TransformAr

Accelerating and upscaling transformational adaptation in Europe: demonstration of water-related innovation packages

Catalogue tool to identify best available solutions

Deliverable 3.2

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TABLE OF CONTENTS

LIST OF FIGURES

EXECUTIVE SUMMARY

The European Commission - EC (2021), in its new EU Strategy on Adaptation to Climate Change affirmed that “Climate change is happening today, so we have to build a more resilient tomorrow”. In alignment with the EC’s ambition, TransformAr seeks to develop and demonstrate adaptation solutions -deemed essential for social and climate resilience- to assure transformational adaptation across the European Union (EU).

In this context the ‘catalogue tool to identify best available solutions’ report is developed to compile and shed the light on existing solutions in Key Community Systems (KCS) addressed by the project (coastal management, agriculture, tourism, urban planning, biodiversity, etc.). The aim of TransformAr through this report is to develop further develop climate adaptation knowledge and solutions. The report will therefore take stock on existing practices in Europe and abroad by examining scientific and grey literature reviews as well as European and international adaptation projects and programs.

The report intends to direct policy makers and sectoral actors that play a key role in developing and accelerating transformational adaptation measures by offering them a guide compiling solution presented by sector.

LIST OF ACRONYMS

BwN	Building with Nature
CDC	Centres for Disease Control and Prevention (USA)
CIs	Critical Infrastructure systems
EAFM	Adopting an Ecosystem Approach to Fisheries Management
EC	European Commission
EEA	European Environment Agency
EU	European Union
FAO	the Food and Agriculture Organisation of the United Nations
GHG	Greenhouse gas
ICM	integrated Catchment Management
ICT	Information Communication Technology
IFRC	The International Federation of Red Cross and Red Crescent Societies
IWRM	Integrate Water Resources Management
KCS	Key Community Systems
LD	Lighthouse Demonstrator
LSA	Living Shorelines Approach
MPA	Marine Protected Areas
NWRM	Natural Water Retention Measures
OECD	The Organisation for Economic Co-operation and Development
SuDS	Sustainable urban Drainage Systems
UHI	Urban Heat Island
WRL	Water Retention Landscape
WHO	World Health Organisation

INTRODUCTION

Climate change is happening, and we are already dealing with its direct consequences manifested by the rise of sea levels, extreme temperatures, heavy storms, the melting of the glacier, among others. To address this global issue, efforts have been developed to mitigate climate change (i.e., limit Greenhouse gas (GHG) emissions and stabilize heat-trapping gases found in the atmosphere) and adapt to it (i.e., address current and projected impacts of climate change).

Climate adaptation is seen as a unavoidable complement to mitigation given that the earth's global temperature has already changed and dealing with the impacts of climate change for the decades to come is inevitable, despite mitigation efforts (Frölicher, Winton, & Sarmiento, 2013). In this context it is nevertheless important to underline that local governments and European national have been more focused on mitigation rather than adaptation (Füssel, 2007; Hallegatte & Coffee-Marlot, 2010; Aylett, 2015; and Campos et al., 2016). Lukat et al. (2016) asserted that while many European territories and cities are limiting GHG emissions, adapting the territory and increasing its resilience to current and projected climate impacts is still a novel challenge. To address this novel challenge, research, projects and programmes have been developed to guide and accompany decision makers and key actors in the implementation of adaptation measures such as the Climate-ADAPT initiative providing information on current and future vulnerabilities and impacts in Europe and adaptation in EU policy sectors.

In efforts towards accelerating and assuring transformational adaptation in Europe and in the World, this report examines existing scientific and grey literature reviews as well as practices, programs, and projects in Europe (e.g., Horizon 2020, LIFE EU programme, Climate Adapt, Climate KIC, etc.) and beyond, to build on the efforts that have been already made to steer climate adaptation, instead of "re-inventing the wheel".

The solution catalogue starts by introducing the probable impacts of climate change on TransformAr's Key Community Systems (KCS), notably: health, agriculture, fisheries and aquaculture, water, environment (biodiversity), critical infrastructure systems, cities, and tourism. It then presents a compilation of best adaptation practices allowing to increase the resilience of each of these KCS to climate impacts.

The catalogue serves TransformAr Lighthouse Demonstrators (LDs) (Lappeenranta-FI, West Country Region-UK, Guadeloupe-FR, Galicia-ES, Sardinia-IT and Egaleo-EL) as a baseline for the selection of promising and cross-sectoral adaptive solutions as part of the adaptation pathway development process. It is also useful for other territories in Europe and internationally as it feeds in the generic Innovation Package used for the project replication. "Even if adaptation challenges are local and specific, solutions are often widely transferable and applicable on a regional, national or transnational scale" (EC, 2021).

The solution considers five categories for the classifications of adaptation measures as presented below:

1. Incentives/Governance/Management: Referring to steering systems and management strategies and action plans allowing to increase the resilience of KCS.
2. Communications & roundtable exchanges: Emphasizing the importance of awareness raising, collaborative efforts and a systemic approach to climate adaptation.
3. Research & innovation: Underlining the role of research and science in supporting decision-making processes based on scientific and sound evidence.
4. Technical/Engineered solutions: Recognising the need for engineered systems, technical and technological developments to address the global issue of climate change.
5. Green/Nature-based solutions: exemplifying the role of natural elements and greenery (e.g., green roofs, green walls, parks, etc.) in acting as buffer zones and increasing the resilience of a territory and KCS to extreme weather conditions.

The catalogue acknowledges the classification of adaptation approaches into three types: Coping, Incremental and Transformative. In this context, coping refers to reactive adaptation approaches and emergency response measures that allow a given system to bounce back following the occurrence of a climate-related event. An incremental adaptation approach reflects progressive and gradual changes implemented to increase the resilience of a system to climate change, whereas transformative adaptation refers to innovative responses, large scale adaptation solutions and changes of practices in contrast to business as usual to address climate issues. In this context it is however important to clarify that what could be considered as an incremental solution in one context, could be seen as a transformative solution in another. Concretely, the rotation and the diversification of crops could be seen as an incremental measure for a territory that has been implementing this measure for years, and is considered transformative for one that is adopting this measure as a new approach to adapt to climate change.

1.0 HEALTH

1.1 Impacts of Climate Change on Human Health and Healthcare systems

Climate change -leading to extreme weather conditions- is already impacting the health sector in many ways. Indeed, the occurrence of extreme weather events (e.g., droughts, floods, heatwaves, heavy storms, etc.) and rises in temperatures is taking a toll on human health and lives. As a case in point, the 2003 European heatwave led to excess mortality in various European countries with an estimate of 14,800 excess deaths in France, 2,100 excess deaths in Portugal and 2,045 excess deaths in the UK (World Health Organisation-WHO, 2004).

1.1.1 Heat stress & Increased temperatures

The 'Centres for Disease Control and Prevention'[1] (CDC, 2021) asserted that the deterioration of health for people with pre-existing conditions (e.g., cardiovascular, respiratory diseases, etc.) could be compounded because of elevated temperatures over prolonged periods, leading in some cases to deaths due to heat strokes. In fact, in the event of heatwaves a general increase in hospital admissions for respiratory, cardiovascular and kidney disorders have been perceived, leading to added pressure on the healthcare system (especially in times of the COVID-19 pandemic). To add to that, many hospitals in Europe are not equipped with air-conditioning or are not well ventilated which could be particularly distressing to patients and staff in the events of heatwaves.

Moreover, warmer weather in light of climate change is likely to lead to longer pollen seasons and high pollen concentrations which can increase and intensify allergic reactions (e.g., asthma, allergic rhinitis[2] and allergic conjunctivitis[3]), and affect human health (CDC, 2021).

1.1.2 Decrease in water flows and availability

As water is a vital element to living creatures, drought risks -likely to increase due to changing precipitation patterns- are seen as a major threat to human health. Indeed, the lack of water supply and the deterioration of water quality could lead to the burst of diseases and viruses due to the important role of water in matters of hygiene, sanitation, food and nutrition. "Water, as well as the availability of sanitation and hygiene infrastructure, are essential to providing safe, quality healthcare. Without water, surfaces remain unclean and medical equipment cannot be sterilized" (Gallegos, 2018).

1.1.3 Wildfires

Lengthy periods of hot temperatures coupled with drought can exacerbate the risk of wildfires which can lead to fatalities and have ramifications on human health. Fire smoke -containing nitrogen oxides (NO), carbon monoxide (CO), particulate matter and organic compounds- reduces are quality and increases risks of respiratory infections and pulmonary illnesses. Not to mention, hospitals or other healthcare services can be directly impacted by forest-fires if located in fire-prone areas. Hospitals can also be located in floodplains. Fires and floods could lead to severe damages to hospital machines, could further traumatize patients and could in some cases lead to shutting down of critical health facilities for a short or long-period.

[1] The national public health agency of the United States of America.

[2] Inflammation of the inside of the nose due to allergens.

