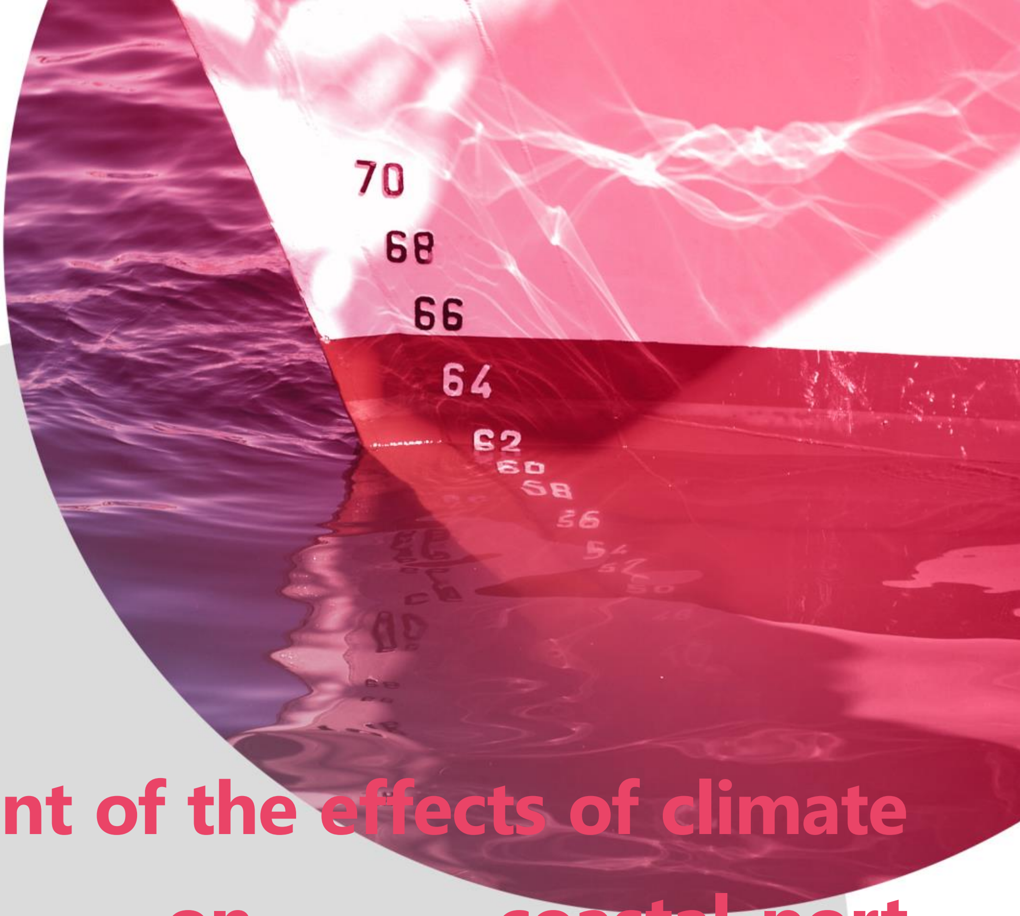
Interreg Sudoe

ecclipse

European Regional Development Fund



Assessment of the effects of climate change on coastal-port environments

T1. Methodology for assessing the effects of climate change on the SUDOE port environment – Project E.1.2.1

31th July 2021

Executive Summary

This report provides a risk assessment framework for ports facing climate change. The risk assessment methodology was developed based on a case study of best practices around the world for assessing the risks of climate change to port assets and activities. The methodology that was developed is divided into four main steps: defining aims, scope and governance; assessing susceptibility and exposure, and finally, risks.

Disclaimer

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Approval

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30/07/2021	Final version	
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28/02/2021	Submitted to the Ecclipse project partners	

Table of contents

Index of illustrations

List of definitions

These definitions are those used in this methodological report.

Hazards: in this report, hazards refer to both the values taken by climatic indexes (values of precipitation, temperature, etc.), as well as the natural consequences generated by a climatic index with or without combination with other factors (floods, land movements, etc.). Hazards may include either extreme weather events: heat waves, storms, floods; or changes in background weather conditions: average temperatures, average precipitation, etc.

Criticality: criticality of a port asset or activity refers to the importance of the asset or the activity for the port. This importance depends on the port strategy, activities, etc.

Susceptibility: susceptibility of port asset or activity refers to the possibility that the asset or activity may be impacted, here: by a climate hazard.

Exposure: exposure of a port refers to the potential for it to be located in an area where hazards may occur.

Sensitivity: sensitivity of an asset or an activity refers to the extent to which the infrastructure or activity could be impacted (damaged) by a hazard.

Risk: Risk refers to the possibility of a hazard occurring and impacting vulnerable assets or activities critical for a port.

Introduction

Port networks have to deal with various climatic hazards: floods, extreme precipitations, storms… These hazards regularly degrade infrastructures, interrupt port services and lead to safety issues. Yet, they are expected to increase in frequency or intensity because of climate change.

The project Interreg Sudoe "Ecclipse" (Evaluación del Cambio CLImático en Puertos del Sudoeste de Europa) is aimed at improving the coordination and effectiveness of tools for prevention, disaster management and rehabilitation of disaster areas, in the framework of climate change.

Different Working Groups are in charge of specific parts of the project, including Working Group 1, which is responsible for the development of a methodology for assessing effects of climate changes on the ports in the Sudoe area.

This report presents the methodology that has been implemented to achieve the development of a risk assessment framework for port environments. It then gives a general overview of the methodological framework developed for this Interreg project. Finally, each step of the framework is detailed this is to say:

- Definition of the aims, scope and governance
- Susceptibility assessment: how to identify the most important port assets and activities potentially at risk from climate change?
- Exposure assessment: how to identify the current exposure of critical assets and activities to climatic hazards, and how to analyse the evolution of these hazards with climate change?
- Risk assessment: how to analyse the extent of a climatic hazard on a port asset or activity in a context of climate change

General overview of the case studies analysed to develop this report

The development of this risk assessment methodological framework for port environments is based on the collection and analysis of case studies for climate change risk assessment. Eighteen case studies on port risk assessment have been collected thanks to a survey shared to the members of the Ecclipse project.

Through the survey, information such as the origin of the study (in which country the study has been led) and the year of publication of the study have been collected.

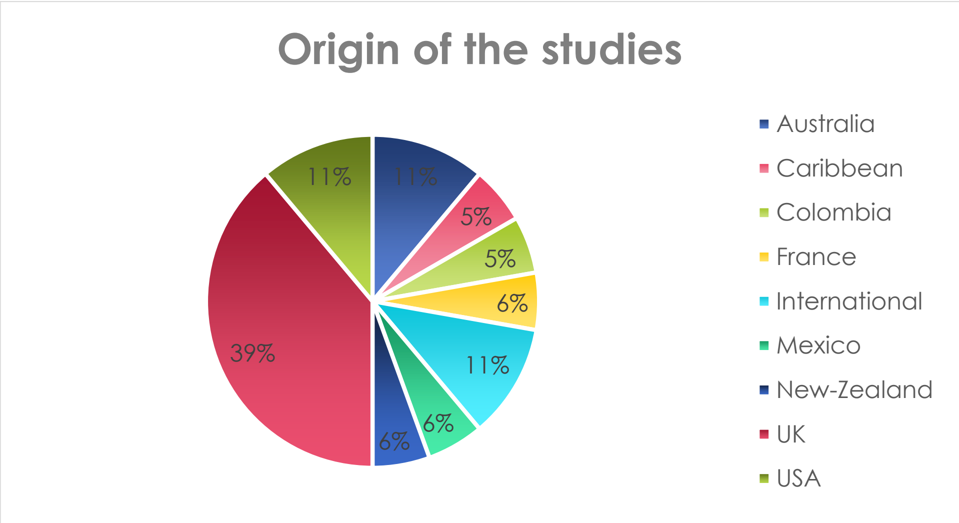

Illustration 1: Origin of the studies. Source: Own elaboration.

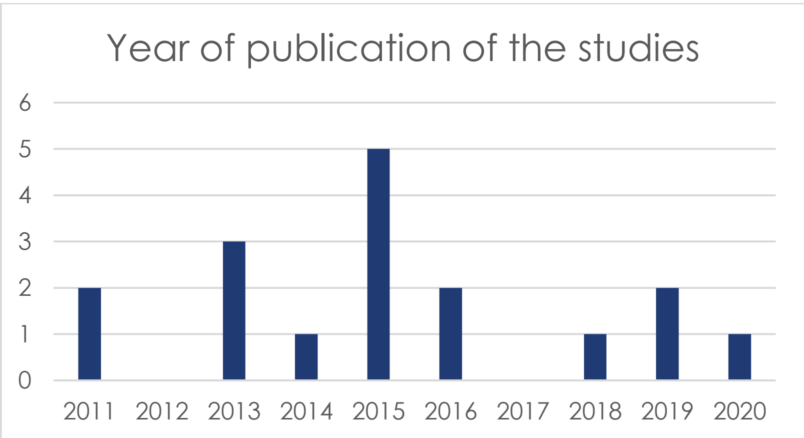

Illustration 2: Year of publication of the studies. Source: Own elaboration.

