AdriaClim

Climate change information, monitoring and management tools for adaptation strategies in Adriatic coastal areas

Activity 3.5

Assessment of vulnerability, hazards and impacts on the Pilot Areas

D.3.5.1

A report on each of the Pilot area related to vulnerability, hazards and impacts

Introductory concepts and identification of key indicators

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Table of contents

1. Introduction

The main aim of this deliverable is to lay the foundations for risk assessment in selected coastal areas of the Adriatic basin. It provides introductory concepts to improve the awareness of hazards, vulnerability, and exposure and to implement their insights.
With this in mind, the first chapter of this document has been realized to provide the fundamental notions necessary to understand and define risk and its components and to explain the key terms and definitions related to climate change issues. They are based on scientific sources and official reports, such as those from the Intergovernmental Panel on Climate Change (IPCC), the European Environmental Agency (EEA), the United Nations Department of Humanitarian Affairs (UNDHA), the United Nations Disaster Relief Organization (UNDRO), and the United Nation Environment Programme (UNEP).
Another important issue that needs discussion and clarifications before assessing coastal risk is the identification of the coastal zone, whose concept has to be defined and established to correctly implement coastal planning activities and protection strategies. For this reason, the concept of coastal zone has been raised in the second section of this document.
The third objective of the present deliverable is to select indicators that will be used in the different pilot sites for tracking modifications in the climate systems, for assessing the impacts of climate change, and for defining adaptation measures. A set of indicators that will be applied at different scales and for different purposes (covering a wide range of aspects related to climate change) in the pilot areas are presented. In particular, they will allow comparisons between Italian and Croatian coastal regions. Indicators have been derived from both scientific literature and documents produced by national and international bodies and agencies dealing with climate change impacts on the environment (e.g. Karl et al., 1999; Peterson, 2001; ISPRA, 2009; Cubasch et al., 2013; IPCC, 2014a; EEA, 2015; CMCC, 2017; EEA, 2017; WMO, 2017; Giordano et al., 2018a; Mäkinen et al., 2018) and selected with the contribution of all the partners involved in the AdriaClim Project, mainly based on their relevance and data availability. The current sets of indicators will be revised and improved if new evidences and results will emerge during the investigations.

2. Climate-related definitions

2.1 An introduction to climate-related definitions

Climate is a meteo-oceanographic assembler characterized by spatial and temporal variations and connecting many sectors due to a broad list of impacts, vulnerability, and risks directly and indirectly connected. The analysis of climate change and the increase of its knowledge allow determining the necessary actions and future research needs to assess climate-change implications.

From research to planning of development sectors, it touches many areas of interest and foresees different consequences according to the frequency and rate of its related phenomena (precipitation rate, frequency of storm surges, changes in sedimentation rate, etc.).
To facilitate the analysis and prediction of the climate change variability, in 1979 the World Meteorological Organization agency (WOM) introduced the first world climate conference, that led to the establishment of the WMO World Climate Programme, resulting from the launch of many experiments and research programs implemented since 1950:

- 1950: WMO convention,
- 1957: setting up of the Global Ozone Observing System,
- 1963: launch of the World Weather Watch,
- 1971: establishing and upgrading of the Tropical Cyclone Programme,
- 1972: setting up of the WMO Operational Hydrology Programme,
- 1976: first assessment of the state of global ozone by WMO,
- 1977: joint establishment with the International Oceanographic Commission (IOC) of the Integrated Global Ocean Services System (IGOSS),
- 1978: launch of the Global Weather Experiment and Monsoon Experiments under the Global Atmospheric Research Programme.

From this starting point, technical and scientific experts have periodically met to discuss the latest developments concerning the climate-change issues, to investigate the added variability caused by natural and human systems, to further assess the future impacts and risks, and to formulate suitable recommendations.
After this event, many other bodies have been established in succession, including the Intergovernmental Panel on Climate Change (IPCC) in 1988 and the United Nations Framework Convention on Climate Change (UNFCCC) in 1992. They have released reports and conventions to give priority to climate-change effects, such as the global warming phenomenon, which is one of the main discussed topics, and stabilized the value of Greenhouse Gas (GHG) concentration in the atmosphere to prevent severe impacts.
Consequently, the use of common terms related to climate change and its effects has become necessary and various definitions have been proposed.
In this document, the most frequently used definitions coming from different sources (i.e., scientific literature and technical documents) are presented in order to obtain an organic comparison. The terms reported here are intuitively understandable by people. Even if over the years several definitions have been proposed, it should be kept in mind that there is no one explanation better than another and each of them can be interpreted and applied according to the type of investigated system.
The terms that have been considered are hazard, exposure, vulnerability, sensitivity, risk, impact, adaptation, mitigation, adaptive capacity, and resilience. In the following table, we want to gather the best definitions closer to the context of analysis considered within the AdriaClim Project.

2.2 Main climate-related definitions

Hazard

Author(s) - Year	Definition
UNDHA - 1992	*A threatening event, or the probability of occurrence of a potentially damaging phenomenon within a given time period and area.*
Jones and Boer - 2003	*A hazard is an event with the potential to cause harm, such as tropical cyclones, droughts, floods, or conditions leading to an outbreak of disease-causing organisms (plant, animal or human).*
IPCC - 2014b, c (part A)	*The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources.*

Exposure

Author(s) - Year	Definition
IPCC - 2014b, c (part A)	*The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.*

Vulnerability

Author(s) - Year	Definition
UNDRO - 1979	*Vulnerability is the degree of loss to a given element or set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude.*
Timmerman - 1981	*Vulnerability is the degree to which a system acts adversely to the occurrence of a hazardous event.*
Liverman - 1990	*[Vulnerability] has been related or equated to concepts such as resilience, marginality, susceptibility, adaptability, fragility, and risk.*
UNDHA - 1992	*Degree of loss resulting from a potentially damaging phenomenon.*

EEA - 2005	*Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.*
Omann - 2010 (in CLIMSAVE project)	*The vulnerability of a system is assessed by considering its exposure to pressures and its coping capacity, which can be increased with adaptation measures.*
IPCC - 2014b, c (part A)	*The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.*
Burkett et al. - 2014	*Propensity or predisposition of a given system (natural or social) to be adversely affected by a given driver. In the case of climate change, types of driver include climate variability, extremes and hazards.*

Sensitivity

Author(s) - Year	Definition
IPCC - 2018	*Climate sensitivity refers to the change in the annual global mean surface temperature in response to a change in the atmospheric CO_2 concentration or other radiative forcing.*

Risk

Author(s) - Year	Definition
UNDHA - 1992	*Expected losses (of lives, persons injured, property damaged, and economic activities disrupted) due to a particular hazard for a given area and reference period.*
IPCC - 2014b, c (part A)	*The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard.*
Adger et al. - 2018	*Climate change creates cascading risks in physical systems, ecosystems, economy and society, often interrelated and creating the circumstances for irreversible and undesirable crossing of*

	thresholds at multiple scales.