[3] Irritation or infection of the conjunctiva (eye).

1.1.4 Floods

Following heavy rainfall or flood events, water intrusion into built infrastructures can lead at the long run to mould contamination which affects indoor air quality. Concretely, people living in humid indoor settings could experience respiratory problems (e.g., coughing, pneumonia, wheezing, etc.). Extreme precipitation events could also impact water quality as heavy rainfalls transports large volumes of contaminants and water into waterbodies. In fact, waterborne disease outbreaks are likely to occur following flood events. The International Federation of Red Cross and Red Crescent Societies (IFRC) in its 'World Disasters Report 2020' affirmed that droughts, increased floods, and rising temperatures have impact on infectious illnesses and zoonotic[4] diseases and asserted that "long-dormant pathogens can re-emerge through climate change, such as the 2016 outbreak of anthrax in a warming Siberia" (IFRC, 2020).

1.1.5 Other

One should also not neglect the impact of climate change on mental health. The environmental deterioration, as well as the occurrence of extreme weather events could increase stress and anxiety. Considering climate change, the population could experience loss or/and uncertainty which is likely have further ramifications on the human health and wellbeing manifested by irritability, mental and physical weakness, mood disturbances, hypertension, and hyperalgesia[5] (Cianconi, Betrò & Janiri, 2020).
As projections foresee an increase in the frequency and the intensity of climate impacts, it is crucial to address the issue and increase the climate resilience of the sector.

1.2 Adaptation response measures to increase the resilience of the health sector to climate change

To increase the resilience of the health care system to climate change various supply side (i.e., ensure continuity of medical services) and demand side (i.e., reduce stress on medical services) measures have been proposed and/or implemented. Some of these measures allow to increase the overall adaptive capacity of the hospitals and healthcare systems to a variety of climate hazards and impacts while others are specific to certain climate risks.

1.2.1 Incentives/Governance/Management

The CDC (2022) asserted that "the health of people is connected to the health of animals and our shared environment"; hence, events perturbing the environment and biodiversity like climate impacts have ramifications on our health. **Adopting a "one health" approach** could be key to addressing climate-related health issues. The WHO (2017a) defined the "one health" approach as one in which professionals in different sectors -including the environment, plant health, animal health and public health- work together and communicate to achieve improved public health outcomes through developing research and designing and implementing policies, legislations, and programs.

Developing early warning systems and developing emergency management strategies and plans is crucial to limit health impacts and mortality in light of climate risks. To cope with extreme events and limit the number of casualties, emergency units could develop **early warning systems as well as a database of highly vulnerable and exposed people** including elderlies, kids, people with reduced mobility, those living in poor conditions, homeless people, people living in energy poverty, among other vulnerable groups. This database allows to reach out for these people, check up on them following the occurrence of extreme weather events, and be informed in case of health complications limiting excess mortality.

[4] Infection or disease transmissible from animals to human (such as COVID-19).

[5] Increased sensitivity/response to pain.

For example, in France, following the 2003 heatwave, and as of 2004, each city with more than five thousand inhabitants had the duty to establish a list of old people at risk to increased temperatures as part of its “Plan Canicule” (i.e., heatwave plan). This initiative proved to be successful as its implementation during the 2006 heatwave event allowed to limit excess mortality. Yet it is important to underline that in France, the heatwave solidarity plan does not include all vulnerable categories and only applies to elderly with no support or family. Not to mention, the Seniors Solidarity Alert Plan is optional and based on the voluntarily registration of the elderly (Khamis, 2021). This underlines the importance of having an inclusive database covering all vulnerable groups.

Climate resilient temporary shelters (e.g., school halls, city halls, multipurpose halls, temples, etc.) **can be made accessible to accommodate people in distress** and **interactive live maps can be developed allowing people to reach the closest shelter.**

Figure 1.1 Cooling centre during heatwave – Oregon, US

Source: Photographed by Maranie Staab/Bloomberg (2021, June 28).

In this context it is important to mention that increasing the climate resilience of the healthcare sector is directly and indirectly linked to the resilience of other systems. Therefore, it is important to **address challenges related to the wider supply chain** such as securing energy supply (e.g., making sure there is no electricity cuts in health complexes), the continuity of ambulance services (e.g., clearing the ways and assuring accessibility to the hospital in the events of climate hazards), medicine manufacturing and supply, among others (ClimateAdapt, 2018).

Developing adequate zoning and regulations could permit to increase the resilience of healthcare centres. For instance, to address **flood** risks, **zoning regulations could be established requiring new hospitals and health service complexes to be built in low flood risk areas and elevate their essential infrastructure and services to ensure their functionality in the event of floods**. As a case in point, regulations were enacted in New York City requiring new hospitals to elevate their surfaces above 500-years flood elevations considering projected sea level rise (Guenther & Balbus, 2014).

Building regulations and standards could also require existing hospitals and healthcare facilities to build integrated protection systems to maintain their functionality in the event of inundations (Seltenrich, 2018). **Regulations and standards could also be established to ensure that hospital buildings are embracing and maximizing passive cooling/heating technics**. Given that hospitals and healthcare centres have the responsibility and a significant role in addressing and manging drought risks, **regulations, standards, incentives, or awareness campaigns could present how hospitals and other healthcare services could contribute to lowering the usage of water, for instance, through installing water-saving devices and fixtures in their complexes and facilities** (Guenther & Balbus, 2014).

1.2.2 Communications & roundtable exchanges

To boost the overall adaptability of the health sector, the World Health Organisation (WHO, n.d.) recommended **including health issues in the national adaptation plan emphasizing the link between climate change and the health sector**. The WHO also deemed essential to **build community understanding and preparedness through developing awareness campaigns and workshops portraying how impacts of climate change could affect the publics' health.**

As key players in the community and in the health sector, it is crucial to **raise the climate awareness of the new generation of frontline health workers** (e.g., nurses, doctors, paramedics, social workers, etc.) **by integrating climate change concerns and its impacts on health into their professional education curricula**. It is also important to **increase the awareness of working health professionals and underline climate risks and their ramifications on the sector through workshops and trainings**. **Simulations could be part of these trainings** permitting to increase the preparedness of the medical staff to health impacts as a result of extreme events (e.g., wildfires, heavy storms, hurricanes, floods, etc.).

1.2.3 Research & innovation

The development of research and innovation is crucial to increase the climate resilience of the health care sector. Indeed, **research could be further developed to determine and further emphasize the links between the impacts of climate change and human health and on health care facilities**. Concretely, maps, simulations and research papers could be established and new technologies could be investigated and developed to delineate and address climate-related health risks. Various actors have the role to fund and support this research including governments, public bodies, research institutes and universities and the private sector.

Health professionals and epidemiologists could collaborate with ecologists to map and survey the probability of the spread of zoonosis, vector-borne, waterborne, and infectious diseases which are likely to increase in the events of droughts, floods, high humidity, etc. (Confalonieri, et al. 2015).

1.2.4 Technical/Engineered solutions

Building small-scale decentralized health services and shelters at proximity of vulnerable and exposed areas could be a way to assure an easy access to these services during extreme events. **The fundamentals of design and construction for newly built health-facilities should consider the likelihood of the occurrence of various climate-related risks** and make sure they remain functional in light of extreme weather events. Not to mention, **built infrastructures and existing health care services and facilities need to be continuously maintained** to be sure they remain functional.

Given that people in healthcare facilities and elderly cares are particularly vulnerable to heat events, it is important to ensure climate-comfort in healthcare complexes and buildings. **Sensors could be installed, and technology could be developed to monitor heat-sensible areas to ensure automatic and efficient ventilation**.

Flood control and protection systems refer to methods permitting to limit the damaging effects of floods such as the construction, extension and improvement of drainage systems, **the development of water retention basins, reservoirs and tanks** permitting to store water in times of floods, as well as **the construction of dikes, dams, or flood walls** (Alcoforado FAG, 2018).

Figure 1.2 Floodwall protecting Our Lady of Lourdes Hospital during Tropical Storm Lee in September 2011– Binghamton (New York), US

Source: Photo by Griffiths Engineering, LLC (2011, September). Retrieved 2022 February 14 from http://www.griffithsengineering.com/Lourdes.html

To give an example, to increase the resilience of the "Ascension's Our Lady of Lourdes Memorial Hospital" – situated on the Susquehanna River quay in Binghamton, New York - and to assure the continuity of its operations in the event of river floods, a protection wall was erected in 2011 (Figure 1.2) (Guenther & Balbus, 2014). This came after the facility experienced three consequential river floods between 2005 and 2011, among which a flood in 2006 resulted in the evacuation of patients and medical service crews and damages estimated at $20 million, as well as the closing of the facility for 10 days as underlined by the New York State Department of Health (2013). In this context it is important to elucidate that the hospital was founded in 1920 on donated land, which happens to be in the floodplain of Susquehanna River, and moving the hospital complex was not feasible, hence implementing flood mitigation measures was inevitable (Guide for Flood Warning & Response Case Study, 2018).

