/or high-end climate change and sea-level rise scenarios (Meinhausen et al., 2011; Stammer et al., 2019), shared socio-economic pathways (Riahi et al., 2017) and local adaptation scenarios considering options such as managed retreat or protecting the coastline (Stive et al., 2013; Oppenheimer et al., 2019). The CoCliCo web-platform interactively links users with the relevant geospatial data allowing to explore these scenarios.

Hence, Integrated Scenarios (sea level and its extremes, socio-economic development, adaptation scenarios from WP3-6) harmonize the production of geospatial data layers in the CoCliCo portal. In the project proposal, we proposed the following scenarios to be refined with users and subsequently produced by WP3-6:

- at least 4 time-horizons: 1990 and 2020 to assess current risks and their recent evolution, 2050 to address the time-horizon of most adaptation programs and 2100 for decisions on long-life infrastructure;
- at least 3 mean and extreme sea-level scenarios (WP3), aligned with the 2°C target of the Paris Agreement (Representative Concentration Pathways RCP1.9 or RCP2.6), an intermediate scenario compliant with current Intended Nationally Determined Contributions (RCP4.5) and a high-end scenario (based on RCP8.5, with additional contributions from enhanced Greenland and Antarctica ice-sheets mass loss);
- at least 3 flood scenarios (WP4), considering chronic flooding at high tide (Sweet and Park, 2014), relatively frequent storms (e.g., centennial storms, as considered in many coastal risk defense designs), and a less frequent "perfect storm", as considered by the Netherlands and the EU Flood Directive;
- at least 3 coastal socio-economic scenarios (WP5), including future population density, city sprawl, infrastructure and economic assets development (e.g., Reimann et al., 2018), elaborated on Shared Socio-economic Pathways (SSPs);
- at least 3 adaptation scenarios (WP6), including protection, accommodation and retreat.

In the proposal, we estimated the data storage capacity of the web-platform at 8Tb, allowing to store pre-cooked geospatial data layers corresponding to relevant combinations of a minimum of 3 climate, 3 hazards, 3 exposure and vulnerability and 3 adaptation scenarios at pan-European scale with a resolution of 25 m for 4 time horizons. The maximum number of scenarios that can be accommodated in the platform was estimated at 20 to 30. The selection of Integrated Scenarios should span a considerable scenario space that is well aligned with internationally accepted scenario frameworks (such as adopted by IPCC and European Climate Assessment programs).

Not all combinations of these scenarios need to be considered: for example, sea-level scenarios tend to diverge after 2050 only (Oppenheimer et al., 2019), and low emission

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scenarios are most consistent with socio-economic developments corresponding to SSP1 (i.e. sustainability). The Integrated Scenarios will make it possible to combine the (intermediate) results and will allow usage by other work package for additional analyses. It also provides a framework to constrain the number of analysed scenarios to a meaningful subset that can be accommodated by the available storage and processing infrastructure.

In the first year of CoCliCo, multiple interactions have taken place with users (WP1; D1.2). Also, the Fast-Track web platform was developed, and interlinkages between WP's were strengthened. This enables us to refine the relevant combinations as Integrated Scenarios and provide detailed specifications.

2 Goal of this document

The final goal of this document is to present a refined set of Integrated Scenarios and to provide specifications to be used as guidance in the production of these scenarios in WP3-6.

3 Scenario framework

In this document, a framework is sketched that consists of a selection of time slices, combined socio-economic and climate scenarios, return frequencies and adaptation strategies. The purpose of this selection is to reduce the number of options of future developments to a feasible number, while retaining a relevant range of future conditions. This set of scenarios complies with the outcome of the user survey, where generally a reference to "standard" scenarios is preferred.

However, this scenario framework requires mapping of SSP socio-economic scenario attributes to local quantities that are used to generate quantitative risk assessments. Given the large spatial heterogeneity of socio-economic drivers at both the global scale (inherent in the SSP scenarios) and local scales (inherent in our focus on local coastal management typologies) this mapping may introduce considerable dependence on subjective and sometimes arbitrary choices.