Impact

Author(s) - Year	Definition
IPCC - 2014b, c (part A)	*Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system. Impacts are also referred to as consequences and outcomes. The impacts of climate change on geographical systems, including floods, droughts, and sea-level rise, are a subset of impacts called physical impacts.*
Agard and Schipper's - 2014	*Effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period.*

Adaptation

Author(s) - Year	Definition
IPCC - 2014b, c (part A)	*The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In natural systems, human intervention may facilitate adjustment to expected climate and its effects.*
Adger et al. - 2018	*Climate change creates cascading risks in physical systems, ecosystems, economy and society, often interrelated and creating the circumstances for irreversible and undesirable crossing of thresholds at multiple scales.*
Füssel and Klein - 2006 (from IPCC AR 2001)	*An adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.*

Mitigation

Author(s) - Year	Definition
UNDHA - 1992	*Measures taken in advance of a disaster aimed at decreasing or eliminating its impact on society and environment.*
Füssel and Klein - 2006 (from IPCC AR 2001)	*An anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases.*
UNEP - 2008	*Effort to reduce or prevent Greenhouse Gas Emissions.*

Adaptive capacity

Author(s) - Year	Definition
Füssel and Klein - 2006 (from IPCC AR 2001)	*The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.*
IPCC - 2014d (part B)	*The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.*

Resilience

Author(s) - Year	Definition
Timmerman - 1981	*The measure of a system's - or part of a system's - capacity to absorb and recover from the occurrence of a hazardous event*
IPCC - 2014b, c (part A)	*The capacity of social, economic, and environmental systems to cope with hazardous events or trends or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation learning, and transformation.*

Those terms could appear easily linkable one to another, but actually a thick connection network exists among these words, touching many sectors at the same time. This peculiarity justifies why these topics cannot be comprehended singularly, but, instead, they must be considered in their entirety and by taking into consideration their relationships. Moreover, by understanding these definitions it is possible to conduct a good investigation on the evolution of direct and indirect effects affecting a particular area of interest, and further to forecast future scenarios.
The explanation of “hazard” represents a good example; while defining this term, it is often necessary to consider the concepts of both vulnerability and exposure, due to their connections. By mapping and monitoring these components, it is possible to obtain a clear view of the system and further develop strategies. In fact, the comprehension of exposure trends allows defining the vulnerability and the hypothetical severity of impacts after extreme and/or non-extreme events. Variations in exposure degree change vulnerability rate.
Key vulnerabilities in a system influence, and accordingly change, key risks and emergent risks that must be taken into consideration while analysing an area. This process allows increasing the knowledge, understanding the dangers, and therefore improving the climate-change perception to finally undertake a suitable implementation of effective and efficient strategies.
By reading this Deliverable it will emerge that finding the most suitable definition allows a better understanding of the processes occurring in the areas of interest. Therefore, it ensures the employment of an integrated approach that considers the innate characteristics and avoids the loss of variability and elasticity, both fundamental characteristics in describing climate change because of the unpredictability of the phenomenon.

2.3 Hazard

This term appears to have been connected to climate change since 1978, when Charles F. Cooper emphasized the rise of health hazards after the increase of atmospheric carbon dioxide, connected also to a global warm increment due to the reflection and absorption of solar radiation by fine particles.
Later, in its last 2014 report (2014b, c - part A), the IPCC have defined hazard as:

the potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources.

From this specific definition, it can be understood that IPCC relates it mainly to physical events, trends, or their physical impacts. Over time, it has been reported that the occurrence of physical hazards could lead to endangerments, such as food insecurity, destruction of infrastructure, and loss of habitats already vulnerable to the effect of climate change. Besides, damages to environments implicate the decline of the ecological network and the disappearance of natural barriers. Consequently, the decrease of the level of biodiversity, as it will be better described later, leads to a reduction of the resistance and resilience capacity beyond the occurrence of a variety of impacts.
It must be also taken into consideration that the environments are a vital part of many social and economic realities; therefore, damages to this sector lead to a decrease of a territory's inner value and to a drop-off of the local Gross Domestic Product (GDP) value.
A proper understanding of impacts and hazard is primarily important and should be discussed with the local stakeholders and decision-makers to adopt appropriate reactions that can be summarized as follows:

- adopting adaptation strategies;
- adopting measures to mitigate the consequent vulnerabilities;
- enhancing the overall resilience of the system.

Inappropriate understanding could lead to unsuitable adjustment measures.

2.4 Exposure

Exposure is a dynamic concept varying in space and time. It changes according to the analysed area since it depends on geographical, demographical, economic, social, and governmental factors. Its level is directly connected to climate-change advancement and spatial heterogeneity because of anthropogenic development. As a matter of fact, Füssel and Klein (2006) reported the link between the increase of CO_2 in the atmosphere and the exposure degree of a system.
In the analysis of the system exposure, it should be promoted as an integrated methodology because exposure allows comprehending both the evolution of a single sector and how the impact would be on other sectors, directly and/or not-directly connected.
The definition contained in the IPCC's volume (2014b, c - part A) confirms the dynamic and multi-scope conception of exposure:

the presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.

Indeed, the lack of consideration of any of these sectors will lead to an increment of the exposure level. Strategies and measures should be developed and implemented in an integrated way and not only if weather and particular climatic phenomena occur; otherwise, they must be taken into consideration during the planning phase, since a bad design can lead to significant damages.
It can be asserted that there is not a unique definition of exposure degree able to be applied to all the systems. They are different for their geographical characteristics, economic, environmental, social, and development sectors. Effects that occur in coastal areas, already threatened by the increase of mean sea-level rise, flooding and storm surges, will be more evident after different changes in intensity of climate hazard.
To plan adequate management measures, able to decrease exposure degree, it is helpful to analyse and study events from the past. Besides, according to the type of events (single, extreme, or occurring for long periods), it is possible to classify different levels of exposure.

2.5 Vulnerability

Vulnerability is probably the most discussed concept when talking about climate change and its effects. It entails exposure, sensitivity, and adaptive capacity and it can give a picture of the potential damage that a system can endure. In 1990, Liverman already noted that vulnerability implies other concepts, relating it to "resilience, marginality, susceptibility, adaptability, fragility, and risk". Consequently, analysing the degree of vulnerability makes it possible to understand the system's capacity to defend itself from climate-change phenomena, which is strictly connected to the social, economic, and environmental characteristics of an area.
One of the first definitions of vulnerability is available from the publication of Timmerman (1981), who delineated it as "a term of broad use", "*almost useless for careful description at the present*" and as "*indicator of areas of greatest concern*". These considerations highlight the high variability that marks vulnerability, where a wrong evaluation could lead to an underestimating of the damages that might affect a system.
In 2005, the European Environmental Agency (EEA) identified vulnerability as a "*function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity*". This definition encompasses the insertion of further crucial terms for the climate analysis, such as sensitivity and adaptive capacity (which will be considered later on), and it is posed specifically within the climate change context, giving a very detailed dimension.
Therefore, in the 2014 IPCC's volume (2014b, c - part A), vulnerability has been defined as:

the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

This definition also considers a wide spectrum of possible combinations and elements.

An added value is given by the definition reported by Burkett et al. (2014), very similar to the above written IPCC's definition, but a specific reference to climate change and its consequences is inserted:

propensity or predisposition of a given system (natural or social) to be adversely affected by a given driver. In the case of climate change, types of drivers include climate variability, extremes and hazards.

From the reported definitions, it can be outlined that vulnerability contains a high rate of complexity: at the same time, it is a starting point, an intermediate element, or an evaluation outcome of an assessment. It could also be related to an external stressor (like climate change) or as an undesired consequence from other impacts (like disease or famine) (Füssel and Klein, 2006). Other difficulties come from the possible appearance of vulnerabilities' effects after a long period from the occurrence of a determined climate-change phenomenon.

Since climate change is not recognized as a localized phenomenon, all European regions are affected by its impacts and their increase. These effects vary according to the specific vulnerability of an area and the nearby zones. Therefore, all these analyses should include the so-called "unwanted effects" that can happen because of processes in the surrounding places.

For all these reasons, management, adaptation, and mitigation measures must be developed in an integrated way and prepared at a system level, instead of being arranged by taking into consideration single elements.