1.2.5 Green/Nature-based solutions

It is important to add that **flood control methods do not necessarily have to be technical engineered systems but could include planting vegetation and increasing the permeability of soils to retain excess water as well as introducing terrace slopes to diminish slope flow** (Alcoforado FAG, 2018). Green areas in hospitals and healthcare centres could include courtyards, green landscaping of the hospital grounds, green roofs, green walls, and planted trees. The English National Health Service (NHS) Forest programme[6] is an example of a campaign developed to green NHS sites (Figure 1.3). The project aims at **emphasizing the direct benefits of green areas in lowering stress, preventing mental health issues, combatting air pollution-related diseases, while lowering risk of flooding** (NHS Forest, 2021).

Figure 1.3 NHS Forest campaign – England

[6] https://nhsforest.org/

Source: Photo posted by NHS forest twitter account (2021, November). Retrieved February 17, 2022, from https://twitter.com/NHSForest/status/1456930357157130242

Green areas in healthcare service complexes also permits to alleviate **heat stresses**, especially in time of heatwaves. Concretely, **green roofs can function as thermal insulation reducing the need for air-conditioning and cooling costs, planting trees, and increasing vegetated surfaces around health care complexes reduce the heat-island effect and ensuring the plantations are properly landscaped and structures allows for an effective airflow** (Hiemstra, de Vries & Spijker, n.d.). However, **when planting vegetation and installing green roofs, it is important to plant adequate species as in warm seasons pollen could trigger allergies and amplify health complications for hospital patients.**

Figure 1.4 Tree blocking Royal Prince Alfred Hospital's emergency department driveway – Sydney, Australia

Source: Photo posted by Daily Telegraph Australia (2022, January 18). Retrieved February 17, 2022, from https://www.dailytelegraph.com.au/news/nsw/tree-branch-falls-outside-rpa-hospital-emergency-department-crushing-car/news-story/ddfe1064377d06d6023fcac4572080b0

Other **extreme events** could have ramifications on the health sector and hospitals such as fires, storms, cyclones, snow or other. In the light of these events, it is important to assure that hospitals retain their functionality. Therefore, **hospital and healthcare complexes need to be continuously maintained to prevent their damage or collapse in such events. The maintenance should also consider the surrounding landscape**. For instance, it is crucial to make sure that broken trees or snow piles will not block access to hospitals or care centres (Figure 1.4), thus it could be pertinent to consider planting tree in appropriate locations as well as species that are resilient to storms, fires, and snows.

Table 1.1 Proposed adaptation measures to increase the resilience of the health sector

Types of adaptation solutions	Proposed Measures
Incentives/Governance/ Management	• Adopting a "one-health" management approach (promoting collaboration between health professional and epidemiologists). • Including health issues in the national adaptation plan (emphasizing the link between climate change and the health sector). • Developing emergency management strategies and plan. • Developing building standards and updating zoning regulations to incite the development of critical healthcare systems in low-risk areas. • Updating regulations and standards to ensure that hospital buildings are embracing and maximizing passive cooling/heating technics. • Developing regulations, standards, and incentives to incite hospitals to lower the usage of water. • Developing a database of the population that is vulnerable to various extreme weather events (e.g., elderlies, kids, people with reduced mobility, etc.) and checking up on them following the occurrence of these events.
Communications & roundtable exchanges	• Developing awareness campaigns and workshops (portraying how impacts of climate change could affect the publics' health). • Developing early warning systems.
Research & innovation	• Developing research to determine and further emphasize the links between the impacts of climate change on human health and on health care facilities (e.g., maps, research papers, new technologies, etc.). • Mapping and survey of probability of spread of zoonosis, waterborne and infectious diseases due to extreme weather events.
Technical/Engineered solutions	• Ensuring access to reliable supply of energy during extreme weather events. • Maintaining roads and emergency vehicles and securing access to hospitals during extreme weather events. • Building new hospitals and health service complexes in low flood risk areas. • Elevating essential infrastructure and services to ensure the functionality of healthcare systems in the event of floods. • Building small-scale decentralized health services and shelters at proximity of vulnerable and exposed areas. • Updating maintenance schedules of hospitals and critical healthcare systems to increase their resilience. • Improving drainage systems. • Developing water retention basins, reservoirs and tanks permitting to store water in times of floods. • Construction of flood barriers (e.g., dikes, dams, or flood walls).

	• Installing sensors and developing technology to monitor heat-sensible areas to ensure automatic and efficient ventilation.
Green/Nature-based solutions	• Planting vegetation and increasing the permeability of soils to retain excess water (Green areas in hospitals and healthcare centres could include courtyards, green landscaping of the hospital grounds, green roofs, green walls, and planted tree). • Collaborating with landscape and botanic experts to plant adequate species as in warm seasons pollen could trigger allergies and amplify health complications for hospital patients. • Introducing terrace slopes to diminish slope flow hospitals and health service complexes in low flood risk areas.

2.0 AGRICULTURE

2.1 Impact of climate change on crops and livestock

The link between agriculture and climate change is twofold. On one hand, agriculture is one of the major global sources of global Greenhouse gas (GHG) emissions strengthening the greenhouse effect leading to climate change, and on the other, climate change has serious ramifications on the agriculture sector. Indeed, the Food and Agriculture Organization (FAO, 2020a) in its report on emissions due to agriculture, asserted that the mentioned sector and associated land use emissions accounted for 17 % of global GHG emissions, which underlines the importance of ensuring sustainable agricultural practices. This report will however focus on the impacts of climate change on the sector and present solutions to address these impacts and increase the climate resilience of agriculture.

Extreme events such as droughts, floods, storms can damage the agricultural sector through negative impacts on crops and livestock, leading to a loss of productivity, disruption of food availability as well as impacts on the food quality which affects food security, the profits of farmers and the economy as a whole. The evolution of climate change will continue to amplify existing pressures, worsening the loss of vegetation and biodiversity, increasing the damage caused by fires, accelerating land degradation, exacerbating soil erosion, water shortages and food security threats (IPCC, 2014).

Climate change will have impacts of different amplitude depending on the exposure and vulnerability of the territory in question as well as the state of development of the country (e.g., developed/developing country) and type of agricultural practices (e.g., pastoral farming, arable farming, sedentary farming, mixed farming, etc.) (Nelson et al., 2009).

2.1.1 Heat stress & Increased temperatures

Due to the increase in winter temperatures, crops tend to mature earlier. Thus, although late frosts are tending to decrease, their impact could be more detrimental given that crops tend to be at an advanced stage of maturity (Ruane & Rozensweig, 2018). The impacts of increased temperatures depend largely on the optimal temperature for the growth and reproduction of the crop (USGCRP, 2014). Some crop types may benefit from the warming as it could strengthen its growth. Yet it is important to highlight that when average temperatures exceed the crop's tolerance, yields will decline.

The recurrence of heatwaves and the decrease of precipitation is a limiting factor for non-drought tolerant crops which are likely to suffer from a diminished soil water content, excessive transpiration, leaf loss and in extreme cases mortality. To add to that, fungi, pests, and weeds thrive under warmer conditions combined with increased CO2 levels and wet climates which could cause problems to crop (USGCRP, 2014). Heat stress can increase the vulnerability of livestock to diseases and have negative impacts on fertility and milk production.

2.1.2 Changes in water flows and availability

Extreme events, especially floods and droughts, can harm crops and reduce yield (USGCRP, 2014). In general, all extreme events will weaken the soil through erosion and salinisation for instance and add an obstacle to healthy agriculture if good practice measures are not put in place. On one hand, moisture and increased precipitation could increase the pervasiveness of diseases and parasites that affect livestock (CCSP, 2008). On the other hand, droughts could have some indirect impacts on livestock as it affects the quality and abundance of fodder available for grazing.

2.1.3 Wildfires

Wildfires, likely to increase in frequency and intensity due to dry weather conditions, heavy winds and high temperatures, pose both direct and indirect pressure on the agriculture sector. It can lead to the burning and the deterioration of yields as well as impacts on livestock, leading in severe cases to their suffocation and death. Not to mention, the carbon deposition as a result of the fires is likely to lead to soil, water and air pollution, which impact the quality of fodder available and have ramifications on the health of livestock.

Figure 2.1 Forest fires impacting livestock on August 2, 2021, in Mugla – Marmaris (Turkey)

Source: Photo by Yasin Akgul/AFP

2.2 Adaptation response measures to increase the resilience of the agriculture sector to climate change

Increasing the resilience of the agricultural sector to climate change is important to ensure food security, job constancy for workers in the agricultural field and economic stability. In this context it is important to note that in Europe, agriculture accounted for the employment of around 9.7 million persons in 2016 (Eurostat, 2018) and agricultural production represented around 418 billion euros for the year 2019 (Eurostat, 2020).