Few case studies on adaptation of ports to climate change have been collected for the SUDOE zone. This might show that the topic is a very new one for this zone. This may also be due to the fact that the collection of case studies was based primarily on a literature search and that some studies conducted in the SUDOE area may not have been published.

As shown by Illustration 2, the case studies collected are relatively recent: this tends to confirm that the topic "adaptation of ports to climate change" is quite new.

As shown by the illustration below, these studies mainly assess the risks incurred by climate changes on ports all around the world and only a few ones aim at defining methodologies to lead risk assessments in a context of climate change.

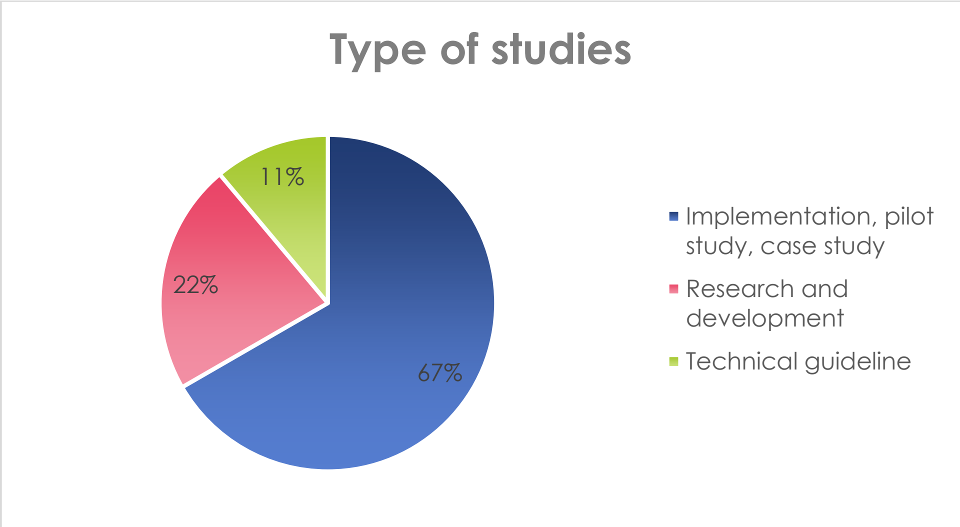

Illustration 3: Type of studies. Source: Own elaboration.

The survey collected additional information, notably the different steps for ports risk assessment used by each collected study. Only two of them use all the steps listed in the illustration below, and some steps have been implemented by a very few number of studies, such as the criticality assessment.

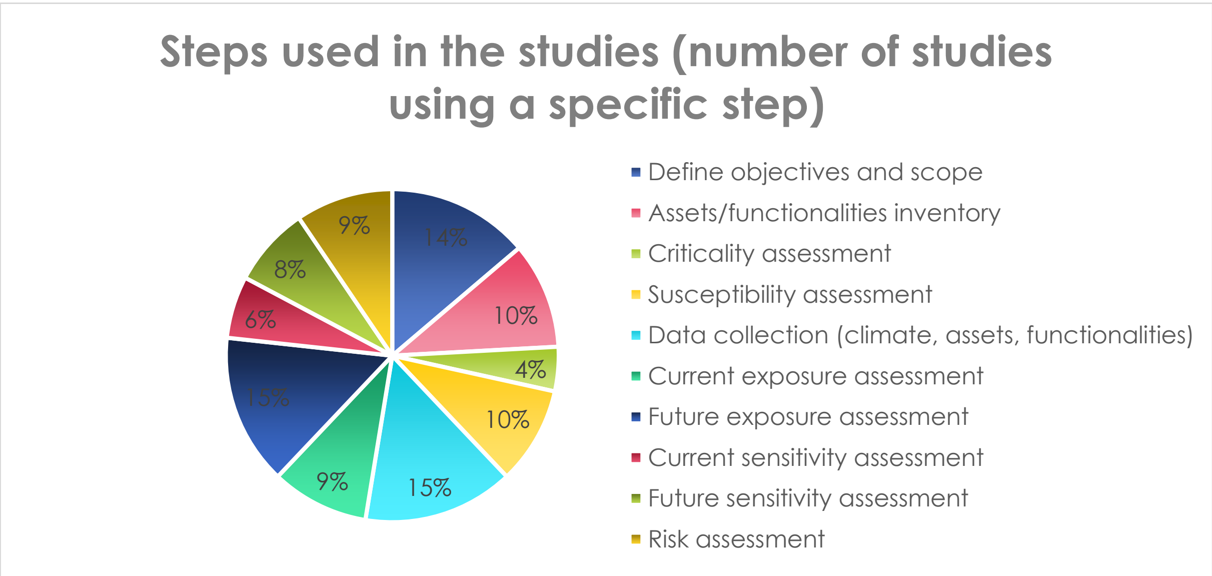

Illustration 4: Steps used in the studies. Source: Own elaboration.

This methodological report is also based on other documents not collected with the case studies collection, because they mainly address other type of networks, notably road networks:

- The methodological report "International climate change adaptation framework for road infrastructure", published by the World road association (PIARC) in 2015 (PIARC, 2015)
- The methodological report "Adaptation methodologies and strategies to increase the resilience of roads to climate change – Case study approach", published by the PIARC (World Road Association) in 2019 (PIARC, 2019)
- The methodological report "Vulnérabilités et risques : les infrastructures de transport face au climat" ("Vulnerabilities and risks: road infrastructures in the face of climate"), published by Cerema in 2019 (Cerema, 2019a)

Main steps of this risk assessment framework for ports environments

Risk assessment methods are based on various concepts such as those of hazards, impacts, risk, etc. The definitions of these concepts vary according to the bibliography, even if the ISO31000 standard defines some of them. The main concepts used in this framework are defined in this report. More particularly, following concepts are used:

- Hazards: in this report, hazards refer to both the values taken by climatic indexes (values of precipitation, temperature, etc.), as well as the natural consequences generated by a climatic index with or without combination with other factors (floods, land movements, etc.). Hazards may include either extreme weather events: heat waves, storms, floods; or changes in background weather conditions: average temperatures, average precipitation, etc.
- Criticality: criticality of a port asset or activity refers to the importance of the asset or the activity for the port. This importance depends on the port strategy, activities, etc.
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- Exposure: exposure of a port refers to the potential for it to be located in an area where hazards may occur
- Sensitivity: sensitivity of an asset or an activity refers to the extent to which the asset or activity could be impacted (damaged) by a hazard
- Risk: Risk refers to the possibility of a hazard occurring and impacting vulnerable assets or activities critical for a port

This risk assessment framework is based on four main steps listed below. It is important to note that the method is iterative. Thus, it can start with a low level of detail and be more and more precise as new data become available.

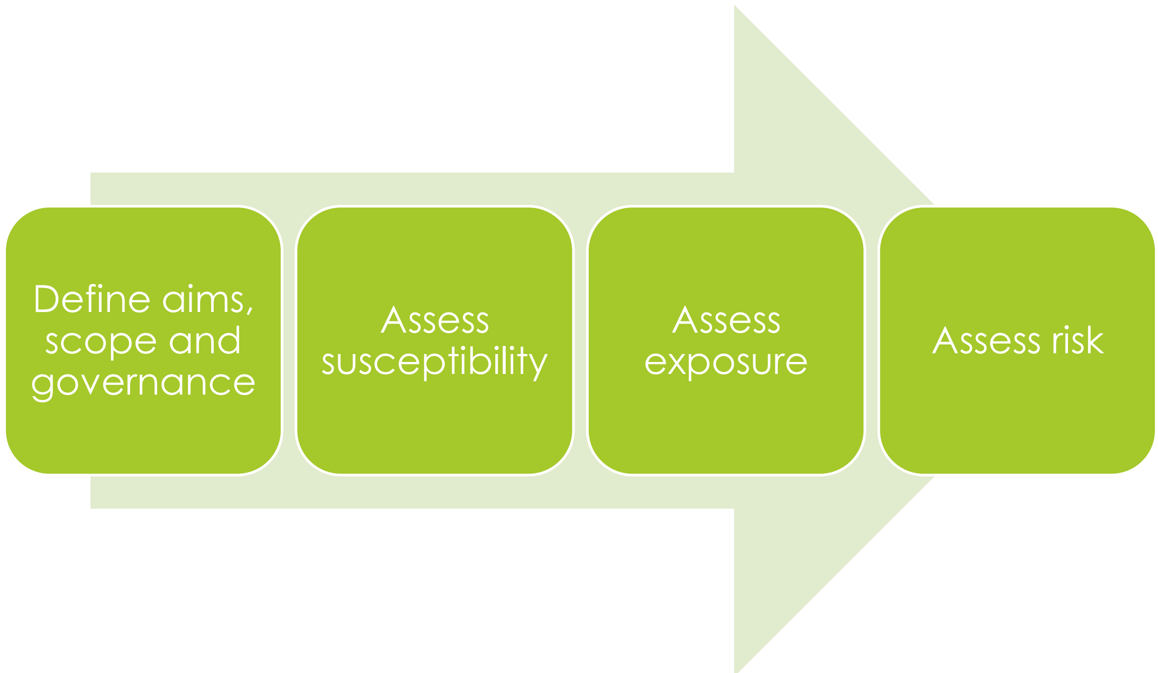


Illustration 5: Main steps of the methodology for risk assessment. Source: Own elaboration.