According to the reported considerations, it can be asserted that vulnerability is a multidimensional and dynamic concept, depending on complex interaction processes and having a high rate of variability besides time and space. It is also characterized by several uncertainties together with a wide range of impact scenarios. In order to account correctly these features, it is necessary to measure the degree of sensitivity to vulnerability and implement adaptation strategies, as further confirmed by Omann et al. (2010) and described in the CLIMSAVE project: *the vulnerability of a system is assessed by considering its exposure to pressures and its coping capacity, which can be increased with adaptation measures*. A good way to measure the degree of vulnerability is by quantifying the variation of the ecosystem services.

Furthermore, in Füssel and Klein's work (2006) vulnerability has been associated also with policies and human geography themes. In this circumstance, these social aspects, which are non-climate related, are considered as an *a priori* condition of a community determined by socio-economic and political factors, designing the different sensitivity and exposure to vulnerability.

Asserting the need to find the best definition of vulnerability according to the system of interest, and further conducting the appropriate analysis, a good method consists in utilizing indicators' set. In the case of a common basin, such as the Adriatic Sea, this set should be prepared with the support of the overlooking Countries and their territorial stakeholders to allow considering the different innate characteristics of all the environments.

2.5.1 Vulnerability assessment

A vulnerability scenario under climate change conditions should be carefully assessed through steps able to evaluate how a given impact can cause effects and which adaptation measure is more appropriate to be implemented. A good assessment does not use single indicators; on the contrary, it is the result of the synergy of forecast and assessment of future climate studies.
Downing et al. (2005) reported the steps that should be taken into consideration in conducting this process:

Step	Description
Definition of vulnerability	The study framework is set up to define the borders and the language that will be used to communicate with stakeholders.
Definition of the objectives	Set up the assessment objectives.
Identification of what is vulnerable	Institutions, places, or people and their vulnerability are taken into consideration, as well as what threat or hazard they are vulnerable to.
Design of the subject state	Obtaining the picture through indicators in order to have the present state of the study subject.
Evaluation of vulnerability	This process is conducted through different types of processes, from the simplest empiric connection between risk and hazard to the most complex one based on processing models. This choice depends on the team who is carrying out the assessment, the stakeholders' typology, and the starting point of the assessment.
Development of knowledge	This step aims to better understand vulnerability and its drivers or to increase knowledge about it. In this way, it is possible to get a clear view of the future vulnerability.

It is important to highlight that the complexity of the assessment strictly depends on the available knowledge. However, Downing et al. (2005) asserted that by following these steps a consistent evaluation of the subject's vulnerability is reachable, obtaining:

1. a description and analysis of the actual vulnerability,
2. a description of potential future vulnerabilities,
3. the comparison of vulnerabilities under different socio-economic condition, climate changes, and adaptive responses,
4. the identification of points and options for intervention, which can lead to formulation of adaptation responses.

All these results must be related to the stakeholders' typologies.

In addition, this roadmap displays that the assessment process could not be simple and linear even if it refers to a few groups. On the other hand, the necessity to encompass the widest variability must be primary, because vulnerability, as mentioned before, is a very dynamic concept and the deepest understanding will permit a better answer to the requested needs. The implementation of assessment at the national level allows and contributes to set up development priorities and to monitor the progress.

2.6 Impact

Several typologies of impacts have increased during the last decades. In Europe, volumes released by IPCC (2014b) and EEA accounted for the occurrence of different impacts according to the analysed region. In Southern and Central Europe, there are areas affected by an increase of heat waves' frequency, with concomitant forest fires and droughts. On the other side, the Mediterranean area is experiencing a drier climate, becoming more vulnerable to droughts and wildfires. Other countries heavily depend on their characteristic natural environment; for this reason, impacts on this heritage could lead to very important damages with loss of social facilities and biodiversity and consequent rise of life, maintenance, and development costs.
In the IPCC report (2014b, c - part A), impacts refer both to natural and human systems; in details:

Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system. Impacts are also referred to as consequences and outcomes. The impacts of climate change on geographical systems, including floods, droughts, and sea level rise, are a subset of impacts called physical impacts.

In Agard and Schipper's (2014) definition, even other sectors are added as a target of the impacts deriving from climate change:

Effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period.

From the above written descriptions, it can be deduced that impacts could be either direct and indirect (e.g., cultural and health) and not only physical. Their effect can last for more time after their occurrence and go beyond the increase of temperature or sea level. Many domains have experienced impacts from climate change, such as changes in water resources that have delivered to possible droughts or loss of reserves in mountain regions and variation in food supply due to the increase of heatwaves, impoverishment of air quality, and take-over of disease. In ecosystems, there could be modifications in time spawning or in species' migration behaviour.

Moreover, the occurrence of impacts has effects on the socio-economic development of an area and, according to its level, it is possible to define and foresee the potential changes in the present and future evolution. Different combinations, natural climatic variability, and variableness due to anthropogenic causes could lead to multiple adaptation scenarios with several responses. The highest degree of impact without the implementation of any kind of measure will lead to a steady increment of dangers. On the other hand, the application of restraining policies would implicate the decrease of the impacts from present to future (Füssel and Klein, 2006).
To avoid crucial changes it is fundamental to define the impacts of climate change through a series of indicators, as pointed out for vulnerability as well.
About that, in 2016 the Italian National System for the Environment Protection (Sistema Nazionale per la Protezione dell'Ambiente – SNPA) launched the initiative of setting up a set of climate change impacts indicators to improve the framework on environmental, social, and economical consequences after climate change (Giordano et al., 2018b). Among its objectives, this process can increase citizens' knowledge and awareness on these themes, enhancing and supporting the decisional processes (Tompkins and Adger, 2004).

2.6.1 Impact assessment

The development of an impact indicator system allows conducting an assessment on the area of interest and evaluating the potential effects of climate change scenarios in a domain. An example of a suitable tool is QSWAT, able to simulate the quality and quantity of surface and groundwater in a watershed to river basin-scale, to predict the environmental impact, and to further implement suitable management practices. Another useful model is LISFLOOD, developed by the Natural Hazards Project of the Joint Research Centre (JRC) of the European Commission, able to simulate the hydrological processes that occur in a catchment. These and many other tools of this typology allow carrying out specific simulations and assessing flooding, effects of rivers behaviour, consequences on land use, and effects of climate change; therefore, thanks to their implementation, end-users are capable to develop measures specifically suitable for their purposes.

2.7 Risk

After having analysed the concept of impact, it is suitable to deal with the definition of risk because the latter is often considered as a direct consequence of the first. Direct risks can be droughts, sea-level rise, increase of temperature, or anything damaging the sectors of agriculture, fish, and tourism. However, it must be taken into consideration the existence of indirect risks too. Some examples are the regulatory risk and the litigation risk. The former affects government systems and leads to a change in priority investments of the costs to be implemented for reducing the climate effects, the latter occurs when industries face important lawsuits if their impacts (e.g., GHG emissions) are connected to environmental damages (Setzer and Byrnes, 2019).

The definition released by IPCC in 2014 volume (2014b, c - part A) draws risk as something not certain by inserting keywords such as “uncertain”, “diversity” and “probability”:

the potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard.

Adger et al. (2018) added further characteristics to climate risk, designing it as not strictly physical but potentially transversal in several sectors:

Climate change creates cascading risks in physical systems, ecosystems, economy and society, often interrelated and creating the circumstances for irreversible and undesirable crossing of thresholds at multiple scales.

Indeed, the intra- and inter-sector occurrence of risks can lead to the loss of something valuable; moreover, further interactions with other factors can cause additional consequences (in some cases systematically), which are able to affect a wider system.
The increment of risks causes an increase of costs in terms of production, purchase of raw material, maintenance, and recovery of facilities. Certainly, these are visible in the short term, but they can have effects lasting for a long period if no proper actions are undertaken. Besides, further issues come from the financial instability, which does not allow efficiently allocating resources for the mitigation of climate risks together with the impossibility to properly reflect the climate change phenomena in the asset prices (ESRB - Advisory Technical Committee and Eurosystem Financial Stability Committee, 2020).
Risks bear within many sectors and processes, and entails dynamism and change; a correct management of risk helps in safeguard and protection of the natural and cultural heritage, allowing also to allocate the financial resources more soundly and to get further savings.