Diverse types of solutions and approaches have been cited in various references to increase the resilience of this sector to climate change, some solutions are concentrated on governance, policy making, and raising the awareness of workers in the sector, while others propose changes in agricultural practices and technological solutions. To increase the overall resilience of the sector, a combination of solutions could be implemented based on the needs of the territory.

2.2.1 Incentives/Governance/Management

It is crucial **to assure that new agricultural methods are implemented in line with climate projections** such as **the plantation of new species** and **the change of sowing dates** to adapt to changing weather conditions. **The diversification of crops** could also allow to limit the sensitivity of planted areas to climate

impacts and the **improved crop rotation** could allow to enhance nutrients' balance, improve soil health, and increase biodiversity.
As a case in point, in the Kraichgau region of Heilbronn in Germany, an arable crop farm participated in the framework of the Life AgriAdapt project to assess adaptation solutions and increase its climate resilience. The pilot farm -at risk of losses in crop productivity due to extreme weather conditions- implemented different crop management measures to improve the structure of the soil, reduce erosion, increase water storage availability and nutrient availability for crops in light of climate change. The pilot farm planted 4 different catch crop mixtures, composed of different species (e.g., clover, tillage radish, pea, etc.) with different characteristics (i.e., resistance against diseases and pests, root development, nutrient requirements, etc.) in alternating seasons to tackle the improvement of soils (ClimateAdapt, 2019). The rich diversity of species within the crop mixture allows the farmer to cover the soil, break pest cycles and minimise erosion risks. In addition to that, sowing dates were adapted to changes in temperatures: e.g., early sowing in springs was considered to prevent food-security risks related to summer heat and drought.

Figure 2.2 Versatile Catch Crop Mixture

Source: AgriAdapt

2.2.2 Communications & roundtable exchanges

To increase the resilience of the agriculture sector, developing new knowledge is not sufficient, it is important to **communicate this knowledge with key stakeholders**. Thus, the importance of **raising the awareness of farmers and workers in the agriculture sector on climate change**, its ramifications on agricultural productivity and the role of this sector in combatting this global phenomenon. **Awareness raising efforts could take the form of campaigns, trainings, workshops as well as the integration of climate concerns in curriculums of agricultural-related academic programs**. For example, ACTERRA Consulting -a climate adaptation consultancy firm based in France and operating in Europe and internationally- in collaboration with the French Environment and Energy Management Agency organized a series of workshop bringing together key stakeholders to construct adaptation pathways and adapt agri-food chains to climate change in Burgundy, Pays de la Loire and Occitania. The workshops were designed to share experiences and enhance the expertise of participants by presenting socio-economic and environmental impacts of climate change on the horizon 2050 (Figure 2.3).
Roundtable exchanges with farmers and experts in the field allow to better understand the challenges they face, existing coping strategies as well as their adaptation needs. These exchanges could also allow for the sharing of best practices. **Ensuring the representation of women during the conducted**

workshops, roundtables or other climate-adaptation activities is important to support women working in the agriculture field and address gender gaps that could exist.

Figure 2.3 Workshop on the adaptation of the cattle in grassland system sector in Burgundy - France (2019)

Source: Photo taken by ACTERRA in March 2019

2.2.3 Research & innovation

To address climate-change related issues and increase the overall resilience of the sector, it is important to improve the understanding of the ramifications of this global phenomenon at a territorial scale **by investing in knowledge, research, and innovation**. Research could be developed to **improve the understanding and knowledge on plant species that are climate resilient**.

Maps of soils with data on structure and nutrients could be developed to adjust fertilization to soil's needs in light of climate change. **Flood maps could also be developed determining the agricultural lands at considerable risks of drought and inundation considering the soil's capacity to retain water as well as current and project water availability**. Consequently**, flood-tolerant species could be planted in these areas while flood-intolerant species could be repositioned to areas that are less-prone to flood risks**. In addition, the **agricultural production period could be adjusted to avoid flood seasons** (Li, et al., 2021). Furthermore, **a mapping of coastal aquifers can be conducted to determine those at risk of seawater infiltration leading to the contamination of the water and soil of coastal agricultural lands**.

It is important to also develop a **better knowledge of crops' water needs**. Furthermore, **studies could be developed to improve knowledge on the vulnerability and exposure of agricultural lands to extreme events (forest fires, snow etc.) in light of climate change**. In response to the developed knowledge, **new**

agricultural methods could be investigated and developed in line with climate projections. The development of agroecology, for example, is a major objective for the European Union. Agroecology farming practices are based, among other things, on strengthening ecological interactions and synergies between crops, animals, humans, biodiversity. These practices thus provide a multitude of services such as reducing the agricultural carbon footprint, recovering biodiversity, restoring soil fertility, increasing the economic resilience of farms, and sustainable food production.

2.2.4 Technical/Engineered solutions

Some engineered solutions could be considered to increasing the resilience of the agricultural sector to drought risks and reduced lack of water availability in light of climate change such as **the implementation of a drip irrigation system** and **the development of new systems allowing to increase the efficiency in irrigation.** To add to that, **the development of sophisticated remote sensing techniques could allow to estimate vegetation drought stress, soil moisture, ground water fluxes, precipitation, and evapotranspiration)**. This would allow for the improvement of drought monitoring in support of pro-active drought planning and early warning systems.

To address flood risks, some solutions could be considered such as **improving the drainage of farmland, adding flood control (e.g., flood barriers, pumping stations, etc.) and strengthening structural capacity, laying fallow farmland, and heightening farmland ridge** (Li, et al., 2021). In this context it is however important to underline that engineered food control systems need to be carefully considered. Concretely, as flood barriers could perturb the existing ecological system, it is important to develop an environmental impact assessment and address the adverse side effects of these barriers. Similarly, to ensure the alignment of adaptation solutions with mitigation targets and sustainable development goals, it is important to use renewable energy sources for water pumping.

Climate resilient agriculture polytunnels able to withstand extreme weather conditions can be erected to protect agricultural produces. Furthermore, physical barriers (e.g., protection wall, engineered protection systems) could also be built to protect coastal agricultural farms. However, the Building with Nature (BwN) philosophy differs with this approach (i.e., erection physical barriers) and promotes ecosystem-based solutions aiming on "building with nature rather than against it" (De Vriend & Van Koningsveld, 2012; Slobbe et al.,2012; Khamis, 2021).

2.2.5 Green/Nature-based solutions

The BwN approach promotes climate adaptation through acknowledging connections between nature protection, conservation, and recreational functions. Based on the BwN philosophy, and to increase the resilience of coastal agricultural lands to climate change, **protected areas could be created**, and **flood-prone areas could be restored to their ecological condition** to limit agricultural losses because of floods.

Water ponds could be constructed to retain excess rainwater which could also serve to address **drought** risks. The Tamera water retention natural basin in Alentejo-Portugal presents an example of a "Water Retention Landscape" (WRL) which was developed to counteract desertification and erosion risks as well as observed droughts due to climate change. **The WRL consists of a system of lakes, other retention systems and swales, terraces, and rotational grazing ponds** (Figure 2.4). The landscape planning considered landscape features (e.g., valleys, natural water courses, and ridges) and the topography to optimise water storage (ClimateAdapt, 2016). The project was conceived to ensure the regeneration of topsoil, pasture, forest and food production, an autonomous water supply as well as a greater diversity of agricultural and wild species. This approach to water management adopted in the Tamera farm intends to demonstrate a model that could be implemented in other Mediterranean areas at risk of severe droughts and desertification (ClimateAdapt, 2016).

Figure 2.4 The Tamera Water Retention Landscape – Portugal

Source: Tamera Ecology Team Retrieved 25, March 2022 from https://climate-adapt.eea.europa.eu/metadata/case-studies/tamera-water-retention-landscape-to-restore-the-water-cycle-and-reduce-vulnerability-to-droughts

Table 2.1 Proposed adaptation measures to increase the resilience of the agriculture sector

Types of adaptation solutions	Proposed Measures
Incentives/Governance/ Management	• Strengthening structural capacity of exploitations. • Adjusting agricultural production period to avoid flood seasons. • Planting of new species and changing of sowing dates. • Diversifying crops. • Improving crop rotation.
Communications & roundtable exchanges	• Ensuring the representation of women during the conducted workshops, roundtables, or other climate-adaptation activities.