These four main steps are themselves composed of sub-steps presented below.

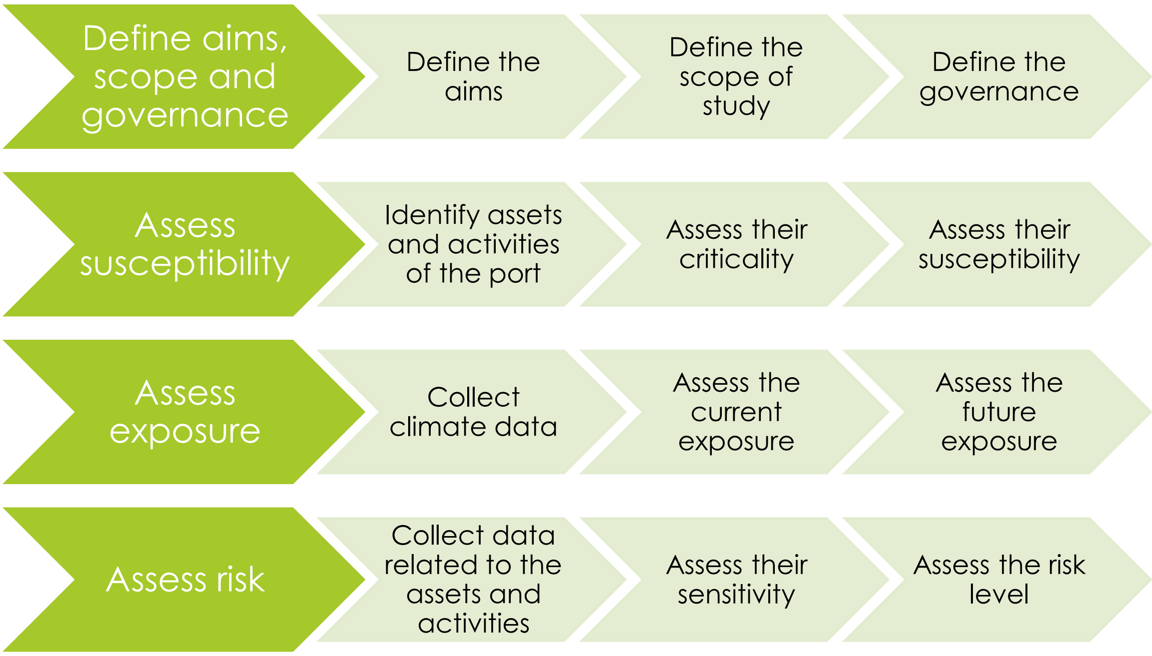


Illustration 6: Detailed steps of the methodology for risk assessment. Source: Own elaboration.

This methodology is based on the analysis of the case studies and on the analysis of three methodological reports, mentioned in the previous chapter. It is important to note that:

- Cerema's methodological report has been first developed and published for road infrastructures, but has been applied to many other types of networks, including port networks
- There are strong methodological connexions between Cerema's report and the PIARC's reports. Even if the PIARC's reports focus on road networks adaptation to climate change, due to these strong connexions and because Cerema's report can be implemented on port networks, these reports have been included in this methodology. Moreover, PIARC's reports also consider the differences of technologies, data, between low and high income countries or between different infrastructures managers, and the methodologies have been adapted to these differences. This is another advantage of using these two international reports to develop this report on port adaptation: all port managers of the SUDOE area might have different management budgets, a different capacity to acquire and structure data, etc. This might influence the implementation of a methodology for risk assessment

The boxes below provide a short description of these three reports.

Box 1: PIARC's international climate change adaptation framework for road infrastructure

Roads, as other transport networks, are mostly concerned by climate change. This is why the World Road Association (PIARC) published in 2015 a methodological framework to "guide road authorities through identifying relevant assets and climatic variables for assessment, identifying and prioritising risks, developing a robust adaptation response and integrating assessment findings into decision-making processes. The framework provides a life-cycle and iterative approach to climate change adaptation".

The methodology is based on 4 stages:

- Stage 1: identifying scope, variables, risks and data
- Stage 2: assessing and prioritising risks
- Stage 3: developing and selecting adaptation responses and strategies
- Stage 4: integrating findings into decision making processes

(PIARC, 2015)

Box 2: PIARC's methodological report "Adaptation methodologies and strategies to increase the resilience of roads to climate change – Case study approach"

After the publication of its framework in 2015, PIARC continued to work on this topic and published in 2019 a report aimed at providing the methodological detail supporting each stage of the refined framework, by refering to state-of-the-art case study examples. Therefore, a PIARC working group undertook a state-of-the-art case study analysis of adaptation strategies to increase the resilience of road infrastructure at the policy, strategic, system level and project specific level. This include consideration of:

- Data requirements regarding climate change adaptation of road infrastructure
- Assessment of the vulnerability and criticality of road infrastructure
- Adaptation measures with regard to possible threats resulting from climate change
- Cost-benefit analysis of climate change adaptation

(PIARC, 2019)

Box 3: Cerema's methodological report "Vulnerabilities and risks: road infrastructures in the face of climate"

To deal with the issue of climate change and its impact on road infrastructures, in connexion with the publication of the first National Plan for Adaptation to Climate Change (PNACC) among others, Cerema has developed practical tools to help network managers to improve their resilience to climate change. In particular, Cerema has developed a methodology for analysing the risks incurred by climate change on transport infrastructures and services and for developing adaptation strategies. This methodology, based on 10 steps, has already been applied to many types of transport networks.

Following these applications, Cerema published in 2019 the methodological guide "Vulnerabilities and risks: transport infrastructures in the face of climate". This guide presents a methodology for risks assessment. This method and the case study carried out on the 750 km of the Mediterranean DIR network in 2017-2018 were highlighted as an example of best practice by the World Road Association (PIARC).

(Cerema, 2019a)

1. Definition of the aims, scope and governance

Before leading a risk assessment, a port manager should define:

- The aims of the risk assessment: how will the results of the assessment help him to better manage the port?
- The scope of the assessment in terms of assets, activities and climate hypothesis
- The governance of the study

This chapter focuses on these topics.

1.1 Definition of the aims of the study

The first step of a risk assessment is to define the aims of the study and thus, the results expected at the end of the risk assessment process. The aims of a risk assessment can be diverse:

- Identify the main climatic hazards likely to impact a port today or in the future
- Identify adaptation measures
- Prioritise adaptation responses at a mid-term horizon
- Raise awareness and develop knowledge on the issue
- Etc.

These aims will guide the working method and help to decide how far to go in the process, in terms of level of detail and methodological steps.

To define the aims of a risk assessment to climate change, it is useful to ask following questions to the port manager or authority: why do you need a risk assessment? In which way will you use the results?

Box 4: aims of the risk assessment "Terminal maritimo Muelles El Bosque", Colombia

The International Finance Corporation (IFC), a member of the World bank group, led a risk assessment on the Terminal maritimo Muelles El Bosque (MEB) in Colombia. Aim of the study was to address the following issues:

- What risks and opportunities does climate change present for MEB?
- What are the most significant risks for MEB?
- How could MEB manage climate change risks in the most economically optimal way, taking account of environmental and social objectives?
- How could climate-related opportunities be developed and exploited?
- Where could MEB work in collaboration with other stakeholders to manage climate risks?
- What tools and techniques for climate risk assessment and management can be applied to understand these issues?

(International Finance Corporation, 2011)

Box 5: aims of the risk assessment "Felixstowe dock and railway company", United Kingdom

In the framework of the UK Climate Change Act published by the Parliament in 2008, many entities were required to assess their risks to climate change every five years, including ports authorities. The Felixstowe dock and railway company took part to this program. The main aims of the risk assessment of Felixstowe dock and railway company is to "protect the port's strategic and operational objectives in the face of a changing climate". The company also identified other specific objectives:

1. To explore the robustness of the port infrastructure to projected future climates.
2. To increase understanding of the effects of the future climate on insurance policies, customer confidence and other specific business concerns.
3. To make recommendations as to how resilience to climate impacts can be improved.
4. To raise awareness of climate change within the organisation.
5. To objectively assess the need to adapt to climate change

(Port of Felixstowe, 2011)

Implementation in the framework of the Ecclipse project

One of the main objectives of the Ecclipse project is to develop a common methodology for risk assessment in a context of climate change in the Sudoe area. The stakeholders of this project must define their own specific aims.