2.7.1 Risk assessment

Because decision-makers are looking at the dangers in delicate systems, such as the coastal zones, over the years the development of a proper risk assessment has become more and more important and strategic. Indeed, as for the assessment of vulnerability and impacts, risk can be also evaluated to study the strategic spots that should be investigated for proper management and future planning.
These processes are designed to support the adaptation planning and to develop implementation actions in interesting areas. Over time, many Decision Support Systems (DSSs) have been formulated, with the objective to deal with different aspects of the risks coming from climate change; some examples are: Delft 3D for hydrodynamic and morphological shoreline processes

(Hsu et al., 2006), BTELSS for ecological functions (Reyes et al., 2000), DIVA for climate impacts and coastal zone management (Hinkel and Klein, 2007), THESEUS for coastal flooding and erosion impacts (Zanuttigh et al., 2014), and DESYCO to support coastal managers in the first phase of risk assessment and to provide an integrated view of the potential threats caused by climate change (Torresan et al. 2016).
It must be specified that those tools are part of a more complex risk assessment framework, aimed to recognize the more likely vulnerable areas to climate change. Indeed, as stated by Jones in 2001, the risk assessment objective is to identify, evaluate, select and implement actions to reduce risk to human health and the ecosystem. A preliminary phase should be inserted too, whose purpose is to formulate the problem to apply suitable and appropriate steps in the next assessment's phases.

2.8 Adaptation

Because many sectors are affected by the increase of climate-change effects, the implementation of adaptation measures, able to moderate or even avoid the rise of intense effects (IPCC, 2014b, c - part A) has become fundamental:

the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In natural systems, human intervention may facilitate adjustment to expected climate and its effects.

In EEA's volume (2014), adaptation has been viewed with the overall objective to avoid adverse effects of climate change on the environment, society, and economy. This consideration is very close to the one written by IPCC. The adaptation measures should be place- and context-specific and follow principles aimed to design an effective adaptation path. Opportunities for implementing these processes must be used at their best, supporting the strengthening of society in being productive, healthy, and resilient. These procedures are not only carried out to prevent negative effects; indeed, equipping society with earlier adaptation responses permits to build resilience and make benefits, coping with climate change and socio economic-related challenges. Other authors (Pelling, 2010; Wise et al. 2014) emphasized the strict correlation between adaptation and resilience, suggesting that the increase of one leads to the increment of the other, promoting a systemic transition as part of a social transformation.
It can be summarized that adaptation to climate change aims to avoid or extenuate the risks deriving from climatic variations and to enhance the potential opportunities of the human-environment systems. Different strategies might be adopted to contrast climate change; they are influenced by agro-ecological and socio-economic factors, the degree of the climate impact, the presence of existing infrastructure and the outstanding capabilities (Alam et al., 2017).
Over the years, adaptation has been categorized into three different typologies: anticipatory, autonomous, and planned. The first one, which takes place before the occurrence of climate-change impacts, is considered a proactive action. The autonomous adaptation is not a

conscious response, it is the ecological reaction to changes and a spontaneous process; the latter, the planned one, is the result of policies and foresees the undertaking of action to return to, or to maintain, a particular state.
In the previous paragraph, it has been noticed how the effects deriving from climate change are not just for their own sake; on the contrary, they are trigger factors starting or enhancing many other effects, as briefly reported hereafter.

Effect	Consequent effect
Increment of GHG emissions	Freshwater risks
Broadening of dry areas (especially in the subtropical region)	Decrease of renewable water and groundwater resources
Advancement of 21st-century climate change	Extinction of terrestrial and freshwater species
Sea level rise	Submerging, of coastal areas, flooding, coastal erosion

The implementation of adaptation measures aims to moderate the adverse effects of inevitable climate-change effects through the undertaking of a wide range of actions targeting vulnerable systems. Adaptation acts on a selected system from a local to a regional scale. The effectiveness of adaptation measures is immediate and lasts decades (Füssel and Klein, 2006).
Societies must be supported in undertaking adaptation processes, and this is confirmed also by international entities, such as the UNFCC, which has defined adaptation as imperative in climate policy and fundamental synergy with mitigation, or the Conference of Parties, which has acknowledged that Countries, by boosting their planning processes, can conduct analysis on their vulnerabilities and mainstream climate-change risks (Least Developed Countries Expert Group, 2012).
Generally, adaptation to climate change requires a broader conceptualization of equitable, legitimate, and sustainable development in an effective and resilient response. In particular, in 2001 the IPCC recognized the importance of sustainable development in its Third Assessment Report suggesting guidelines for its component scientific assessments. These processes refer to the actions that can be undertaken in response to projected or actual changes in climate, to reduce adverse impacts or to take advantage of the opportunities posed by climate change; on the contrary, adaptation is the path to return to a prior state (Tompkins and Adger, 2004).
An important initiative has been launched by UNEP, the United Nation Environment Programme, that aims to trigger a global movement for restoring the world's ecosystem through its UN Decade on Ecosystem Restoration strategy. Indeed, it has been demonstrated that nature is the best defence against climate change. The objective is to implement ecosystem-based adaptation by restoring urban forests, mangroves along the coasts, and re-greening mountain slopes.

2.8.1 The European evolution of the adaptation framework

The European Union (EU) has tried to define a common strategy to approach the adaptation framework. Among its objectives, the European Commission (EC) aims at reaching a timely, efficient and effective adaptation action that crosses among sectors and governance levels; together with EEA the EC, it has found reasons to take action on climate-change adaptation:

- many climate change impacts and adaptation measures have cross-border dimensions;
- climate change and adaptation affect EU policies;
- solidarity mechanisms between European countries and regions might need to be strengthened because of climate change vulnerabilities and adaptation needs;
- EU programs could complement Member State resources for adaptation.

Economies of scale can be significant for research, information- and data-gathering, knowledge-sharing, and capacity building.
The EU puts efforts into applying a wide strategy and achieves coordination among the Member States, in coherence with various kinds of planning and management levels. The Union tries to fill in the adaptation gap by addressing resources in EU research and in innovation programs and expanding the Climate-ADAPT Platform. By giving access to relevant publications, tools, websites, and other resources related to climate change and health, the EU puts a lot of attention to the relation between climate analysis and citizens' health. Through its research, the Union finds the key vulnerable sectors. In particular, in 2013 it issued new policies addressed to agriculture and fisheries, involving also the private sectors in usage-based insurance and financial products and further increasing the resilience in investments and business decisions.
If adaptation measures are implemented by single countries, their effect will be weak compared to the measure adopted at the international level. Adaptation should not be bound to general policies; on the contrary, it should be considered as a guide for government authorities and non-state actors. These processes must enhance the establishment of coordinated initiatives; furthermore, the development of strategies at a national level will provide the design of the framework where relevant sectors can cooperate in order to reach, plan and apply a suitable adaptation measure.

2.9 Mitigation

Whereas adaptation aims to adapt inhabitants' life in a changing climate by reducing the vulnerability to harmful effects, mitigation's purpose is to reduce the climate-change effects through the application of reducing measures or storage tools. An ideal example is given by the GHG emission, where mitigation's objective is both to decrease the gas sources and enhance the sinks able to accumulate and store them (e.g. forest, soil, or ocean).