The selection of future time horizons will allow to explore the potential acceleration of SLR and associated risks (which is for quite some users an important topic) but does leave the near future relatively poorly sampled. For the hazard profile a strong temporal trend cannot be expected in the near future, but the socio-economic attributes of risk may undergo rapid changes.

Also, the mapping of adaptation characteristics to only 2 scenarios is not straightforward. Adaptation has financial, technical and political (or behavioral) dimensions with large heterogeneity across the European coastal regions. Therefore, extensions to this selection may be considered at a later stage.

However, it is of importance to document the procedure that defines the characteristics used to identify the range of scenarios. For each domain in the risk framework (hazard, exposure, vulnerability and adaptation as addressed in WP3-6 respectively) key drivers are specified that are expected to vary strongly across the scenarios, and will determine the final outcome

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of the calculated risk profiles. The next sections will elaborate on these primary drivers per risk domain, characterized as a set of primary indicators, input and output variables per work package.

3.1 Mapping coastal risk features in the scenario space

Our risk framework has different domains that will vary over time:

- In the hazard domain, *mean sea level rise* is a main risk driver with considerable variation of future values. In addition, *extreme sea level* is governed by variations in storm climate, waves and compounding drivers, where natural variability is a major source of uncertainty;
- In the exposure domain, the *flood extent* is strongly varying with both the geographical configuration of flood plains and their occupation by infrastructure, buildings, ecosystems and other assets affected by flood and SLR. Here the major scenario driver is the socio-economic development (scaling with economic and population growth and with political choices determining urban and land use planning and ecosystem management);
- In the vulnerability domain, damage is usually quantified using *damage functions*, where uncertainty is mainly originating from the empirical processes leading to the aggregated distribution of assets and its flood-depth dependent damage functions. For indirect effects uncertainty arises from estimating economical consequences of *infrastructure disruptions*, long-term *damage* to e.g. ecosystems or agriculture, and *recovery processes*;
- For adaptation drivers are technical or economic *limits to adaptation,* political choices (leading to e.g. varying levels of *risk tolerance* or *distribution of risks* over sectors or regions) and *behavioural choices* (affecting e.g. political mandates).

These risk domains are well covered in our collection of work packages.

For different locations and applications the meaningful fraction of the possible range of drivers will be different. This is particularly true for the range of time horizons (different applications have different planning and functional time scales), but also applies to other risk characteristics. Therefore, it will be not trivial to generate a scenario framework that is equally applicable for all European regions considered by CoCliCo. However, for each of the applications and user groups some selection of drivers is inevitable, as no practitioner can or wants to afford to explore an extremely large number of options. It is therefore of interest to produce a scenario framework that spans a large fraction of the plausible range of drivers for each of the relevant risk domains.

3.2 WP-specific indicators and inputs

For each WP contributing to the risk assessment the primary input and output is listed below (see summary Table 3.1). The resulting collection of chosen drivers and inputs will create considerable variability in the final risk profile, spanning a relevant scenario range.

The proposed collection of drivers will subsequently be grouped and mapped onto the SSP or adaptation scenarios that were selected originally to construct the Integrated Scenario framework. For this logical reasoning will be followed to justify which driver value best matches

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the selected SSP or adaptation scenario, for which time horizon and which statistical return time. Below an indicative discussion of potential driver values for each of the WPs is presented.

WP3 – sea level rise, wave, tides, currents

Global SLR is generated from a combination of CMIP5/6 model outputs and the ice mass contribution derived from external information sources. A selection of CMIP5 and CMIP6 models needs to be made and justified, and from each model ensemble members have to be selected. Regional downscaling refines currents, surge, tides and waves at the local scale, which involves another level of selection of the downscaling model set-up. Note that the contribution of ocean dynamics to decadal sea level fluctuations along the European coast differs greatly between CMIP5 and CMIP6, and a selection of models has to reflect this variability.