1.2 Definition of the scope

In parallel of the definition of the aims, the scope of the risk assessment should be defined. The scope encompasses the port assets and activities to be analysed, their geographical location, the projection horizon for the study, a general idea of the climatic hazards to be considered and the potential drivers other than climate change that may influence the results of the risk assessment.

To precise these items, the port manager or authority may ask the following questions:

- Do I want to understand and analyse the impacts of all kind of climatic hazards on all kind of assets and activities? Do I want to assess the risks on a specific asset or activity? Will I involve and work with other stakeholders, who can be responsible for certain assets and activities?
- Do I want to assess the risks linked with a failure of connected infrastructures such as road, water networks, etc.? Do I have specific assets or activities located away from the main port site?
- Do I want to have a mid-term vision of these potential impacts? Do I need to understand long-term tendencies?
- Do I want to understand and analyse the potential global changes that can occur in parallel with climate change: political, economic, societal changes for example?

There is no good answer to these questions, but the responses need to be consistent with the aims of the risk assessment.

It is important to note that the area of study depends on the choice of the assets and activities to be analysed. This area can be more or less wide, as it may include the sites where are located: buildings useful for the port activities; channels and rivers where vessels navigate; lighthouses, green dependencies, or other assets and places located outside of the main port area; roads or railways connected to the port; etc. It is also influenced by the choice of climatic hazards to be analysed: some climatic hazards depend on very localised parameters (e.g. frost), whereas other ones depend on parameters that vary on a wider geographical scale (e.g. floods and water runoff).

At this stage, it is not necessary to have a comprehensive list of assets, activities and climate parameters to take into account, but it is important to define the area of study. The comprehensive list will be developed for the susceptibility assessment. As a risk assessment is an iterative process, the area of study could be marginally adapted during the susceptibility assessment.

Implementation in the framework of the Ecclipse project

The project's members have to choose which assets, activities and climatic hazards they want to address. Each port has to define an area of study consistent with the lists of assets, activities and hazards.

Furthermore, discussions need to be held to define the horizon of projection.

Finally, it might be easier not to take into account global changes: economic, political, etc.; but the project partners might bring this issue up for discussion.

1.3 Definition of the governance

A variety of stakeholders has to be involved in the risk assessment process, including decision-makers and specialists and field-actors.

Specialists in the following area of expertise will provide useful information for the risk assessment: port assets management; port activities e.g., port logistic; climate change. According to the aims and scope of study, it is necessary to involve specialists with knowledge in other area of expertise, such as port economics, insurance, risk management, etc.

Field-actors working for or with the port will provide essential information, such as: feedbacks on previous impacts, assets condition, potential relevant adaptation measures and measures already implemented, the internal organisation of the port, etc.

Decision-makers will help to embed the results of the risk assessment in the port strategies and thus, to implement adaptation action plans.

It is important not to forget other potential stakeholders, such as port customers, local politicians, financial players, etc. These actors could be impacted by a low adaptation of the port to climate change and by the adaptation measures. Furthermore, they can have an influence on the future of the port in terms of economy, reputation, etc.

Box 6: governance of the risk assessment of the Port of Dover, United Kingdom

The Port of Dover has conducted a first risk assessment in 2011 and updated it in 2015. Various activities and the related assets were considered: maintenance of port facilities, navigational safety functions, port operations, prevention of pollution… To identify the impacts of climate change on these activities, the Port conducted a range of workshops with harbour masters; pilots; operational managers and directors; health, safety and environmental experts; mechanical, electrical and development engineers; buildings and estates managers; commercial managers; financial and insurance experts; and human resources managers.

(Port of Dover, 2015)

Implementation in the framework of the Ecclipse project

The governance of the Ecclipse project is defined, but the involvement of members of the ports strategic management should be considered.

2. Susceptibility assessment

This chapter focuses on how to identify the assets and activities critical for a port and at risk from climate change.

2.1 Identification of assets and activities

A port is composed of a large range of assets and support various activities. It is important to identify and to list these assets and activities at the beginning of the risk assessment, because it will dimension the next steps. This list must be consistent with the scope previously defined.

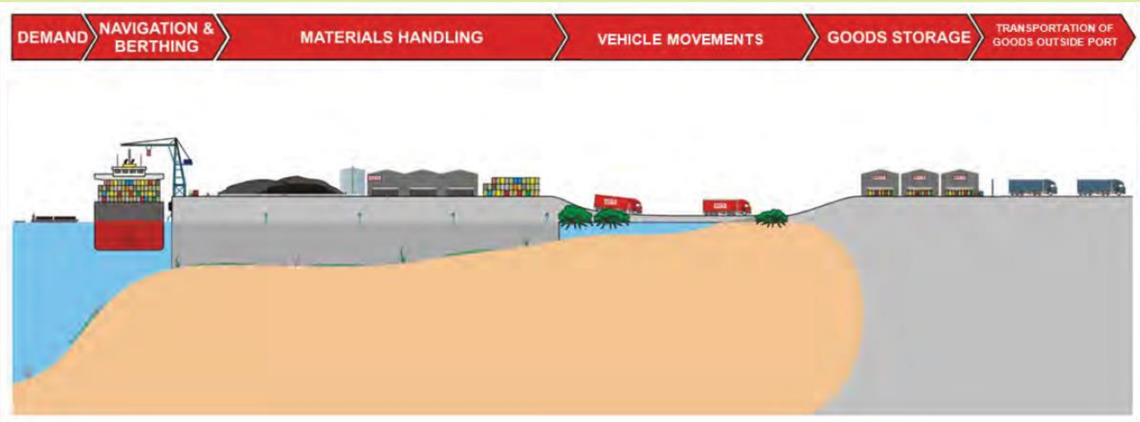
Box 7: example of assets and activities taken into account in the risk assessment led for Harwich Haven Authority, United Kingdom

The risk assessment led for Harwich Haven Authority has taken into account following assets and activities: pilotage; vessel services; VTS, radar, VHF, etc.; maintenance dredging and disposal; marine engineering including vessel maintenance; civil engineering, jetties, pontons; hydrographic surveying; nav-aids, beacons, buoyage; environmental monitoring; buildings; staff/personnel including business continuity; licensing and consenting.

(Jan Brooke Environmental Consultant Ltd., 2011)

Box 8: example of activities taken into account in the risk assessment "Terminal Maritimo Muelles El Bosque", Colombia

The risk assessment led on the Terminal Maritimo Muelles El Bosque (MEB) in Colombia took into account various activities: demand of transport, navigation and berthing, goods handling and storage, etc., as shown by the illustration below.



(International Finance Corporation, 2011)

Developing a categorisation is helpful to identify port assets and activities. The categorisation can be based e.g. on different geographical areas of a port, on different services provided by the assets or it may follow pre-existing categorisation used in asset management tools. The categorisation can be based on a survey, exchanges with experts, a field visit or the analysis of management tools.

Box 9: example of categorisation of assets and activities for a climate change risk assessment

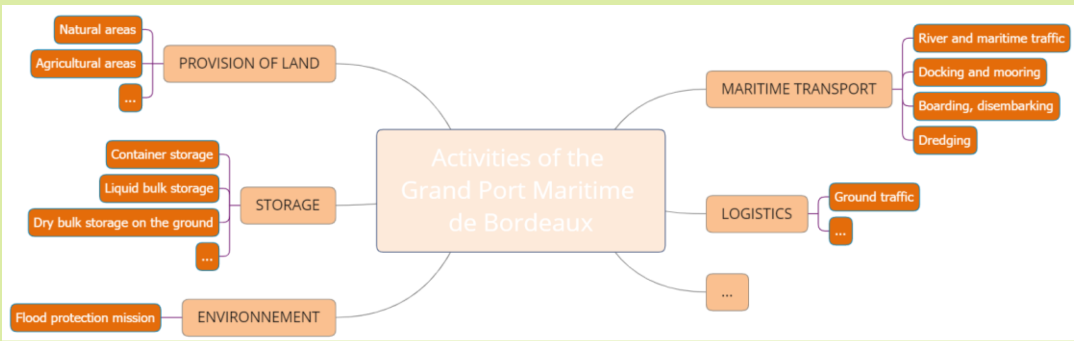
The World Association for Waterborne Transport Infrastructure (PIANC) published in 2020 a framework to plan climate change adaptation for ports and inland waterways. In this framework, the PIANC propose the following assets categorisation:

- Physical assets such as breakwaters, quays and berths, docks, etc.
- Terrestrial or hinterland assets associated with the port estate or waterway operation such as equipment, storage facilities, etc.
- Other assets such as channels, disposal sites for dredged material, etc.
- Interdependent services or systems such as road, rail, power stations, etc.