UNEP specifically defines mitigation as the "*effort to reduce or prevent the emission of GHG*" (2008). In this explanation, the concept of preventing is included; indeed, by applying these measures together with new technologies and renewable energies, it is possible to reach a more efficient use of resources in the future, allowing to aspire to a good mitigation degree in synergy with the change of management practices and also consumers' behaviour.
The Paris Agreement, adopted in 2015, is one of the most important treaties at the international level, which has highlighted the need to enhance mitigation measures. Its main objective has been to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels" and to pursue efforts "to limit the temperature increase to 1.5°C above pre-industrial levels" by 2100, by putting attention in reducing fossil-based CO_2 emission. However, the conventional mitigation measures are not enough to reach the objectives settled by the Paris Agreement, and the lack in stipulating any other conventions does not allow to meet the targets (Fawzy et al., 2020). The general conclusion is the encouragement to start using mitigation measures, permitting all systems to experience benefits at a global scale; but it should be noticed that these measures take several decades to become efficient (Füssel and Klein, 2006).
Plans of reforestation or avoiding waterproofing of soil allows to enhance the natural environmental mitigation capacity. Conventional mitigation efforts employ the application of decarbonisation technologies to reduce CO_2 emissions.
There are plenty of typologies of mitigation measures that can be applied in many sectors. Hereafter, some of them will be mentioned, but the list is not exhaustive. It is worth noting that many realities are a source of GHG emissions, from building industry to agriculture and animal husbandry, transports, and production of electricity.
Fawzy et al. (2020) have suggested strategies concerning the energy sector: use of renewable energy, fuel switching, use of nuclear power, increase efficiency gains and apply methods of carbon capture storage and utilization. In other sectors, such as agriculture and forestry, different recommendations to reduce economy-wide greenhouse gas emission have been considered. These measures comprehend improvement of practices for fertilizer and livestock waste, improvement of water management with the cultivation of appropriate crop varieties, boost of soil carbon sequestration with forestry and agricultural interventions, avoiding the conversion of forest to non-forest land, promoting forest expansions and improvement of forest management (Aggarwal et al., 2018).
Another approach is to implement a new set of technologies and methods able to capture and sequester CO_2 from the atmosphere. These techniques are named "negative emissions technologies" and include bioenergy carbon capture and storage, biochar, direct air carbon capture and storage, ocean fertilization, reforestation, wetland construction and reforestation, and so on.
Likewise, the strategy of altering the earth's radiation balance through the management of solar and terrestrial radiation is worth mentioning, even if it is still theoretical and characterized by a lot of uncertainty in terms of practical large-scale deployment. The objective is to stabilize or reduce the temperature values with the injection of stratospheric aerosol, cirrus cloud thinning, and surface-based brightening. Ambitious as it sounds, this is considered a potentially suitable

alternative in the face of the technological, socio-economic and political challenges associated with the global-scale zeroing of the net emissions. On the other hand, besides the practical difficulties in the actual operation of this kind of solution, a major drawback that has been pointed out is their possible role in disincentivizing the reduction of GHG emission. This would lead to a continuously increasing dependence on these technologies to keep the “engineered” climate at pace with the increasing GHG concentrations, as well as to an intensification of the environmental issues associated with high concentrations of GHGs (e.g. ocean acidification in the case of CO_2).
While a mitigation strategy is studied and applied, it is fundamental to use an integrated approach that must consider urban development, energy use, environment, and synergy between human health and the ecosystem. Nowadays, there is not an ultimate solution able to tackle climate change definitively.
It can be concluded that mitigation refers especially to GHG emissions-reducing actions that are particularly enhanced by the advancement of climate change.

2.9.1 The application of mitigation and adaptation measures

Mitigation and adaptation strategies are not often considered jointly; however, it must be remembered that single measures undertaken by themselves are not enough to contrast climate change. A joint implementation at different scales and levels of cooperation will enhance the initiatives aimed to improve these strategies. Mitigation and adaptation are underpinned by common enabling factors: effective governance, innovation, and investments in technologies and sustainable livelihoods. Innovation is the key to address the challenge to reduce GHG emissions, while investments are crucial for low-carbon or carbon-neutral results.
The analysis carried out by Füssel and Klein in 2006 has evidenced that mitigation and adaptation measures are born from the demand of response policies after the recognition of the vulnerability of a system. These terms aim to the same objective: avoid the effects of climate change. They act at two different temporal and spatial levels: the shortest one, which is more immediate, and the longest one, which ensures a more stable result. Mitigation refers to adopt actions to limit level and rate of climate change; it is defined as “*an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases*”; whereas adaptation, defined as “*an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities*”, encompasses within many and various actions of implementation for different sectors of application, allowing to produce structural changes.
Besides, suitable adaptation and mitigation plans should respond to a plurality of needs coming from citizens, residents, and society demands. This bottom-up process might permit adaptation to the available resources, to integrate with sector policies, and to coordinate with local participative processes (Vitelletti and Bonaldo, 2020).

2.10 Adaptive capacity

Adaptive capacity, the capability to adjust to potential damages and react to their direct and indirect consequences, is influenced by many factors and finds its strength in the diversity characterizing a system. This can be compared to the rate of biodiversity in an ecosystem: more diversity means to have a high capacity to oppose impacts and vulnerabilities and react consequently. In a climate-change contest, this process acquires particular importance by entailing the social, environmental, economical, and political sectors, and should foresee an integrated site-specific application.
Füssel and Klein (2006) reported the 2001 IPCC concept of adaptive capacity to climate change, describing it as an inner characteristic of a system, influencing the vulnerability of communities and regions to climate changes:

the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

In detail, adaptive capacity is the ability to modify the characteristics and behaviour allowing to cope with changes due to external stressors. Also, non-climatic factors, such as economic resources, technology, infrastructure, and institutions, should be inserted in the analysis as well, because they are relevant to determine the sensitivity of a system and/or a community to climate change.
Jones et al. (2010) asserted that adaptive capacity can be influenced at the local level and defined it as a part of the Local Adaptive Capacity (LAC) framework. To assess this capability, it is necessary to identify five core and interrelated characteristics and features:

1. asset base: the availability of key assets is needed to respond to circumstances;
2. institutions and entitlements: an institutional evolving environment should exist to reach a fair access and entitlement to assets and capitals;
3. knowledge and information: knowledge and information regarding adaptation have to be collected, analysed and disseminated;
4. innovation: in order to take advantages and new opportunities it is necessary to foster innovation and experimentation;
5. flexible forward-looking decision-making and governance: the system should be able to anticipate, incorporate and respond to changes properly.

In this publication, attention has been addressed to the capacity of a system to boost its adaptation power; furthermore, the LAC framework incorporates the innate capital and resource-based components of an environment. Indeed, at the local level it is important to identify

the characteristics that feature the area. In other frameworks, the attention is focused at the national level, where the use of indicators can give a picture of the spot and the state of goods and capitals.
Continuing, in the IPCC glossary of AR5 (2014d, part B) it is possible to find a definition of adaptive capacity that is near to the ones above reported:

the ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.

Here adaptive capability is described as an inner characteristic of a system, influencing the vulnerability of communities and regions to climate changes. In this specific context, the concepts of sensitivity and vulnerability can be connected: the first one refers to the degree to which a system is adversely or beneficially affected (directly or not) and the second one is the degree to which a system is susceptible to adverse climate change. More in detail, as written previously and from the definition reported in the cited technical assessment report, vulnerability should be delineated as a function of the degree of exposure, sensitivity, and adaptive capacity.
Together with adaptation, the term “maladaptation” has been introduced by Engle (2011) as the peculiarity to not cause harm but to exacerbate it. The existence of these two opposites allows analysing correctly the adaptive capacity of a system, illustrating how adaptation is a complicated issue based on a lot of spatial and temporal variables. Due to the high number of uncertainties, the characteristic to react or anticipate perceived or current stresses assumes importance according to different systems and contexts.
Adaptive capacity is strictly related to the concept of resilience considering that the increment of the first is directly proportional to the second. Indeed, adaptive capacity is a latent ability able to reduce the negative effects of climate change exposure and allows one to react to potential harm and hazards.