	• Communicating knowledge on climate change impacts with key stakeholders. • Raising the awareness of farmers and workers in the agriculture sector on climate change (campaigns, trainings, workshops as well as the integration of climate concerns in curriculums of agricultural-related academic programs). • Exchanging with farmers and experts in the field to better understand their needs and to assure that new agricultural methods are implemented in line with climate projections.
Research & innovation	• Investing in knowledge, research, and innovation. • Improving the understanding and knowledge on plant species that are climate resilient. • Mapping of soils with data on structure and nutrients. • Mapping of coastal aquifers to determine those at risk of seawater infiltration leading to the contamination of the water and soil of coastal agricultural lands. • Developing flood maps to determine the agricultural lands at considerable risks of inundation. • Developing studies and maps determining the vulnerability of agricultural lands to drought, considering the soil's capacity to retain water as well as current and projected water availability. • Improving knowledge of crops' water needs. • Improving knowledge on the vulnerability and exposure of agricultural lands to extreme events (forest fires, snow etc.) in light of climate change. • Developing new agricultural methods in line with climate projections.
Technical/Engineered solutions	• Improving the drainage of farmland. • Adding flood control (e.g., flood barriers, pumping stations, etc.) • Laying fallow farmland. • Heightening farmland ridge. • Erecting physical barriers (e.g., protection wall, engineered protection systems) to protect coastal agricultural farms. • Constructing water ponds to retain excess rainwater. • Implementing drip irrigation system and developing of new systems allowing to increase the efficiency in irrigation. • Developing sophisticated remote sensing techniques to estimate vegetation drought stress, soil moisture, ground water fluxes, precipitation, and evapotranspiration. • Developing climate resilient agriculture polytunnels able to withstand extreme weather conditions to protect agricultural produces.
Green/Nature-based solutions	• Planting flood-tolerant species in flood-prone areas while flood-intolerant species could be repositioned to areas that are less-prone to flood risks. • Developing agroecology.

	• Creating protected areas. • Restoring flood-prone areas to their ecological condition. • Developing Water Retention Landscape (system of lakes, other retention systems and swales, terraces, and rotational grazing ponds).

3.0 FISHERIES & AQUACULTURE

3.1 Impact of climate change on fisheries sector

Global climate change is likely to have both direct and indirect impacts on the fishing sector influencing the availability and distribution of fish species in oceans and seas. It is anticipated that this global phenomenon would cause the loss of 7–12% of fish species by 2070 (Freitas et al., 2013). Changes in the distribution and availability of species are likely to affect fishing practices and techniques, hindering fish producers, exporters, and consumers. The effects of climate change on fishing activity vary with latitude, habitat, water column characteristics, and in riverine systems and flow regimes (FAO, 2016a). Some opportunities could be found in light of climate change as warmer sea temperatures could extend growing seasons, growth rates, feed conversions and primary productivity, benefiting inland fishing (Kibria et al., 2017).

In Europe climate change is expected to lead to an increase in fish production and sector-related employments in northern waters, whereas a marked decrease is projected at the southern edges of the continent. Increasing temperatures will allow Norway and Iceland, for example, to have a significant increase in fish catch (Barange et al., 2014). Nonetheless, higher water temperatures have adverse effects on the production of both wild and farmed freshwater salmon. To add to that, ocean acidification may disrupt the early developmental of shellfish (Kovats et al, 2014).

The known direct effects of climate change include changes in the abundance, distribution, and assemblages of exploited species as well as increases in the frequency and severity of extreme events, such as floods and storms, which affect fishing operations and infrastructure. Indirect effects of this global phenomenon include the alteration of the quantity and quality of aquatic habitat, changes in ecosystem productivity as well as changes in the distribution and abundance of aquatic competitors and predators (FAO, 2018).

3.1.1 Changes in water flows and availability

Floods -likely to become more frequent and intense in light of climate change- have both negative and positive impacts on the fishing sector in Europe (Kibria et al., 2017). Concretely, fast-flowing rivers could damage fish larvae[7] and juveniles. To add to that, floods could impact marine fishing areas by affecting the salinity of freshwater and brackish water fishing ponds, reducing fish stocks. It is however important to note that flooding could also present some opportunities like facilitating fish migration, promoting the spawning of native fish, and improving the water quality of rivers and lakes (FAO, 2018). Furthermore, it could help increase movement of sediments, nutrients, and energy, which are vital for aquatic ecosystem functions (Kibria & Haroon, 2016).

Drought, expected to become more marked in some areas due to climate change, also have ramifications on the fishing sector. It induces low-water quality, reduces the growth of fish, and increases their sensitivity to other drivers (FAO, 2018). Prolonged drought periods are likely to lead to overcrowded in small refuge pools which would negatively impact the quality of fish habitat, and, in severe cases, it could cause the loss of fish habitats and wetlands stimulating mass mortality (Kibria et al., 2016). As a case in point, in September 2019, “tens of thousands of dead fish have been found on the banks of a lake in a protected nature reserve in northern Greece after high temperatures and drought conditions caused a severe drop in water levels.” (Kantouris, 2019) (Figure 3.1).

Figure 3.1 Oxygen-starved fish laying on the shores of the drought-hit Koroneia Lake in northern Greece

[7] The newly hatched young of oviparous fish.

Source: AP Photo/Giannis Papanikos

3.1.2 Sea level rise

The rise of sea level due to climate change has impacts on the physical environments, fish stocks, ecosystems, coastal infrastructures, leading to a disruptive shift in activities upstream and inland (FAO, 2016a). It could also lead to fish-habitat destruction given that higher sea levels could impact sunlight penetration and change water characteristics (Kibria et al., 2017). This is a major concern because two thirds of all marine fish species are associated with coral reef environments (Guidry & Mackenzie, 2012). Not to mention, sea level rise coupled with lower water flows could lead to saltwater intrusion affecting estuarine-dependent coastal fisheries (FAO, 2018).

3.1.3 Heat stress & Increased temperatures

According to study from the University of British Columbia, extreme temperatures caused by climate change are expected to eliminate hundreds of thousands of tons of fishing catch worldwide, in addition to decreasing fish stocks (Cheung et al., 2021). Water temperature is an imperative stimulus in determining the health, abundance, and tenacity of fishes. When water temperatures exceed the thermal tolerance of fish species, they experience increased physiological stress, slower growth rates, and higher susceptibility to environmental toxins, parasites, and pathogens (USDA, 2017). Local extinctions are occurring at the edges of current ranges, particularly in freshwater and diadromous[8] species such as salmon and sturgeon (FAO, 2016a). In France, because of sea warming due to climate change, a 55% decline of flatfish species in the Bay of Biscay was perceived between 1987 and 2006 (Hermant et al., 2008). Also, in Australia during the consecutive summers of 2011/12 and 2012/13 temperatures were 2 to 3°C above the long-term monthly average for all the west coast locations resulting in 99% mortality of Roei abalone (Lough & Hobday, 2011).

[8] Species migrating between fresh and salt water.

3.1.4 Ocean acidification

The increased acidification of oceans in light of climate change is considered among the primary causes of the reduced productivity of the fishing sector in various countries in Europe (Spain, Italy and France). Concretely, the acidity of seawater can lead to the dissolution of limestone and thus prevent certain organisms (corals, plankton, etc.) from forming their skeletons. The disappearance of these organisms at the base of the food chains leads to the collapse of the whole chain. At the scale of the European continent, the annual impact of reduced productivity is estimated to be over 1 billion USD by 2100 although subject to considerable uncertainty (FAO, 2018).

3.1.5 Other

The increase in the occurrence of other extreme events (e.g., swells, storms, hurricanes, etc.) in light of climate change is expected to mainly affect artisanal fishing communities along the coast (FAO, 2018). To add to that, a gradual scarcity of resources in productive areas will have an impact on the profitability of artisanal fishing operations because of the increase in the time spent searching for fish, fuel expenditure and irregular catches. Climate change will lead to abnormal water currents circulation and wind inducing sudden change in stratification directly impacting fishes (FAO, 2O18).

Furthermore, the increased frequency and intensity of bush fires due to climate change could result in the deposition of organic matters and nutrient loads in lakes, dams, streams, and rivers, causing water quality problems (turbidity and low dissolved oxygen) and killing fishes (due to lack of oxygen in rivers and storages) (Kibria, 2014).

3.2 Impacts of climate change on aquaculture

Aquaculture is strictly linked to the fisheries sector as it refers to the cultivation of aquatic species in controlled environments. According to FAO (2020), the share of aquaculture in global fish production has continued to increase, reaching 82.1 million tons of the estimated 179 million tons of global production (Around 46%). The share of aquaculture production in global fish production is projected to increase from 46% to 53% in 2030 (FAO, 2020b). However, the most pressing question is whether the sector will grow fast enough to meet projected demand, which is exacerbated by a rapidly growing human population and climate change (Myers et al., 2017).

Climate change has direct and indirect impacts on aquaculture, both on the short and long run. It damages livelihoods, means of production, and affects aquatic ecosystems (FAO, 2018). In aquaculture, some climatic events, such as increasing temperatures, changing precipitation patterns, and increasing frequency of some extreme events, are already impacting aquatic resources both negatively and positively, while others are still emerging (Zolnikov et al. 2019). Determining the impacts of climate change on this sector is crucial to identifying appropriate livelihood measures for aquaculture-dependent communities.

3.2.1 Changes in water flows and availability

Altered precipitation patterns, in light of climate change, would affect aquaculture through both increased rainfall (flooding) and periods of little or no rainfall (drought).