WP4 – floods, and dependence on bathymetry/topography, land cover/roughness

Obviously mean sea level, surge and tides are determining the flood event, but its extent greatly varies with local coastline typology, which in turn depends on land cover (e.g. presence of forests, urban settlements), adaptation infrastructure and coastal slope. Land mass distribution is assumed to be static ("hold the line"). Main drivers of variety in flood extent/flood depth are obviously related to the surge and wave height (varying with sea level and selection of return time), and to land cover/adaptation scenarios.

WP5 – development of infrastructure, distribution of assets, damage curves

Important drivers of infrastructure and asset development are economic and population growth, development of land cover and land use, and societal approaches to adaptation and asset management. Empirical damage functions rely on a degree of statistical aggregation, and it needs to be determined whether the uncertainty associated with these functions is reflected appropriately in different scenarios.

WP6 – adaptation and damage recovery scenarios

Different adaptation paradigms can be represented in scenarios: a risk-based cost/benefit analysis, where the adaptation is assigned to secure selected safety standards, is different from an approach where non-monetary values (e.g. environmental quality, distribution of risks over population classes) are weighted. Characteristics to explore include the safety standard[1], Expected Annual Damage, damage per event, number of affected people, and different technical options. Updated information on current safety standard in the selected case studies is needed. Note that the adaptation scenarios provide a feedback to both the flood extent/flood depth assessment (WP4), and possibly also to the infrastructure inventory (WP5).

[1] It can be considered to allow flexibility in the choice of the safety standard (as is implemented with a slider in the Aqueduct flood risk analyzer).

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Table 3.1 Primary input (drivers) and output per work package

Work package	Primary input		Primary output
WP3: Mean and extreme sea levels	Relative sea level rise		regional variation of relative SLR bandwidth & timescale
	thermal expansion		regional extreme wave and surge characteristics
	ice mass loss		Nearshore waves
	subsidence (best estimate)		Total water level (TWL) at different return periods
	Offshore waves (Return Periods; RP)		
	Water levels and currents (RP)		
WP4: Natural hazards (flood + erosion)	Total water level (TWL; RP)		inundation characteristics (depths and duration)
	DEM + bathymetry		mitigated inundation
	Coastal typology		future shoreline positions
	Waves		
	Land cover / use (roughness)		
	Adaptation: coastal defence		
WP5: Exposure and vulnerability	Asset management (infrastructure and economic assets development; now and future)		Mean Annual Damage
	Population density (now and future)		People & assets exposed
	City / urban sprawl		
	Land cover / use projections		Development of infrastructure
	Uncertainty on empirical damage		Distribution of assets
			Damage curves
WP6: Adaptation	Adaptation - Business as Usual for protection, accommodation, and retreat		modification of flood characteristics and exposure layers
	Cost-efficient adaptation		

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3.3 Information flow for an Integrated Scenario

The graph below illustrates the information flows required to obtain the demanded output of a single Integrated Scenario (see Figure 3 1). The graph highlights the primary input to the work packages as well as the interdependencies and feedback between the work packages.