(PIANC, 2020)

Box 10: categorisation of assets and activities for the risk assessment of "Port de Bordeaux", France

The Cerema, a technical resource centre under the supervision of the French Ministry for Transport has led a risk assessment on the 7 terminals of the Port and the channel connecting them, in strong cooperation with employees of the Grand Port Maritime de Bordeaux. The risk assessment take into account 13 categories of assets such as civil engineering structures, equipment, the channel, etc., and 16 categories of activities, such as storage, maritime transport, environmental protection and management, etc.



(Cerema, 2019b)

Box 11: categorisation of connected infrastructures for the risk assessment of Avatiu Port, Cook Islands

Avatiu Port is located in the Cook Islands, between French Polynesia and American Samoa. The risk assessment led on the port is based on the following categorisation of assets and operational areas: waterside, interface, land based assets and activities, and connected infrastructures. As tourism accounts for a large part in the economy of the Cook Islands, the Avatiu Port is a strategic site and its proper functioning is important. This is why connected infrastructures were taken into account in the vulnerability assessment. Connected infrastructures include notably following assets: roads, bridges, drainage, water supply, water and solid waste, fuel, airport and power, food and goods and communications.

(University of New South Wales, 2013)

Implementation in the framework of the Ecclipse project

As the Ecclipse project is aimed at developing a common methodology for risk assessment, it is advisable that partners follow these steps: developing a categorisation for assets and activities, then listing the assets and activities that will be studied. However, as the aims of each site may be different, the categorisation of assets and activities may differ.

2.2 Criticality assessment

Since ports are composed of a large range of assets and activities, according to the level of detail of the risk assessment, it may be necessary to prioritise the assets and activities to be studied. The criticality assessment refers to the prioritisation of the most important assets and activities for a port, this is to say, those whose degradation, destruction or disruption could cause major impacts on the port (operational, financial, etc.).

Box 12: operational core assets of ports in Australia

The Australian National Climate Change Adaptation Research Facility (NCCARF) published in 2013 a framework to assess climate change risks on ports. The framework is notably based on a literature review and on case studies lead on three Australian ports: Port Kembla Port Corporation, Sydney Port Corporation and Ports of Gladstone. The research project first established a list of operational assets, defined as tangible "resources from which economic benefits can be derived", "in the context of their role in performing logistics operations in ports". This list does not include assets managed by entities other than the port authority. In this research project, it is consider that core operational assets are those supporting activities directly related to the trans-shipment logistics functions, for example: buoys, rail tracks, communication equipment, etc.

(National Climate Change Adaptation Research Facility, RMIT University, 2013a)

To identify critical assets, it is necessary to refer to the aims of the study. For example, if one of the main aim is to increase the robustness of the port assets, then, critical activities are related to asset maintenance and repair.

Criticality assessment is not specific to climate risk assessment and thus, port authorities might already have identified critical assets and activities in business activity plan or in risk or crisis management plans. The selection of the critical assets and activities can also be based on expert judgements of the different field-actors working for or with the port.

Box 13: advices to determine criticality of assets or activities

In its framework, the World Association for Waterborne Transport Infrastructure (PIANC) suggest to consider that an activity or an asset is critical for example if:

- "Port or navigation activity or business continuity would be adversely impacted
- There would be health and safety implications
- There would be strategic consequences (e.g. for the regional or national economy or for the distribution of aid, either directly or because of interdependencies or network or supply chain connectivity issues)
- The functioning of the emergency services would be affected
- There would be unacceptable social, socio-economic or environmental implications"

It proposes then the following table to assess the criticality:

Implications for: / Scale of impact:	Safety	Economic effects; business continuity	Public effects and local community	Environment sustainability and compliance	Critical?
Catastrophic	Risk of large numbers of serious injuries or loss of life	Loss or degradation would risk long-term viability of business including supply chains	Essential services lost, daily life becomes intolerable, unacceptable physical suffering	Irrecoverable damage, proven breach, prospect of corporate penalty	Yes
Major	Risk of isolated instances of serious injuries or loss of life	Loss or degradation would have serious effects on business requiring significant remedial action	Severe disruption of essential services and hence daily life, high levels of physical suffering	Severe and continuing loss, significant management effort needed to deal with compliance failure	Probably
Moderate	Risk of small numbers of injuries	Intervention needed to protect business continuity	Frequent disruption of essential services; daily life difficult, moderate levels of physical suffering	Minor, reversible damage, action needed on issues of compliance	Unlikely
Minor or insignificant	Risk of near misses or minor injuries	Isolated difficulties (e.g. in supply chain, replacements or alternatives exist)	Intermittent disruption of essential services and daily life, low levels of physical suffering	Negligible damage, minor breaches, easily resolved	Not critical

(PIANC, 2020)

Box 14: example of a criticality assessment matrix for vessels refuelling with liquefied natural gas

Others examples of criticality assessment matrix exist, such as the one provided below by ABS Group that focuses on liquified natural gas bunkering operation. Based on the risk matrix, the risks were ranked in terms of importance (from low probability, low consequence risks to high probability, high consequence risks). The risk matrix highlights risks that are unacceptable without countermeasures to reduce either the probability, consequence, or both. It focuses on consequences that affect people, followed by damage to equipment or structure.

Severity categories	Impacts			
	Death and injury	Economic	Environmental	Reputation
Low (1)	Low level short term subjective inconvenience or symptoms. No measurable physical effects. No medical treatment.	No shutdown, costs less than €1,000 to repair	No lasting effect. Low-level impacts on biological or physical environment. Limited damage to minimal area of low significance.	Public concern restricted to local complaints. Ongoing scrutiny/ attention from regulator.
Minor (2)	Objective but reversible disability/ impairment and/or medical treatment injuries requiring hospitalization.	No shutdown, costs less than €10,000 to repair.	Minor effects on biological or physical environment. Minor short-term damage to small area of limited significance.	Minor, adverse local public or media attention and complaints. Significant hardship from regulator. Reputation is adversely affected with a small number of site focused people.
Moderate (3)	Moderate irreversible disability or impairment (< 30%) to one or more persons.	Operations shutdown, loss of day rate for 1-7 days and/or repair costs of up to €100,000.	Moderate effects on biological or physical environment but not affecting ecosystem function. Moderate short-medium term widespread impacts (e.g., oil spill causing impacts on shoreline).	Attention from media and/or heightened concern by local community. Criticism by Non-Governmental Organizations (NGO). Significant difficulties in gaining approvals. Environmental credentials moderately affected.
Major (4)	Single fatality and/or severe irreversible disability or impairment (> 30%) to one or more persons.	Operations shutdown, loss of day rate for 7-28 days and/or repair costs of up to €1,000,000.	Serious environmental effects with some impairment of ecosystem function (e.g., displacement of species). Relatively widespread medium-long term impacts.	Significant adverse national media/ public/NGO attention. May lose license to operate or not gain approval. Environment/ management credentials are significantly tarnished.

(ABS Group, Without date)

Implementation in the framework of the Ecclipse project
Ports should refer to the main aims they have defined for their risk assessment. Critical assets and activities may be already identified in business continuity plans, this selection should be analysed again with regard to the aims of the risk assessment.

2.3 Susceptibility assessment

A susceptibility assessment provides a first overview of the (most critical) assets and activities that are likely to be impacted by climate change. The susceptibility assessment is based on the results of the criticality assessment and the hazards identified with the definition of the scope. The main climatic hazards relevant for this assessment notably depend on the area of study. After the listing of the critical assets and activities and the definition of the area of study, it is possible to have an overview of these climatic hazards.

The susceptibility assessment can be based on expert judgement, on a survey or on a literature review. It is advised to develop a yes/no matrix with each critical asset and activity and each climatic hazard previously identified and to try to identify if:

- An asset or an activity has already been impacted by a hazard in the past
- A new hazard could occur on the area of study and put assets or activities at risk, for example sea level rise

Box 15: susceptibility assessment for Port of Manzanillo, Mexico
The Authority of Port of Manzanillo and the Inter-American Development Bank have cooperated to assess the risks incurred by climate change on the port. The risk assessment focuses on the port commercial success. According to the study, it relies on:

- "Trade levels and patterns and the consequent demand for port's services
- Navigation in and out of ports and ship berthing
- Goods handling and storage inside ports
- Movements of goods, vehicles and people inside ports
- Inland transportation beyond ports' fence lines"

The susceptibility assessment determined that the port will have to face increased rainfall intensity, causing water flooding and increased sedimentation. Among the most important activities listed by the study, the main ones that will be impacted by these evolutions will be goods handling, navigation in and out of the port and inland transportation beyond port's fence lines. For example, port operation and access to the port through roads and rail connections will be disturbed in case of water flooding, and terminal access will be more difficult in case of an increased sedimentation.
(Inter-American Development Bank, 2015)

Box 16: example of susceptibility assessment for Caribbean ports

The United Nations Conference on Trade and Development (UNCTAD) led in 2018 a risk assessment for the Caribbean small island developing states. The risk assessment focused on the impacts of climate change on ports and airports. In this study, docks and berths, cranes, utilities, buildings and warehouses, access roads and utilities are considered as critical components. A susceptibility assessment has been led for various climatic hazards and their potential evolutions in a context of climate change: changes in winds, extreme heat, heavy precipitations, etc.