On the one hand, **floods** can damage production facilities and reduce the availability of fish stocks. As a case in point, in the Czech Republic, 54% of fish losses in aquaculture between 2006 and 2013 were recorded as a result of extreme flood events (Rutkayova et al., 2017). In addition, floods can lead to the introduction of undesirable wild species that affect aquaculture production through invasive fish and deterioration of water quality (Rutkayova et al., 2017)

On the other hand, **drought events** can lead to the decrease of water quantities and the degradation of water quality, which can negatively impact aquaculture production. Droughts can cause changes in the water levels of lakes and rivers, affecting the abundance, distribution, and composition of fish populations (Barange et al., 2018). Not to mention, water scarcity could increase water conflicts between different activities such as aquaculture, agriculture, households, and industry, affecting all aspects of aquaculture sustainability (FAO, 2020b).

3.2.2 Sea level rise

Aquaculture in coastal areas provides social and environmental benefits that may be affected by **sea level rise**, impacting the production and sustainability of the sector (Maulu et al., 2021). The increase of storm surge and tide levels in light of climate change could push salt water further inland through tidal creeks and ditches is likely to increase salinization. This could be detrimental to aquaculture. Addressing the issue of salinization in controlled aquatic environments results in higher production costs and lower economic profits (Kibria et al., 2017). In addition, sea level rise can destroy coastal ecosystems such as mangroves and salt marshes. These ecosystems are considered important for maintaining wild fish stocks and providing seed for aquaculture production (Kibria et al., 2017). A positive impact of sea level rise could be the expansion of suitable areas for brackish water species such as shrimp and mud crab, opening new opportunities for aquaculture in coastal areas (Kibria et al. 2017).

Furthermore, climate change is projected to **increase the frequency and intensity of extreme events** such as hurricanes, storms, wildfires, heavy precipitation, and heat waves (FAO, 2018). Extreme events impact daily operations and access to the land, creating health and safety concerns for workers (Collins et al., 2020). Heavy rains and storms can lead to higher sediment loads in coastal areas, which can cause stress and physical damage to fish and shellfish. The occurrence of storms can also increase fish escapes, infrastructure costs, and insurance costs (Kibria et al. 2017) (Figure 3.2). In addition, intense heat waves resulting in extreme temperatures over short periods could cause the mass mortality of fish and shellfish and reduce aquaculture production (FAO, 2020b).

Figure 3.2 Pieces of a mussel raft destroyed during a storm, stranded on a beach, 2015

Source: Figure retrieved December 22, 2021 from https://loqueyotedigo.net/2015/12/18/o-barbanza-el-temporal-costero-destroza-una-batea-y-arrastra-hasta-barrana-parte-de-su-plataforma/.

3.2.3 Heat stress & Increased temperatures

Temperature plays a significant role in the growth and development of aquatic species (FAO, 2018). Cold-water species are most at risk in light of the projected 1.5°C **increase in global average temperature** this century due to thermal stress, including Atlantic halibut, salmon, cod, and intertidal mussels (Gubbins et al., 2013). To add to that, rising temperatures affect the metabolism and physiology as well as the feeding performance and growth of most finfish and shellfish (Lemasson et al., 2018).

3.2.4 Ocean acidification

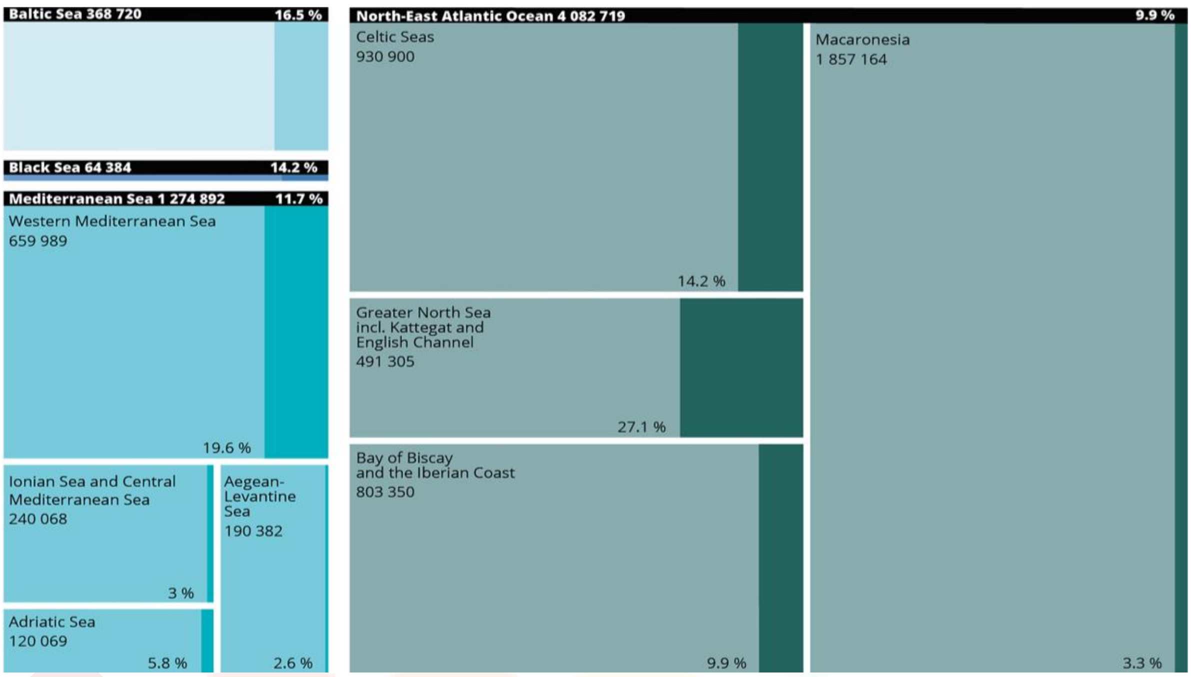
Furthermore, **the rising temperatures and the acidification of oceans** alter the hydrology and hydrography of aquatic systems and the occurrence of red tides, which are a source of disease for aquatic species (Kibria et al., 2017). For example, in the United Kingdom, 30% of salmon aquaculture losses are linked to diseases caused by temperature rise and ocean acidification (Collins et al., 2020). The situation is critical as it is expected to lead to increased management costs and lower productivity, threatening the economic and social sustainability of aquaculture. Nevertheless, the temperature rise may favour the production of species in warmer waters in temperate regions, such as king prawns, tilapia, oysters, and mussels (Collins et al., 2020).

3.3 Adaptation response measures to increase the resilience of the fisheries and aquaculture sector to climate change

The Organisation for Economic Co-operation and Development (OECD, 2020) asserted in its fisheries policy brief that "urgent action is needed to end overfishing and make fisheries and aquaculture production more sustainable and coastal communities more resilient, particularly in the context of climate change". Adapting the sector -directly responsible for the employment of hundreds of thousands across the EU and for the food security of millions of people worldwide- to climate change is deemed critical.

3.3.1 Incentives/Governance/Management

Figure 3.3 EU part of the regional sea surface areas (Km^2) and area covered by Marine Protected Areas (MPA) in 2016 (%)



Source: ETC/ICM - Spatial Analysis of Marine Protected Area Networks in Europe's Seas II, Volume A, 2017.

From a top-down perspective, **the development of national and regional strategies preventing habitat destruction and ensuring the conservation of marine ecosystems and biodiversity** is important to ensure the sustainability of the fisheries and aquaculture sector and its resilience to climate change (Johnson, 2012). This stresses the importance of land use planning in coastal zones. **The reduction of seas and oceans' pollution** should also be addressed as it is important **to reduce non-climatic stressors exacerbating the effects of climate change** to the detriment of fish stocks (Johnson, 2012). **The creation of marine reserves and protected areas and the regulation of fishing** allows for the ecosystem to recover and renew itself which increases biodiversity and the reproductive potential of fisheries and marine species. Indeed, "the establishment of marine reserves can help slow the effects of climate change and alleviate some of its expected hardships, such as reduced food security and sea level rise" (Rand, 2020). In Europe, the Greater North Sea (including Kattegat and English Channel) has the largest percentage of Marine Protected Areas (MPA), accounting for 27.1% of the total EU part of the regional sea surface area (133 143 Km^2 out of 491 306 Km^2), whereas the Aegean-Levantine Sea has the lowest percentage of MPAs standing at 2.6 % of the total EU part of the regional sea surface area (4 949 Km^2 out of 190 382 Km^2) (ETC/ICM, 2017) (Figure 3.3).

Adopting an Ecosystem Approach to Fisheries/Aquaculture Management (EAFM) considering the ecological boundaries of the marine environment and preserving biological wealth and processes necessary for the functioning of habitant is important to manage fisheries and the use of natural resources in light of climate change (Johnson, 2012; Shelton, 2014; Ramírez-Monsalve et al., 2016). The EAFM considers that ecological and human well-being are intertwined. I.e., Protecting maritime environments and conserving biodiversity is strictly linked to providing livelihoods, income, and food for humans. It therefore implicates an integrated management approach across marine and coastal areas through the development of effective governance policies for capacity building as well as improved and data-driven fisheries management.