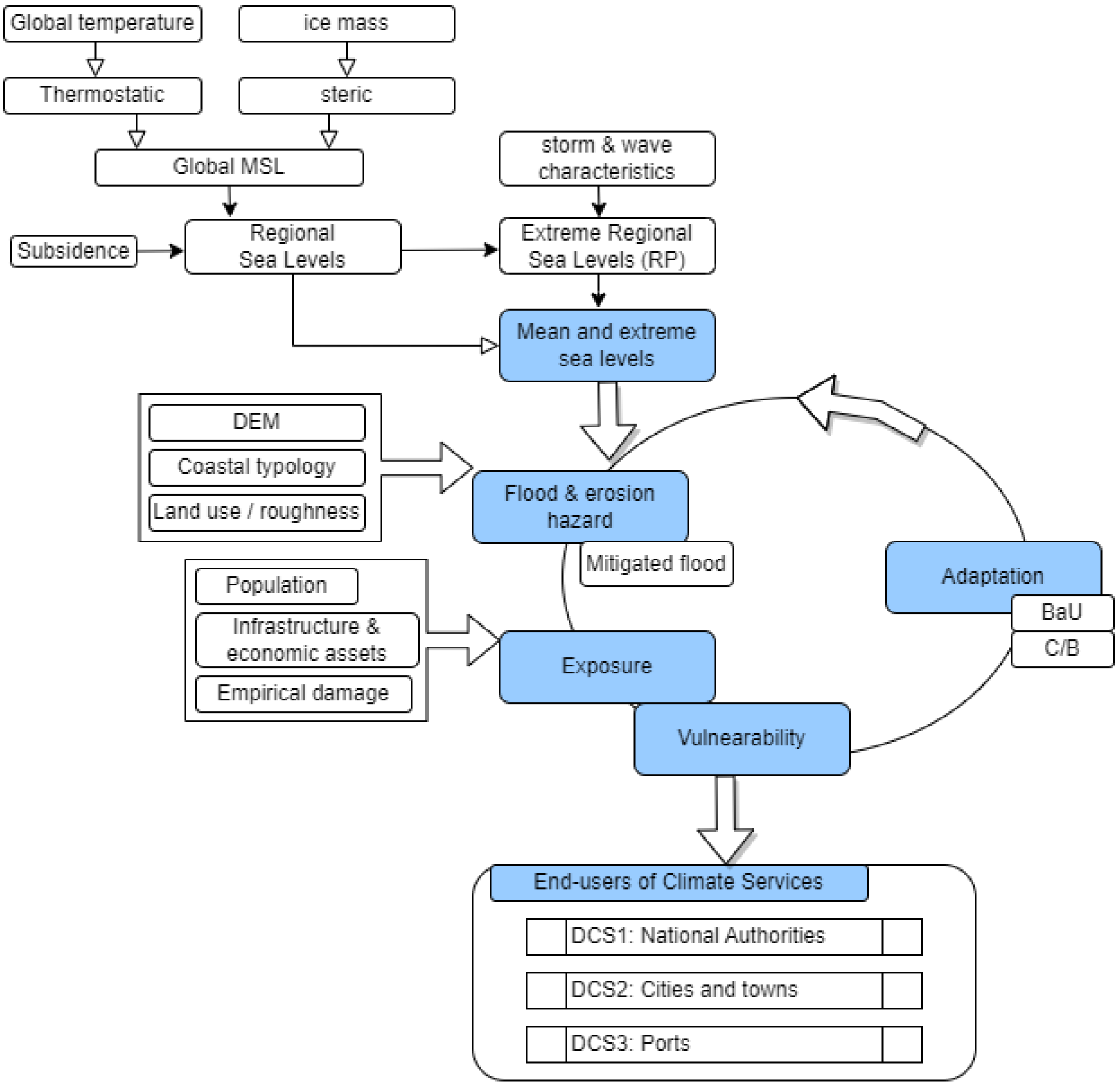

Figure 3-1 Information flows for an Integrated Scenario.

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4 Refining the Integrated Scenarios

The main goal of CoCliCo is to identify changes in future coastal risk, therefore future states relevant for the CoCliCo research are defined along five degrees of freedom:

1. Time horizons
2. Return frequencies
3. Climate change and socioeconomics
4. Adaptation strategies

In the section below, the parameter and scenario space based on the preferences of stakeholders (D1.2) and consortium partners will be discussed.