2.11 Sensitivity

Sensitivity is specifically defined by IPCC (2018) in reference to climate change and its effects by reporting the following definition:

“*climate sensitivity refers to the change in the annual global mean surface temperature in response to a change in the atmospheric CO_2 concentration or other radiative forcing*” – definition from Special Report: Global Warming of 1.5°C (2018).

In addition, climate sensitivity is generally delineated by two different time scales: the first refers to the short-term and is called “transient response”, while the second one relates to the “equilibrium sensitivity”.
Transient response is defined as:

"*the change in the global mean surface temperature, averaged over a 20-year period, centered at the time of atmospheric CO_2 doubling, in a climate model simulation in which CO_2 increases at 1% yr-1 from pre-industrial. It is a measure of the strength of climate feedbacks and the timescale of ocean heat uptake*",

while the equilibrium climate sensitivity

"*refers to the equilibrium (steady state) change in the annual global mean surface temperature following a doubling of the atmospheric carbon dioxide (CO_2) concentration. As a true equilibrium is challenging to define in climate models with dynamic oceans, the equilibrium climate sensitivity is often estimated through experiments in AOGCMs where CO_2 levels are either quadrupled or doubled from pre-industrial levels and which are integrated for 100-200 years. The climate sensitivity parameter (units: °C(Wm-2)-1) refers to the equilibrium change in the annual global mean surface temperature following a unit change in radiative forcing*".

All definitions bring up the rise of average temperature, settled by IPCC in the AR4 (Climate Change 2007 Report) to 3°C with a range of uncertainty from 2 to 4.5°C.
Understanding the climate sensitivity will help in understanding the amount of CO_2 that will be released into the atmosphere in the future. A very useful specification comes from the Met Office website, the national meteorological service for the UK:

"*the global temperature rise following a doubling of CO_2 concentration in the atmosphere compared to pre-industrial levels. Pre-industrial CO_2 was about 260 parts per million (ppm), so a doubling would be at roughly 520 ppm. Current levels of atmospheric CO_2 have exceeded 400 ppm, with the 520 ppm threshold expected in the next 50-100 years depending on future greenhouse gas emissions*".

Because climate sensitivity is strictly connected to the CO_2 concentration and its sequestration, its determination is important for the economic sectors too, considering that they depend on carbon usage; consequently, they influence policy-making decisions and related implications.
In conclusion, understanding the climate sensitivity range permits knowing how a system is experiencing a specified degree of climate-change effects. However, uncertainties should also be considered because, by analysing and reaching the highest rate of confidence, it is possible to implement good future adaptation and mitigation measures. Decreasing the amount of uncertainty is essential to collect as much information as possible on the future scenarios; therefore also comprehending the past events is helpful. These concepts will lead to gain a proper and wider knowledge of the climate processes affecting sensitivity, such as clouds, water vapour, aerosols, and further enhance the development of satellite remote sensing.

2.12 Resilience

Resilience to climate change (or climate resilience) is the capacity of a system to absorb stress and to be able to maintain the inner functions after an event. Enhancing resilience is crucial to understand the inner tissue of a sector and comprehends the analysis of the social, economic, environmental, technological, and political directions from the local community to the global level.
Many authors (Folke, 2006; Turner Ii, 2010; Adger et al., 2011) agree on defining resilience with three main characteristics:

1. capacity to respond to disturbance,
2. capacity to self-organize,
3. capacity to learn and adapt.

The IPCC (2014b, c - part A) has reported the following complete definition of resilience:

the capacity of social, economic, and environmental systems to cope with hazardous events or trends or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation learning, and transformation.

Local communities cover a crucial role in this ability acting as the so-called "social resilience". In fact, a high rate of this capacity represents the ability of citizens and residents to deal with external stresses and shocks, preparing for disaster, reaction, and recovery. This is important since it allows responding to rapid changes in the environmental conditions; moreover, solid social webs enhance the innate resilience factor of a system (Tompkins and Adger, 2004). Therefore, including the stakeholders and the local community in the adaptation implementation to climate change is an essential step.
Besides this topic, the Sendai Framework for Disaster Risk Reduction 2015-2030 (2015) has outlined four priorities with a prevention objective:

1. understanding disaster risk,
2. strengthening disaster risk governance to manage disaster risk,
3. investing in disaster reduction for resilience,
4. enhancing disaster preparedness for effective response and to "build back better" in recovery, rehabilitation, and reconstruction.

The main outcome of this framework is to reduce disaster risk with a "*more explicit focus on people and their health and livelihoods*", pursuing the objectives with perseverance and persistence. Community resilience plays an important role because disaster risk reduction must be

multi-hazard and multi-sectoral, inclusive, and accessible. The collaboration between governments and relevant stakeholders becomes crucial in the design and implementation of policies, plans, and standards. Translating national policies in actions allows enabling analysis and identification of gaps, and further applying suitable and correct measures.
Nowadays governments and non-governmental organizations consider the enhancement of the resilience capacity as a priority; it means that more importance is given to research, program development, enhancing crisis management and education initiatives. This kind of capacity specifically is outlined as social resistance, defined by Maguire and Hagan (2007) with three aspects:

1. resistance: the community ability to withstand impacts;
2. recovery: the ability to return to pre-disaster condition;
3. creativity: learn from past experience and achieve a higher functioning level.

This capacity allows groups or communities to respond to adversity or even predict and anticipate events.
A way to increase resilience in a system is by strengthening diversity; indeed, as reported by Bernhardt and Leslie (2013), a high rate of diversity increases the variety of responses to disturbance. Consequently, biodiversity and the presence of a variety of species become crucial because they allow overcoming the temporal lack in the natural resilience, and the enhancement of the capacity recovery by boosting the connections among species, populations, and ecosystems.

3. Identifying the coastal zone: concepts and approaches

The concept of "coastal zone", though intuitively within grasp at a first glance, becomes progressively more elusive when one probes into the process of practically defining the boundaries of an assessment, management or planning task. In fact, while for several individual processes at the interface between land and sea it is reasonably easy to identify some spatial references under given conditions (e.g., the region that can undergo the action of the sea during a storm), a unique definition accounting for all the processes and their interactions is a much trickier task. This is even more the case when the temporal dimension comes into play, either in terms of time variability of the process (in the previous example, whatever the complexity of the system, which is the reference event? Will we refer to the maximum storm occurring once in a year, once in a decade, or once in a century?) and of net long-term evolution of the process and its statistics (again, will the strongest yearly storm at the end of this century be equivalent to the strongest yearly storm in present days?). Thus, although coastal protection has been a primary topic at the global scale for several decades (a paramount example can be found in the famous Agenda 21, from the 1992 Rio Conference, chapter 17), on the wake of a historically "flexible" approach to the identification of the coastal zone (see for instance Dal Cin and Simeoni, 1994; Scialabba, 1998; and references therein), the pursuit for a generally accepted definition has progressively been abandoned both in policy frameworks and in the scientific literature. Besides some semantic shades implicitly emphasizing some specific aspects, such as the geographical extent of a "coastal area" or the network of interdependencies of a "coastal system", the general trend is to tailor the definition of the coastal domain to the specific needs of the study. Such is for instance the approach declared by the EU Demonstration Programme on Integrated Coastal Zone Management (ICZM), addressing the coastal zone in terms of a "strip of land and sea of varying width depending on the nature of the environment and management needs" (http://ec.europa.eu/environment/iczm/situation.htm, accessed on May 27th, 2021). Wong et al. (2014) also acknowledge the lack of a unique definition of the coastal systems and tackle the problem of the assessment of global climate-change effects by extensively addressing the different components of the coastal landscape.