Both public and private investments in the fishing sector are important to ensure its modernization which is crucial for safeguarding food security and the economic stability of fishing communities. **It is particularly important to promote sustainable fishing initiatives and investments**. For example, in December 2021, the government of the United Kingdom dedicated £ 75 million pound sterling to boost the efficiency and capacity of processing facilities and harbours while improving the sustainability of the fishing industry on the long-run and increasing jobs and other opportunities for coastal communities across the country. The proposed funding scheme prioritises projects that align with the kingdom's 2050 NetZero commitment, also a part of the budget is dedicated to developing aquaculture facilities (UK Government, 2021). In this context it is important to underline that, **when building new maritime facilities for fishing and aquaculture, climate projections and risk should be taken into account (i.e., developing climate resilient structures).**

Furthermore, to increase the resilience of fisheries and aquaculture sectors, governments and responsible authorities should also **consider including measures and plans assuring the fast recovery of maritime communities, following the occurrence of climate-related incidences, in developed and implemented disaster risk management strategies. Developing early warning systems and increasing the awareness of coastal communities** would allow them to be better prepared and bounce back in the aftermath of extreme weather events impacting maritime critical infrastructure systems.

3.3.2 Communications & roundtable exchanges

The organisation of various knowledge activities such as workshops and roundtable exchanges with fishers and aquaculture workers allows for **improving communication and information sharing** on the impacts of climate change on the sectors and adequate response measures. The organisation of such activities is a shared responsibility underlining the **importance of collaboration among various**

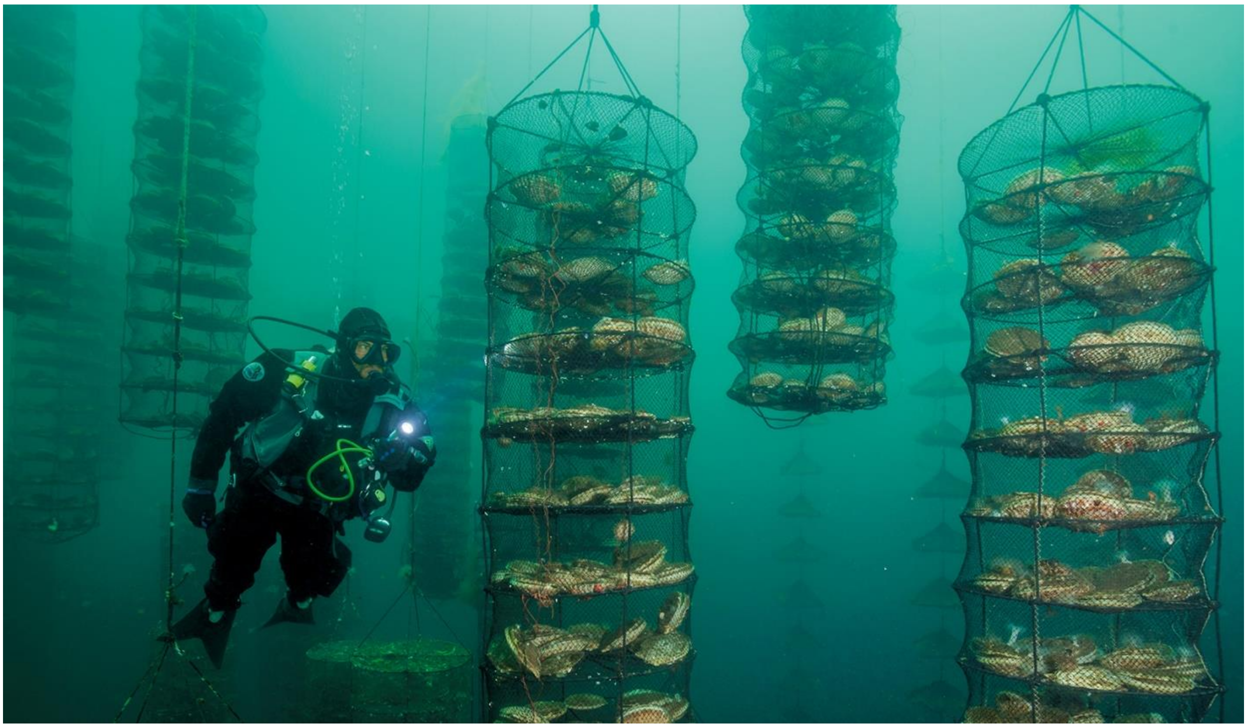
stakeholders including research centres, universities, authorities, NGOs, maritime workers, and other workers in the private sphere (e.g., consultancy firms, advisors, etc.).

In June 2016, the Food and Agriculture Organisation (FAO) of the United Nations organised a technical workshop in Rome on planification for aquaculture diversification due to climate change. During the workshop 3 main axes of development where identified: 1) **increasing the number of farmed species**; 2) **ensuring the evenness of species being farmed** and 3) **increasing the diversity of species that are currently farmed (i.e., developing new strains)** (FAO, 2017). Similar events could be organised in coastal communities and across Europe to address climate ramifications on key community systems including fisheries and aquaculture and develop ways forward.

3.3.3 Research & innovation

Governments are becoming increasingly aware of the limitations of aquaculture and fisheries management frameworks and the need to improve the viability of these sectors by attuning existing regulations and introducing new ones; yet it remains difficult to collect data on marine ecosystems and resources for evidence-based policy making (OECD, 2020). This stresses the importance of **investing more in data collection, biodiversity monitoring systems, forecasting as well as climate-related experimentation areas in marine habitats** to increase the overall resilience of the fisheries and aquaculture sectors to climate change (Johnson, 2012). Indeed, drawing clearer links between this global phenomenon and its ramifications on the mentioned sectors is crucial through developing and sharing knowledge.

Figure 3.4 Japanese scallops thrive on fish waste at an experimental farm off Canada's Vancouver Island



Source: Photo Retrieved March 9, 2022, from https://www.nationalgeographic.com/foodfeatures/aquaculture/

3.3.4 Technical/Engineered solutions

Programs could be set up **to support small and medium-sized fishers and workers in aquaculture to improve their climate resilience**. Some short-term coping adaptation solutions could be proposed to address impacts of climate change on fisheries and aquaculture such as **lowering of culture rafts to**

greater depths when surface water temperatures are high, **selecting growing sites nearby depths with chilly water coming** up, and **encouraging workers in the sector to diversify livelihoods** (Johnson, 2012). Nevertheless, the focus of support programs should be on ways forward that go beyond the mere coping to ensure the long-term viability of these sectors. **Changing aquaculture feed management** to provide nutritionally adequate and cost-effective feed as well as **resorting to selective breeding** could allow to increase the resilience of aquaculture to reduced yields and profitability in light of climate change (Shelton, 2014). It is also important to **assist fishers to shift to culture-based fisheries and support workers in aquaculture by guiding them on the types of species that could be farmed and incentivising the adoption of sustainable fishing techniques** (Johnson, 2012). For instance, culturing herbivorous species is advised as it has a minimal impact on the environment as well as the development of aquatic plants and shellfish which can eradicate wastes from polluted waters (Johnson, 2012). Also, opportunities could be investigated for farming brackish water species considering increased salinity due to climate change.

Hard defence systems (e.g., sea walls) could protect maritime infrastructure systems from storm surges and sea level rise but are likely to perturb local livelihood and ecosystem processes, thus **the development of soft defences (e.g., wetland rehabilitation creating natural buffer zones)** is advised instead to allow maritime infrastructure systems to withstand increased storm damages.

3.3.5 Green/Nature-based solutions

Adopting the Living Shorelines Approach (LSA) which incorporates natural habitats and uses sand, rocks, and natural vegetation to protect shorelines presents itself as an alternative approach to hard defences assuring shoreline stabilization while minimizing adverse impacts. As a case in point the Durant's Point project adopting the LSA was adopted in Hatteras Village in North Carolina (Figure 3.5) to provide a natural protection barrier dissipating wave and storm energy while protecting fisheries habitat and water quality. The project created 0.486 hectares (1.2 acres) of coastal marsh and protected around one hundred meters (three hundred linear feet) of shoreline (North Carolina Coastal Federation, n.d.).

Figure 3.5 Before (left) and after (right) images of the Durant's Point living shoreline project in Hatteras Village, North Carolina.

Source: North Carolina Coastal Federation, n.d.