4.1 Time horizons

As a common reference period the year 2010 is selected upon request by most users and motivated by the fact that literature refers more to 2010 than e.g. 2020. For the future time horizons 2030, 2050 and 2100 are selected. Stakeholders have indicated that analyses beyond 2100 are generally not prioritized. However, 2150 changes are incorporated in a scenario that focusses on changes with large potential impacts.

Present-day:	2010	Reference year; most literature use baseline around 2010
Medium term:	2030	Relevant for Insurance and financial stress testing
	2050	Time-horizon of most adaptation programs
Longer term:	2100	Relevant for decisions on long-life infrastructures

Optionally a far outlook up to 2150 can be considered.

4.2 Return frequencies

Coastal flood risk implies an inadequate protection against impacts from extreme events. Across Europe different return frequencies are used as safety standard to define coastal protection. Using feedback from stakeholders and the consortium partners the following return frequencies of safety levels will be considered:

Yearly	1:1 year	Chronic flooding
Centennial	1:100 years	Standard protection levels in e.g. France
Extreme	1:1000 years or worst ever	EU Flood Directive / The Netherlands

Regarding the ‘extreme’ regime, events with higher return frequencies, or outside the statistical range (e.g. perfect storms) will be selected in collaboration with stakeholders. These will be included in the scenario that focusses on changes with large potential impacts.

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4.3 Climate change and socioeconomics

It is proposed to select three warming scenario's and one high-end scenario, leading to a combination of SSP / SLR scenario's:

1. SSP1-2.6 (benchmark)
2. SSP4-4.5
3. SSP5-8.5
4. SSP5-8.5 and high-end SLR

Sea-level rise over the selected time horizons will follow the SSP projections as published by IPCC. Next to that a high-end SLR projection will be selected in the scenario that focusses on changes with potentially large impacts.

Future socio-economic development will be linked to the three Shared Socio-economic Pathways (SSPs), as presented above: SSP1, SSP4 and SSP5. Since also the climate change / SLR scenarios are linked to these SSPs this set of scenarios does not introduce a new layer to the collection of Integrated Scenarios. Nevertheless, regional refinement of these SSP's will have to be considered for amongst others population growth (Merkens et al. 2016), urban sprawl, infrastructure, and economy. In addition, an additional scenario representing more challenges on adaptation for population will be considered (e.g. SSP3).

4.4 Adaptation strategies

The platform will be designed to support coastal managers to take present-day action to adapt/adjust the coast to future conditions. It is expected that human interference will influence future coastal risk conditions, since measures will be taken to adapt to the changing conditions. Adaptation options can be implemented with a large range of variety and are expected to have a large impact on future risk. To constrain the number of layers in the data portal and the CoCliCo research, two adaptation options will be considered:

1. Business as usual. Raise defences by the same amount as sea-level rise;
2. Cost-efficient adaptation. Allowing for relocations where adaptation is not economically robust.

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5 Summary

5.1 Selected set of Integrated Scenarios

Below table summarizes the selected parameter and scenario space that spans the set of Integrated Scenarios. Hence, a total number of 96 Integrated Scenarios will be considered giving a substantial set of scenarios to select from when developing the Rich User Narratives and its associated functionalities in the platform.

Parameter space	
Time horizon (4)	2010 (ref), 2030, 2050, 2100 (2150)
Return periods (3)	1:1, 1:100, 1:1000 (black swan)

Scenario space	
Climate change and linked socioeconomics (4)	SSP1-2.6 SSP2-4.5 SSP5-8.5 SSP5-8.5 and high-end SLR
Adaptation options (2)	Business as usual Cost-efficient adaptation

5.2 Specifications of the data delivery to the platform

The details on the specifications of the data delivery to the platform can be found in D8.2: Data delivery guideline. First version submitted in November 2022.

That document is intended to function as an instruction (guideline) for the data delivery from WP3 to 6 to the core platform, which is being co-developed by Deltares. The guideline is not set in stone; the document (D8.2) is a 'live' document that might be updated and is subject to change upon project progression.

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