Climate Hazard	Docks	Crane Operations	Access	Other
Sea Level Rise	Higher sea levels can increase the risk of chronic flooding and lead to permanent inundation of dock facilities, making a port inoperable.	Not sensitive.	Sea level rise could affect port access routes.	Not applicable.
Tropical Storms/ Hurricanes/ Storm Surge	Storm surge can damage marine port facilities, causing delays in shipping and transport. For example, Hurricane	Not sensitive.	Tropical storms can cause roadway damage and debris movement, blocking access to the port for staff and ground transport.	Port operations may be halted for the duration of the storm. Floodwaters or winds can also transport debris

(United Nations Conference on Trade and development, 2018a)

Implementation in the framework of the Ecclipse project
To assess the susceptibility, a yes/no matrix could be developed for each port.

With the susceptibility assessment, the main critical assets and activities at risk from climatic hazards have been identified. It is then necessary to assess the current and future exposure of these assets and activities in a context of climate change.

3. Exposure assessment

At this stage, the risk assessment focuses on the current and future exposure of the critical assets and activities previously identified. Exposure assessment will help ports to answer to these questions: could climatic hazards occur on the area of study? What are their characteristics? Will they evolve in a context of climate change?

3.1 Data collection

To assess the current and future exposures, data describing precisely the current climate and its potential changes are required:

- The location of the hazard. It could cover a large area, e.g. in case of heat waves, or it could be localised to a very precise site, e.g. land slope
- The frequency of a climatic event describes how many times this hazard could occur per year, per month, etc.
- The duration of the hazard describes the length during which the area of study will have to face this hazard
- The intensity of the hazard has an influence on the level of impact.

A risk assessment could take into account the following climatic hazards, according to its aims and scopes:

- Changes in temperatures: mean temperature, extreme heat, cold temperatures, etc.
- Changes in precipitations: mean precipitations, heavy rain, drought, snow, etc.
- Changes in wind pattern
- Changes in ground movements: landslide, mudflow, etc.
- Changes in flooding, including runoff, sea level rise, swell, etc.
- Changes in forest fires

This list is not exhaustive and must be completed according to the scopes of the risk assessment.

Box 17: list of climatic hazards for the risk assessment of Milford Haven Port, United Kingdom

In 2011, a risk assessment to climate change has been conducted on Milford Haven Port, the largest UK's energy port. The evolutions of following climatic hazards were expected to impact the port and thus, were analysed: relative sea level rise, waves, pressures, storm surges, seasonal precipitation and associated changes in freshwater flow, erosion, accretion and sediment transport, air temperature, water temperature, water quality, salinity and stratification, total cloud cover, fog, wind, extreme events.

(Milford Haven Port Authority, 2011)

This kind of data can be found in local, national or international climate projection databases, in specific studies or research projects or in general risk assessment like natural hazard prevention plans. As the collection of data may be time consuming, this step can start after the definition of the aims and scopes of the risk assessment.

Box 18: listing of climate data sources for Associated British Port (UK) risk assessment

Associated British Port (ABP), an UK's leading port group owning and operating 21 ports in the UK, assessed the risks incurred by climate change and developed an adaptation strategy for four of its ports. ABP published its first report on climate change in 2011 and updated it in 2016.

To assess the exposure of the ports, ABP has identified and collected climate data from:

- The Committee on Climate Change (CCC)
- UK Climate Projections (UKCP09)
- MCCIP Annual Report Card 2013
- The Environment Agency Flooding Risk Maps
- Local tide records
- Local knowledge and experience in relation of the areas of jurisdiction

ABP also developed following complementary studies:

- Flood resilience port reports
- Future evolution of Spurn breach

(Associated British Ports, 2016)

Box 19: climate data collection for Port of Manzanillo risk assessment

In the framework of the exposure assessment of Port of Manzanillo, a major port in Mexico, many data on the current climate as well as projected data have been collected from various sources and gathered in a table per climate event.

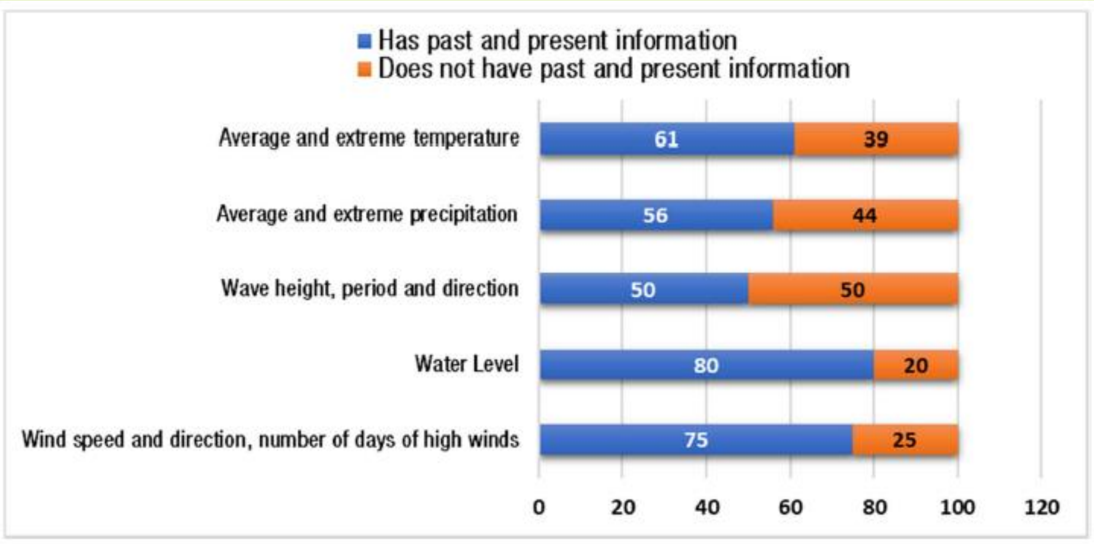
Variable	Current conditions	Future changes compared with current climate (under RCP8.5 scenario)[4]			
		2020s	2040s	2070s	Comments
Mean dry season rainfall	Less than 1mm decrease between 1979 and 2012 (not statistically significant)	Decrease of approximately 50mm over the dry season (-0.3mm per day)	Decrease of approximately 90mm over the dry season (-0.5 mm per day)	Decrease of approximately 126mm over the dry season (-0.7mm per day)	The very small drying trend evident in the current period strengthens and continues into the future
Mean wet season rainfall	Increase of about 37mm (1.1mm per year) between 1979 and 2012 (not statistically significant)	Decrease of approximately 18mm over the wet season (-0.1mm per day)	Decrease of approximately 54mm over the wet season (-0.3 mm per day)	Decrease of approximately 72mm over the wet season (-0.4 mm per day)	The drying trend replaces the current (statistically insignificant) wetting trend and the decrease strengthens into the future

(Inter-american development bank, 2015)

Box 20: climate knowledge: a challenge for many ports

The United Nation Conference on Trade and Development (UNCTAD) conducted a survey in 2018. Aim of this survey was to improve knowledge on the impacts of climatic hazards and climate change on ports and to identify the need of information to improve their resilience.

One of the results provided by this survey is that improving climate knowledge is challenge for many ports. The illustration below show that a high percentage of the ports that responded to the survey suffers from a lack of data on past and present wave height, period and direction, on average and extreme precipitation, etc.



(United Nation Conference on Trade and Development, 2018b)

Implementation in the framework of the Ecclipse project

Each region / country should identify the data available at a national or regional scale. Stakeholders of the Ecclipse project could also identify and share data available at an international scale. Then, the data should be gathered in a table per climatic hazard, with a description of the current and future climate trends and the sources.

3.2 Current exposure assessment

Aim of the current exposure assessment is to answer the question: to which hazards is my site exposed currently and what are the characteristics of these hazards? To answer the question, it is first useful to identify:

- The current climate characteristics of the area of study
- The hazards that already occurred in this area
- The hazards that commonly impact the assets and activities selected for the risk assessment
- Etc.

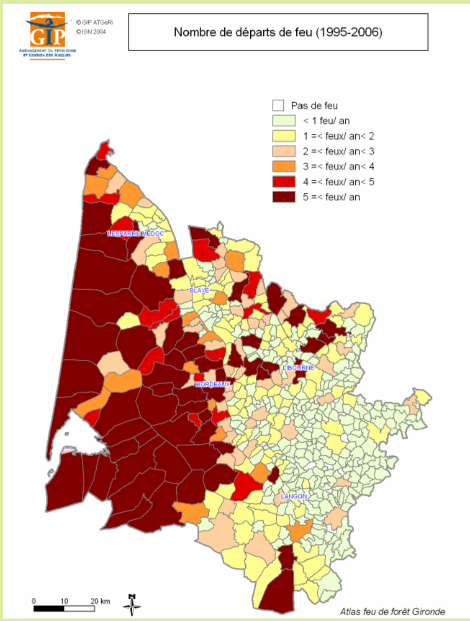
After the development of a list of hazards, a scoring scale must be defined, to rate the frequency or intensity of each climatic hazard.