The present paragraph, far from striving for a systematic reordering of this picture or for a providential filling of this denotation gap, aims at providing a brief overview of the factors and concepts typically underlying the definition of the coastal zone, directing the identification of the aspects to be addressed when dealing with a coastal management problem in a given context. In the framework of the ADRIACLIM Project activities it means to set up a simple scheme, applicable to all Pilot Sites, for the computation of the indicators to be considered in the assessment of the coastal risk under climate-change conditions and in the planning of adaptation strategies.

For large-scale planning frameworks at a high jurisdictional level, the simplest practically usable definition of coastal zone typically relies on a small set of metrics identifying the landward and seaward boundaries of the land-sea interface. At the EU level, a 2006 definition by the European Environmental Agency identifies a 10 km buffer around the coastline, with the possibility of specifically focusing on the "immediate coastal strip" up to 1 km in the landward side, and of adjusting the seaward boundary based on the issue considered (EEA, 2006). A similar approach, with slightly variable numbers, is adopted in several National legislations. This allows approximating the complexity of the coastal processes, pressures and activities by means of a purely spatial criterion, requiring very little pre-existing information on the characteristics of the zone under investigation. The price is the need to give up the insight on how the system works, with obvious consequent difficulties in predicting the possible outcomes of any policy option.

A small step toward a more insightful approach can be made by including some information on the land use dynamics: this can be done still relatively easily and unambiguously by considering not only a buffer around the coastline, but also around some specific land use categories identified by widely recognized criteria. This is the approach followed by Lavalle et al. (2011), aiming at considering both the ecosystems and anthropic pressures on the coastline proper and the inland areas typically influenced by the marine environments. In this case, the uniqueness of the definition (at least at the EU level) is ensured by referring to the Corine Land Cover classification, including coastal lagoons, estuaries, salt marshes, salines, and intertidal flats. Outside of the EU, a similar approach is followed in Brazil, where the definition of coastal zone is based on geographical, administrative and land use criteria (de Andrés et al., 2018), with marine boundaries identified by the limits of the Territorial Sea (12 nautical miles) and landward boundaries encompassing coastal municipalities plus administrative areas, infrastructures and land-use categories unambiguously identified. Distance criteria have been recurring also in other concepts related to coastal zone identification and protection, such as the “coastal setback”, for which again the definition is far from unique (PAP/RAC, 2013).

This classification method mostly based on spatial concepts, while sparingly demanding in terms of required information and easily repeatable and replicable in different contexts, suffers from the lack of an explicit (though possibly simplified) description of the coastal processes in place. This typically leads to failure in accounting for the results of more or less complex interactions among terrestrial and marine processes. For instance, salt intrusion in coastal aquifers following relative sea-level rise is certainly a landward effect of a sea process, but its actual extent depends also on hydrological and hydrogeological processes as well as water management strategies that can extend for several hundreds of kilometres inland. On the other hand, a complete outline of the causal loops and feedbacks framing the coastal system can be practically unachievable on the large scale, due to both the increasing complexity of the problem and the lack of quantitative information.

Another major limitation of the approaches mentioned so far is the depiction of a static view of the system, hampering any prediction of its evolution with severe implications for long-term planning. For some specific processes, such as in the case of coastal retreat, the inclusion of the temporal dimension can be relatively straightforward. For sea-level rise in low-lying coastal regions, an elevation threshold can provide a proxy of the areas potentially flooded in a future scenario: this is at the base of the concept of Low Elevation Coastal Zone (LECZ), commonly used in both scientific literature and policy frameworks with a typical threshold set at 10 metres above the sea level (McGranahan et al., 2007; Vafeidis et al., 2011; Neumann et al., 2015; Oppenheimer et al., 2019). A corresponding idea can be applied for high-elevation coasts on eroding cliffs, where buffers can be identified for management purposes based on estimates of the retreat rate and consequently on projections of cliff retreat under a given time horizon (Pena et al., 2021). Of course, the quality of the existing data and the uncertainties on the projections can significantly affect the outcome of the analysis. Lichter et al. (2011) point out that the use of different digital elevation models and population distribution datasets can lead, at the global scale, to an uncertainty on the order of 100% in the estimate of the population in the LECZ possibly susceptible to relative sea-level rise. Like for any “static” definition, dynamic criteria can include several natural and anthropogenic processes based on the management needs, but this comes at the obvious price of further complicating the conceptual framework and increasing the need for quantitative information.

The degree of complexity (including both process insight and spatial detail) of the system description and the time limits of the analysis are in fact the two main variables in the definition of the coastal zone. The choice of both depends on the management problem to be addressed and is constrained by the quantity and quality of the available data and on the degree of understanding of the system functioning. These requirements become increasingly difficult to be fulfilled as the geographical extension of the study area increases, forcing a trade-off between process insight and spatial scale of the assessment. When facing a practical management or planning task, this

potential shortcoming can be overcome by complementing a sufficiently widely accepted and relatively simplistic approach to the identification of the coastal zone, suitable for being easily linked to broad (National to International) policy frameworks and conventions, with a dedicated tool addressing the specific characteristics and needs of a more restricted area (e.g., Gallina et al., 2020; Ramieri, 2011, and references therein).
Based on these considerations and on the specific local goals and issues addressed by AdriaClim, Table 1 gathers the definitions of Coastal Zone adopted for the Pilot Areas in the framework of the Project activities. This provides the spatial reference for the different phases of the planning process, from the characterization of the impacts of climate change to the identification of adaptation strategies.

Pilot Site	Definition
Friuli Venezia Giulia Pilot	The coastal zone of this Pilot is geographically composed by the strip of land and the wetlands, limiting the Gulf of Trieste and the Lagoon of Grado and Marano, which are directly influenced by the exchange of momentum, mass and energy with the bordering water, and that host anthropic activities strictly based on therein natural resources and the ecosystem
Veneto Coastal Pilot	Venice and its lagoon are the focal point of the pilot with extension and guidelines for the whole Veneto coastline tested in three municipalities. Most of the coastal municipalities have a landward extension between 2 and 5 km while Venice and its lagoon is of the order of 10-20 km.
Emilia-Romagna Coastal Pilot	Emilia-Romagna lies on the Adriatic Sea with a low, sandy coastline which stretches for approximately 130 km from the Goro Po mouth to the Gabicce headland. The distinctive element of this coast is the beach, produced by the interaction, over a long period of time, between sediment carried to the sea by rivers, redistribution and deposition by the waves and marine currents and the modelling action of the wind.
Puglia Region Pilot	The coastline of Puglia extends for approximately 800 km with a high variety of sandy beaches and rocky sea bottoms. The coastline also includes some important wetlands (Lesina and Varano lagoons) and hosts several anthropic activities and tourist locations.
Dubrovnik-Neretva Pilot	The transnational Neretva River flows near the port-town of Ploče in Croatia and represent one of the principal sources of freshwater in the Adriatic Sea with an average water discharge of about 300 m 3 s^{-1} . The area has around 35,000 inhabitants,