Then the exposure can be assessed by identifying if a hazard is likely to occur at the location of an asset or an activity. Thus, a precise location of the hazards, assets and activities is helpful. If a geographical information system (GIS) is available, the results of the exposure assessment can be presented in form of a map of exposure showing the level of exposure according to the scoring scale previously defined. If no GIS is available, the result can be presented in form of a matrix. If necessary, a modelling of the exposure can be developed. This might be particularly useful to assess the exposure to sea level rise or to flooding for example.

Box 21: assessment of the current exposure of "Port de Bordeaux"

Before assessing the future exposure of the port, the risk assessment focused on the current exposure. This was useful to provide an overview of the potential evolution of the exposure. Therefore, a list of the current hazard that might occur has been set. The list is based on the analysis of historical databases, such as a French natural disaster database, a departmental document on major risks, etc. The analysis describes the main impacts of past hazards on the port, the date of occurrence, duration, intensity and location of each hazard.

Then, the study analysed data from climate models for a period of reference. A scoring scale has been defined to compare the current and the future projected climate conditions.



Example of extract from a database: number of fire starts from 1995 to 2005

Echelle de notation adoptée	
Variation de température	Notation
0-1°C	1
1-2°C	2
2-4°C	3
>4°C	4

Example of scoring scale

(Cerema, 2019b)

Implementation in the framework of the Ecclipse project
Each country involved in the project should develop a list of hazards that might already affect the ports and analyse their current characteristics. A common scale for all the ports should be developed. If possible, the results could be presented in form of maps of exposure.

3.3 Future exposure assessment

To assess the exposure of a port to the future climatic conditions, climate projections are required. Therefore, it is necessary to choose:

- One or more climate scenarios. Climate scenarios are based on the estimated evolutions of greenhouse gases in the atmosphere
- Climate models, this is to say the mathematical models that link greenhouse gases to climatic variables
- Climate variables, that describes in different ways the climate events. For example, hot temperatures can be described by the maximum number of consecutive hot days (the intensity of hot days has to be defined) or by the daily maximum temperature between June and August
- The level of uncertainties of the selected climate projections (e.g. median values, etc.)
- The timescale of projection

These data could be available through climate models or specific research studies on climate change. If no data are available:

- If the evolution of the hazard whose projections are not available mainly depends on other hazard whose projections are available, it might be relevant to develop an indicator to approach its evolution. This indicator should combine hazards whose projections are available
- If necessary, models should be developed to analyse the future exposure to sea level rise, flooding, water runoff, etc., based on the data previously found
- The evolution of a hazard could also be approached by analysing the evolutions of the past characteristics of this hazard and extending them into the future

The scoring scale already used to characterise the current exposure has to be used to assess the future exposure. This will allow to compare the exposure evolution over time.

Box 22: future seal level rise exposure assessment of Port of Long Beach, United Sates of America

The Port of Long Beach, located in California, is one of the largest ports in the United States of America. It developed a Climate Adaptation and Coastal Resiliency Plan (CRP) "to manage the direct and indirect risks associated with climate change and coastal hazards".

Sea level rise was identified as an important risk for the port and thus, the future exposure of the port to this hazard has been analysed. Therefore, the study estimated the local sea level rise by mid- and end-of-century on the basis of projections developed in 2013 by the Coastal and Ocean Working Group of the California Climate Action Team (Co-CAT) and in 2012 by the National Research Council. According to these projections, sea level near the port is expected to rise 5 to 24 inches by mid-century and 17 to 66 inches by end-of-century. To represent the variability and uncertainty of sea level rise projections, the CRP considered 3 scenarios of sea level rise: +16 inches, +36 inches and +66 inches, without a specific time horizon. The future exposure to sea level rise has then been modelled for two tide conditions: daily high tide and extreme tide (storm surge).

Figure 4-1. Overtopping and Inundation Map (16-inch scenario)

(Port of Long Beach, 2016)

Implementation in the framework of the Ecclipse project

This step is partially developed by another working group (in charge of the working package 3) of the Ecclipse project. Members of the projects should share common hypothesis of climate projections and develop a common scale to assess the future exposure of each port.

At this stage of the risk assessment, results provide an overview of the current and future exposures of the most critical assets and activities susceptible to be impacted by various climatic hazards.

Results can be presented in the form of a matrix or of exposure maps highlighting critical assets and activities.

4. Risk assessment

The risk assessment is based on a sensitivity assessment and on the results obtained with the previous stages of the methodology. The sensitivity assessment is used to study differences in the impact of a given climatic hazard on assets or activities of the same category. This chapter presents how to lead a sensitivity assessment and then, a risk assessment.

4.1 Data collection

To precisely identify the impacts of a hazard on various assets and activities, it is necessary to identify their characteristics, in terms of condition, maintenance, etc.

The potential extent of an impact on a critical asset is notably influenced by its condition, state of maintenance, design rules, materials and construction techniques. Other data could be gathered to precise the results of the risk assessments.

A large range of parameters can influence the extent of an impact on an activity. These parameters might be very different according to the aim of the risk assessment. Thus, it is not possible to develop an exhaustive list of data to collect for the risk assessment, however, a good way to identify relevant data could be to select or develop performance indicators that characterise each critical activity. For example, if the risk assessment take into account the activity “transit of goods”, following performance indicators could be useful: maximum number of container ships that can be accommodated in the port, number of container ships accommodated in the port during / after a hazard occurred, normal unloading time and effective unloading time, etc.

Box 23: example of indicators to measure ports resilience

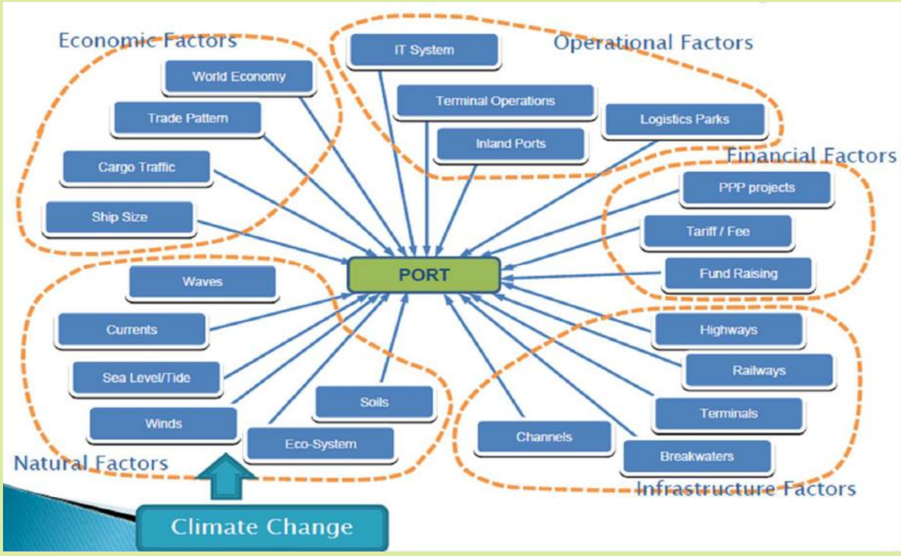
The Engineer Research and Development Center of the US Army Corps of Engineers conducted in 2019 a research project to identify the vulnerability factors to measure the resilience of North Atlantic medium- and high-use maritime freight nodes to climate change. The project identified indicators to assess the exposure of nodes as well as indicators to assess the sensitivity of port assets and activities. These indicators are for example: tanker capacity, vessel capacity, channel depth… The project also propose indicators to assess other drivers, such as economic drivers with the following indicator: marine transportation gross domestic product.

(Engineer Research and Development Center, 2019)

Other drivers can also influence the future of a port. Even if these events are not climatic hazards, it might sometimes be relevant to take them into account in a risk assessment to climate change: this depends once again on the aim of the study.

Box 24: example of drivers that influence the future of a port

The United Nation Conference on Trade and Development (UNCTAD) published in 2018 a report dealing with the need of information to improve port resilience. The report highlight that the future of ports can be influence by drivers other than climate change. These drivers could be taken into account in a risk assessment process.



(Inoue, S., 2013, in: United nation conference on trade and development, 2018b)

All the data previously mentioned can come from databases of the port authority, expert judgements, specific studies, plans and strategies of the port authority, etc., and can be gathered through questionnaires and surveys for example.

Implementation in the framework of the Ecclipse project

This step is being completed by another working group (in charge of working package 2) of the Ecclipse project. It is advised to check if all data needed have been collected, according to the list of assets and activities listed for the susceptibility assessment.

4.2 Sensitivity assessment

One of the first step of a risk assessment to climate change is the susceptibility assessment. It provides first overview of the assets and activities the most likely to be impacted by climate change, but without a precise analysis based on climate change values. Then, the exposure assessment provides data on current and projected characteristics of climate events and mean climate conditions. Aim of the sensitivity assessment is to analyse precisely if, according to the exposure assessment, a critical asset or activity is likely to be impacted by climate change and to which extent.

Therefore, identifying impact threshold values may be useful. An impact threshold value corresponds to the value of a climate event from which an asset or an activity can be impacted. These values may be available in design documents, specific studies with or without modelling, feedback on hazards that impact ports. As threshold values are not always available, an idea of these values can be approach by interviewing experts.

Then, it is useful to describe the type of impact that can occur. This depends notably from the characteristics of the impacted asset or activity and this part of the assessment requires data described in the previous chapter, such as construction materials, age of an asset, etc.

Box 25: example of impacts thresholds for ports in Australia

To develop its framework to assess climate change risks on ports, the Australian National Climate Change Adaptation Research Facility (NCCARF) conducted a research project published in 2013. For this research project, interviews of ports experts resulted in the collection of thresholds for impacts on assets and activities. Different values of an impact can cause different types of impacts, from a slow-down to a stoppage of an activity for example.

Climate variable	Asset Vulnerability			Current effects of climate variable
	Interface	Significant (operation down for days)	Moderate (operation down for hours)	
FLASH FLOODS	SEA-LAND	• shore cranes	• multi-trailers (roll trailers)	Flash flooding can cause the entire port to close. This was the case in 2011 during February and March where three days of rain caused the port to close while several truck-loads of sand were brought into the terminal area to prevent straddle slippage as oil had risen above the water
	LAND	• yard cranes • rail trucks	• trucks • straddle carriers	
HEAT WAVE	SEA-LAND		• pilot / port control room / vts • communication equipment • shore cranes • multi-trailers (roll trailers) • power supply	The ports temperature policy states that at 36 degrees, breaks become longer and at 38 degrees, operations related work ceases. Current day conditions – temperatures exceed 38 degrees Celsius once annually
HEAT WAVE cont.	LAND	• rail tracks	• trains • trucks • roadways • storage areas • warehouses	

(National climate change adaptation research facility, RMIT University, 2013b)

Implementation in the framework of the Ecclipse project

This step is being completed by another working group (in charge of working package 2) of the Ecclipse project. It is advised to try to collect thresholds values for each potential impacts on all critical assets and activities previously listed.

4.3 Risk assessment

The risk is often defined as the combination of the consequence and the likelihood.

With the previous steps, the consequence level (cf. sensitivity assessment) has been analysed. To assess the risk level, it is necessary to define a scoring scale for the level of consequence. In this scoring scale, it is possible to take into account the physical threats on assets, activities, or any other criteria such as the impacts on the port authority reputation, on the environment, etc. This can be based on the results of the sensitivity assessment, either the qualitative feedback or the impact thresholds values.

Box 26: consequence scoring scale for the risk assessment of the Port of London, United-Kingdom

The Port of London Authority assessed its risk level to climate change in the framework of the UK Climate Change Act (2008). It published in 2015 a review of the results of the risk assessment, to take into account organisational, environmental changes, as well as the implementation of adaptation actions. In this new report, the following risk matrix were applied.

Climate Change Adaptation Matrix

Severity or consequence of impact							
	Likely to threaten the survival or effectiveness of the organisation, likely to have major impact of whole operation	5	5 Low	10 Medium	15 High	20 High	25 High
	Significant impact on the organisational strategy or operational activities, likely to have major impact on many areas of business	4	4 Low	8 Medium	12 High	16 High	20 High
	Moderate Impact on organisational strategy or operational activities	3	3 Low	6 Medium	9 Medium	12 High	15 High
	Primary impact on the internal business, likely to have minor effect on many areas	2	2 Low	4 Low	6 Medium	8 Medium	10 Medium
	No Significant Impact on business as a whole	1	1 Low	2 Low	3 Low	4 Low	5 Low
			1	2	3	4	5
			Longer Term (to 2080)	Long Term (20-50 Years)	Medium Term (10-20 Years)	Short Term (5-10years)	Very Short Term (1-5 years)
			Probability short or long term impact				

(Port of London Authority, 2015)

The likelihood is based on the results of the exposure assessment and of the sensitivity assessment. It corresponds to the likelihood of occurrence of a hazard or to the likelihood that an impact threshold will be exceeded (if the impact threshold is available).

Box 27: likelihood scoring scale proposed by the PIANC

The PIANC proposes the scoring scale below to rate the likelihood with qualitative data. If quantitative data on the occurrence are available, the PIANC proposes to link the probability of occurrence, e.g. 50%, to one of the scores on the scale, e.g. score 3.

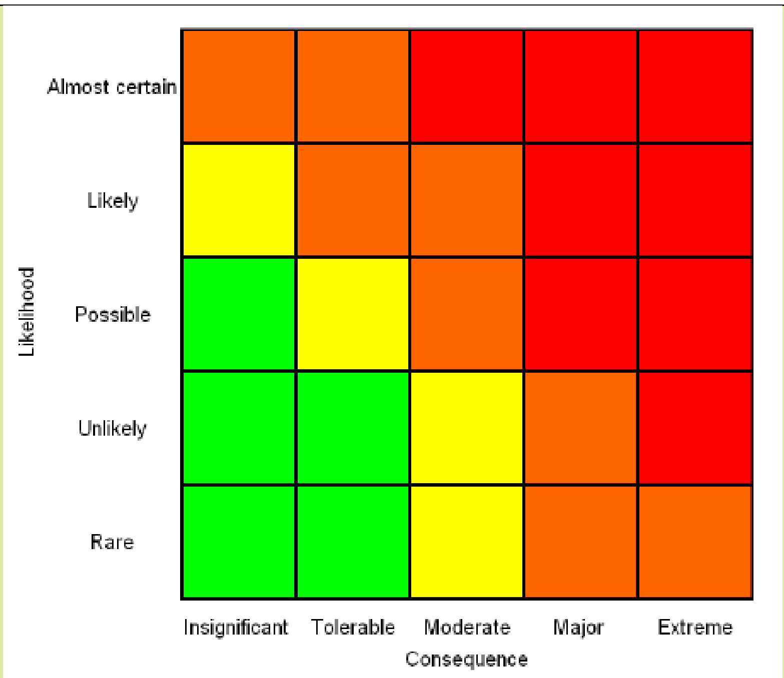
Qualitative description of likelihood	Likelihood rating	
It is **expected that** the climate hazard will occur, that the threshold will be exceeded or there will be another significant impact within the adaptation planning horizon under all climate change scenarios investigated.	Almost certain	5
It is **likely that** the climate hazard will occur, the threshold will be exceeded or there will be another significant impact within the adaptation planning horizon under some of the climate change scenarios investigated.	Likely	4
The climate hazard **may** occur or the threshold may be exceeded or there may be another significant impact within the adaptation planning horizon under some of the climate change scenarios investigated.	Possible	3
The climate hazard **could** occur, or the threshold could be exceeded or there could be another impact within the adaptation planning horizon under one or more of the climate change scenarios investigated.	Unlikely	2
The climate hazard (or the exceedance of the threshold or the manifestation of an impact) is **not expected** to occur other than in exceptional circumstances within the adaptation planning horizon under most of the climate change scenarios investigated.	Rare	1

(PIANC, 2020)

Once the consequence and likelihood have been rated, it is possible to assess the risk level.

Box 28: risk matrix for the risk assessment of PD Teesport, United-Kingdom

PD Teesport is one of the major port in the UK. Located in the North Yorshire, it handles mainly dry bulk and project cargoes. In the framework of the UK Climate change Act, it published its first climate change risk assessment report in 2011. In this report, the risk was assessed with a matrix combining the exposure level with the likelihood level. Here, the likelihood refers to the level of confidence that the impact might occur.



Beside the scores of likelihood and consequence, the report also provides information on the level of confidence on the climate projection.

ID	Risk	Likelihood (1 - 5)	Consequence (1 - 5)	Risk Priority (VH, H, M, L,)	Confidence (H, M, L)	Comments
PD Teesport Limited Port Authority Statutory Duties						
4	Sea defences adversely impacted or compromised by sea level rise (combined with any changes in storminess), with associated impacts upon surrounding infrastructure	4	4		M	*Applicable to sections of sea defences for which PDT have both partial and total maintenance responsibility .*

(Haskoning UK LTD Environment, 2011)

Implementation in the framework of the Ecclipse project

The members must define which criteria should be considered in the consequence scoring scale. This depends on the main aims of the risk assessment.

Conclusion

There is a large panel of engineering and research works relating to port risk assessments in a context of climate change. Based on the analysis of 18 case studies, this report proposes a method adapted to the context of the Ecclipse project. This method is applicable to other contexts, as it can be modulated according to the needs of the port manager or authority and the resources at his disposal.

Conducting a risk assessment has a real interest for a port manager or authority: it enables to become aware of the current and future level of risk and thus, to prioritize vulnerabilities. This knowledge is necessary for developing an adaptation strategy.

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