	and a wastewater system is partially established only in cities Ploče, Metković and Opuzen, but without treatment plants.
Split-Dalmatia Pilot	The coastal zone of the pilot area covers the administrative area of the Kaštela City. The land area covers 58 km^2 and the sea area belongs to the Kaštela Bay. According to the Landscape Regionalization of Croatia, the area of the Kaštela belongs to the landscape unit Coastal Area of Central and Southern Dalmatia. The length of the coast is 23 km and almost the entire coastal area of Kaštela is urbanized. The river Jadro (in Solin) and the stream Pantana (near Trogir) flow into the Kaštela Bay. In the Bay, there are several islands such as Školjić, Galera, Barbarinac and Šilo cliffs. The town is located along the Kaštela Bay narrow coastal strip, from the north and northeast closed by the mountain, from the south by the Split peninsula, and from the west and southwest bordered by Trogir and the island of Čiovo. The coastal settlement is followed by agricultural land (Kaštela field) and a sudden relief rise towards the mountain Kozjak. The coastal zone of the City of Kaštela has been exposed to long-term adverse anthropogenic activity and it is influenced by the proximity of two strong tourist destinations, Trogir and Split, and by the proximity of the airport. Due to its natural characteristics (closed bay) and intensive industrialization in the past, as well as increased urbanization, Kaštela Bay is one of the areas where the ecological balance has been disturbed, consequently increased eutrophication has been recorded in this area.
Marche Region Pilot	The pilot considers the whole coastal area of the regional territory considered eligible within the Italy-Croatia Programme (Provinces of Pesaro, Ancona, Fermo, Ascoli Piceno and Macerata). The coast boasts long sandy strands, clear water, small bays and coves surrounded by unspoiled landscapes. The coast is near the old towns: a few miles from the long beaches and the steep cliffs plunging into the sea there are plenty of typical rolling hills.
Molise Region Pilot	The pilot area is represented by the 4 municipalities that overlook the Adriatic Sea. The municipal limit for the administrative part and the search for physical and vegetational

	limits for the detailed analysis part. The administrative choice is the most suitable in terms of application of the actions.
Zadar County Pilot	The Zadar Country pilot site is not on the coastal zone.

Table 1: Coastal zone definitions for each Pilot Site

4. Indicators

According to the European Environmental Agency (https://www.eea.europa.eu/help/glossary/eea-glossary/indicator), an indicator is an observed value, representative of a phenomenon, that quantifies information by aggregating different and multiple data. Therefore, the resulting information is simplified and synthesized.

Within the AdriaClim project, indicators are considered knowledge-based tools that will be part of the integrated information systems developed for the implementation of regional climate adaptation plans. They provide reliable means that can reflect not only changes in climate but also their impacts on the environment. Consequently, for each Pilot Area, indicators are relevant to support adaptation planning and policy and their identification and application are fundamental to perform risk analysis.

Scientific indicators, which convert data outputs into more usable information, are the basis to define sector indicators that are used to identify the responses of specific societal sectors to climate changes and to monitor and assess whether the application of particular mitigation and adaptation strategies will allow achieving the intended objectives.

As one of the main results expected from the AdriaClim Project is the development of climate adaptation plans, mitigation measures, and decision support systems in nine coastal Pilot areas, key indicators have been properly selected according to both data availability and the specific characteristics of each site (e.g., local hydrodynamics, morphological and ecological features, etc.). However, some of them will also probably be applied at the Adriatic Sea scale; so, it will be possible to compare local results with those obtained at the basin scale.

Different sets of indicators have been selected for the different Pilot areas. In particular, they have been grouped into three main types: indicators describing changes in the climate systems, indicators relevant for climate change impacts, and indicators relevant for adaptation. The relevant indicators for each Pilot area are listed in Annex 1, Annex 2, and Annex 3. The selection of indicators to be used in each Pilot area was performed with the contribution of all the partners involved in the AdriaClim Project, mainly based on their relevance and data availability.

4.1 Indicators for changes in the climate systems

Indicators for changes in the climate systems are a set of parameters that are used to track the state of climate and its variations over time. They mainly comprise physical and chemical

responses. The former include, for example, changes in sea level, air and sea temperatures and precipitation, whereas the latter are represented by modification of ocean chemistry, such as acidification.
It is very important to explain the difference between weather and climate to better understand the significance of the different types of indicators used to identify climate variations. Weather refers to the conditions of the atmosphere occurring over a short period of time (minutes to months and even years) (Cubasch et al. 2013, https://www.esa.int/Applications/Observing_the_Earth/Space_for_our_climate/Weather_vs_climate_What_s_the_difference, https://www.nasa.gov/mission_pages/noaa-n/climate/climate_weather.html). It includes many elements, such as temperature, precipitation, wind, cloudiness, atmospheric pressure, and humidity, and other special phenomena (e.g., thunderstorms, dust storms, tornados). Climate represents an average of weather observations over a longer period of time (usually 30 years, as defined by the World Meteorological Organization, or more). Therefore, climate generally changes less quickly than weather. In a wider sense, climate is also defined by the statistics associated with the mean weather conditions (e.g., frequency, magnitude, persistence, trends), often obtained combining parameters to describe phenomena (Cubasch et al. 2013).
Climate change refers to significant modifications in the typical average weather conditions that persist over several decades or longer. It can be assessed through the analysis and processing of observational records resulting from land, ocean, atmosphere and cryosphere. Different statistical methods are also used to test the results obtained from models based on these observations.
Indicators for changes in the climate systems are calculated to demonstrate the range and speed of climate change (World Meteorological Organization, 2017) at different spatial and temporal scales and to inform about observed trends and their effects.
The relevant indicators for changes in the climate systems for each of the Pilot areas are listed in Annex 1.

4.2 Indicators relevant for climate change impacts

These indicators measure the effects of climate change on the environment and society. They are also used to assess the sensitivity of populations and natural and anthropogenic systems to the observed climate modifications and to predict potential future impacts. Consequently, they will allow identifying sectors and areas more exposed to climate-related risks.
Indicators relevant for the effects induced by climate change are crucial for the implementation of mitigation and adaptation strategies. Indeed, even if many impacts are experienced at the local level, they can produce adverse consequences over wider areas that require large-scale socioeconomic and environmental policies and actions.
Within the AdriaClim Project, they have been grouped into nineteen categories that are listed in Annex 2. Each category refers to a specific aspect (i.e. water resources; desertification, land degradation and drought; hydrogeological instability; terrestrial ecosystems and biodiversity;

marine ecosystems; inland water ecosystems; health; forests and forestry productivity; agriculture and food production; sea fishing; aquaculture; energy; coastal zones; tourism; cultural heritage; transport and infrastructure; industries and dangerous infrastructure; urban settlements; society).

4.3 Indicators relevant for adaptation

Adaptation refers to actions taken to prepare the society to face both the current and the future impacts of climate change (https://ec.europa.eu/clima/eu-action/adaptation-climate-change_it). It includes adjustments in ecological, social, and economic systems aimed at reducing damages caused by climate modifications or at taking advantage of potential opportunities associated with climate change (IPCC, 2014a; https://unfccc.int/topics/adaptation-and-resilience/the-big-picture/what-do-adaptation-to-climate-change-and-climate-resilience-mean#:~:text=Adaptation%20refers%20to%20adjustments%20in,opportunities%20associated%20with%20climate%20change; https://climate.nasa.gov/solutions/adaptation-mitigation/). Moreover, adaptation has to be flexible to efficiently respond to changing climate conditions.

IPCC have distinguished different types of adaptation, including anticipatory (occurring before impacts are observed), reactive (occurring in response to climate impacts), private (initiated and implemented by individuals, households or private companies), public (initiated and implemented by governments and usually directed at collective needs), autonomous (spontaneous), and planned (as a result of a deliberate policy decision) adaptation (https://archive.ipcc.ch/ipccreports/tar/wg2/index.php?idp=689). In addition, adaptation measures may be different also because they can be applied to different geographic areas, environments, and sectors in various ways, covering anthropogenic to natural ecosystems.

In deciding which adaptation strategies need to be developed and implemented, particular attention has to be paid to their efficacy, potential future implications, and costs in relation to their benefits.

Indicators relevant for adaptation are used to monitor and assess if actions and policies designed to reduce climate change impacts are appropriately designed and effective. For this purpose, it is also fundamental to predict trends and potential future environmental effects.

These types of indicators, suggested within the AdriaClim Project, are listed in Annex 3.

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