Table 3.1 Proposed adaptation measures to increase the resilience of the fisheries and aquaculture sectors

Types of adaptation solutions	Proposed Measures
Incentives/Governance/ Management	• Setting up programs to support small and medium-sized fishers and workers in aquaculture to improve their climate resilience. • Encouraging workers in the sector to diversify livelihoods. • Changing aquaculture feed management. • Adopting an Ecosystem Approach to Fisheries/Aquaculture Management (EAFM). • Developing national and regional strategies preventing habitat destruction and ensuring the conservation of marine ecosystems and biodiversity.
Communications & roundtable exchanges	• Organizing various knowledge activities such as workshops and roundtable exchanges with fishers and aquaculture workers. • Improving communication and information sharing on the impacts of climate change on the sectors.
Research & innovation	• Investing more in data collection, biodiversity monitoring systems, forecasting as well as climate-related experimentation areas in marine habitats.
Technical/Engineered solutions	• Lowering of culture rafts to greater depths when surface water temperatures are high. • Selecting growing sites nearby depths with chilly water coming up. • Resorting to selective breeding. • Assisting fishers to shift to culture-based fisheries and support workers in aquaculture by guiding them on the types of species that could be farmed and the promotion of sustainable fishing techniques. • Increasing the number of farmed species. • Ensuring the evenness of species being farmed. • Increasing the diversity of species that are currently farmed (i.e., developing new strains).
Green/Nature-based solutions	• Reducing seas and oceans' pollution. • Creation of marine reserves and protected areas and the regulation of fishing. • Developing soft defences (e.g., wetland rehabilitation creating natural buffer zones). • Adopting the Living Shorelines Approach (LSA) which incorporates natural habitats and uses sand, rocks, and natural vegetation to protect shorelines.

4.0 WATER

4.1 Impact of climate change on the water sector

Water is one of the most important natural resources for living beings. Globally, 70% of water is used for agriculture, around 19% for industry, including energy production and 11% for domestic water use (FAO, 2016b). Over decades, global climate has been changing, impacting temperature and precipitation patterns, and affecting the quantitative and qualitative status of water resources by altering hydrological cycles and systems (EEA, 2018a). Worldwide, about four billion people live under severe conditions of water scarcity for at least one month per year (Mekonnen & Hoekstra, 2016; UN-Water, 2020). The situation is likely to worsen in light of climate change.

In Europe, there is a wide range of water-related issues and vulnerabilities due to climate change. The severeness of these issues as well as the degrees of vulnerability and exposure vary across the continent due to different hydrological conditions, including long and dry summers in the south, less variance in the west, and strong river-flow periods in the north due to snowmelt (FAO, 2016b). The impact of climate change on water resources also varies with time and scale. Some impacts are perceived on a daily and local scale, while others are observed on long-terms and larger scales.

4.1.1 Changing precipitation patterns

According to the European Environment Agency (EEA, 2018a), climate-related extremes, such as bushfires, storms, and heavy rainfall, are increasing in frequency and intensity in Europe. Precipitation patterns are changing, making wet regions in Europe more humid and dry regions more arid (EEA, 2018a). Heavy rain events can increase the amount of natural organic matter in reservoirs by creating high river inflows that gather it from the catchment's shallow soil layers (Hughes et al, 2013).

4.1.2 Melting of snow & ice covers

Climate change has also increased the average water temperature of rivers and lakes and has shortened the length of ice cover seasons. The accelerated melting of glaciers is likely to have negative effects on water resources of mountainous regions and their adjacent lowlands (Buytaert et al., 2017). Although the accelerated melting of glaciers may locally and temporary increase streamflow, the reduction of glacier cover trends to lead to more variable rivers flows and reductions in baseflow in the long terms, as well as changes in the seasonal timing of peak streamflow (Buytaert et al., 2017).

Comparably, climate change is already having a significant impact on snow cover in Europe. Since the 1980s, in Switzerland, France, Austria, Italy, and Germany perceived a significant decline in snow depth and snow cover duration over the European Alps (Marty, 2013). The IPCC projects with high confidence that snow cover will continue declining, alongside with permafrost and glacial due to change in precipitation pattern, increasing temperature and extreme heatwaves (IPCC, 2019). These changes, along with increased river flows in winter and lower flows in summer, have important impacts on water quality and on freshwater ecosystems (EEA, 2018a).

4.1.3 Changing water flows

In southern and south-eastern Europe, more extreme heatwaves have been occurring which, besides their negative effects on human health, increase evaporation and contribute to the further depletion of water resources in locations where they are already scarce (UN-Water, 2020). To add to that, droughts are increasing in frequency and severity worldwide due to increased rainfall variability with prolonged periods of dry spells (Dai, 2013; Trenberth et al., 2014). Consequently, major rivers are expected to have a significant increase in the frequency of hydrological drought conditions in the coming decades, notably in Europe's southern regions (Hirabayashi et al., 2008; Mosley, 2014). Considering these events, water conflicts could arise and intensify particularly during severe and extensive droughts (EEA, 2018a).

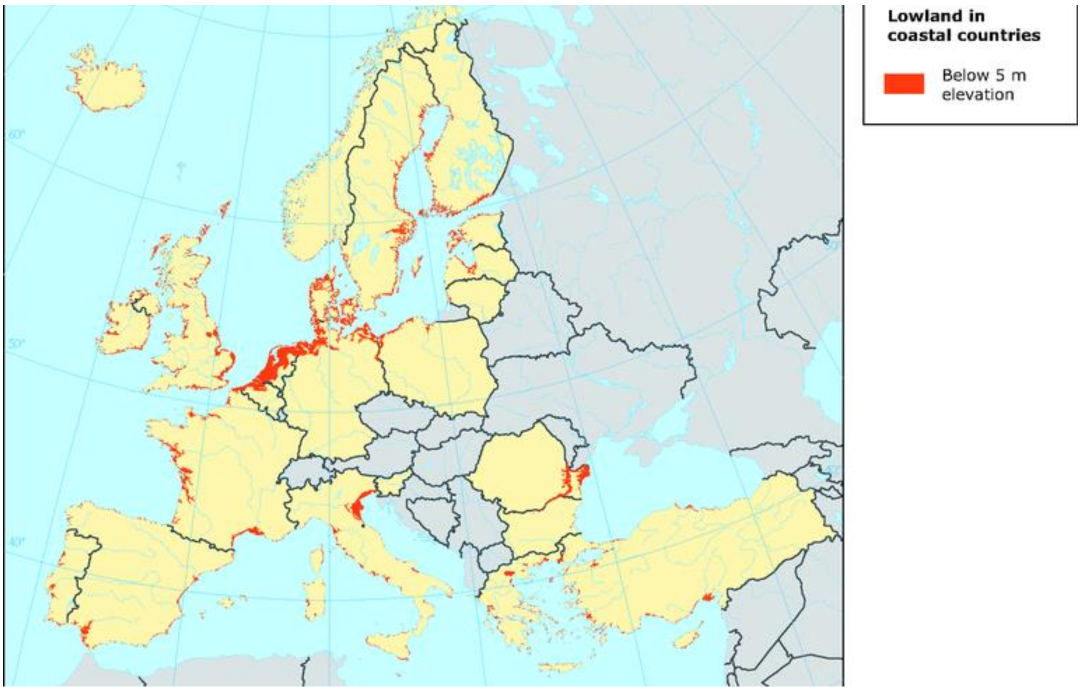
Similarly, in coastal locations, particularly in southern Europe, where water demand is already high owing to agriculture and tourism, lower surface water availability, due to long drought periods and reduced groundwater recharge, can significantly increase the pressure on groundwater (EEA, 2018a). Not to mention, the decrease of water availability and flows normally lead to the deterioration of water quality due to reduced dilution and the concentration of mass (Burt et al., 2014). Also, the turbidity, nutrients and algal levels in lakes and water bodies are likely to increase due to diminished flushing, leading to eutrophication, impacting water species (Mosley, 2014; Chun-hau Li et al., 2020). In the same way, bushfires are another extreme occurrence that can degrade water quality by increasing nutrient and sediment flows (Smith et al. 2011).

Worldwide the risk of flooding has grown over recent decades (UN-Water, 2020). The same tendency is observed in Europe and is projected to continue (EEA, 2018a). The negative impacts of flooding include the spread of transmissible and water-borne diseases, the destruction of natural habitat and damages to crops, livestock, critical infrastructure systems, properties, and homes (Yun Chen et al., 2015). Floods could also have serious ramifications on human beings. As a case in point the extreme flood events that have occurred in western Europe in July 2021, impacting majorly Switzerland, Belgium, Germany, and the UK have led to the death of over 190 people stressing that even the most developed countries, which have invested in flood preparations are not exempt from dealing with severe flood damages (Khamis, 2021).

4.1.4 Sea level rise

In coastal areas, the rise of sea level will impact the salinity of groundwater and estuaries, reducing the availability of coastal freshwater supplies (EPA, 2021). Saltwater intrusion will lead to higher water treatment costs. Furthermore, the sea level rise poses direct threats to coastal communities due to high tide floods, leading to direct damages to properties and infrastructure systems and the perturbation of traffic. Not to mention, it obstructs drainage in deltas increasing inundation risks (EPA, 2021). Many European countries are at direct risk of sea level rise and coastal flooding events due to lowland coastal elevations (Figure 4.1).

Figure 4.1 European coastal lowlands most vulnerable to sea level rise



Source: EEA, 2009

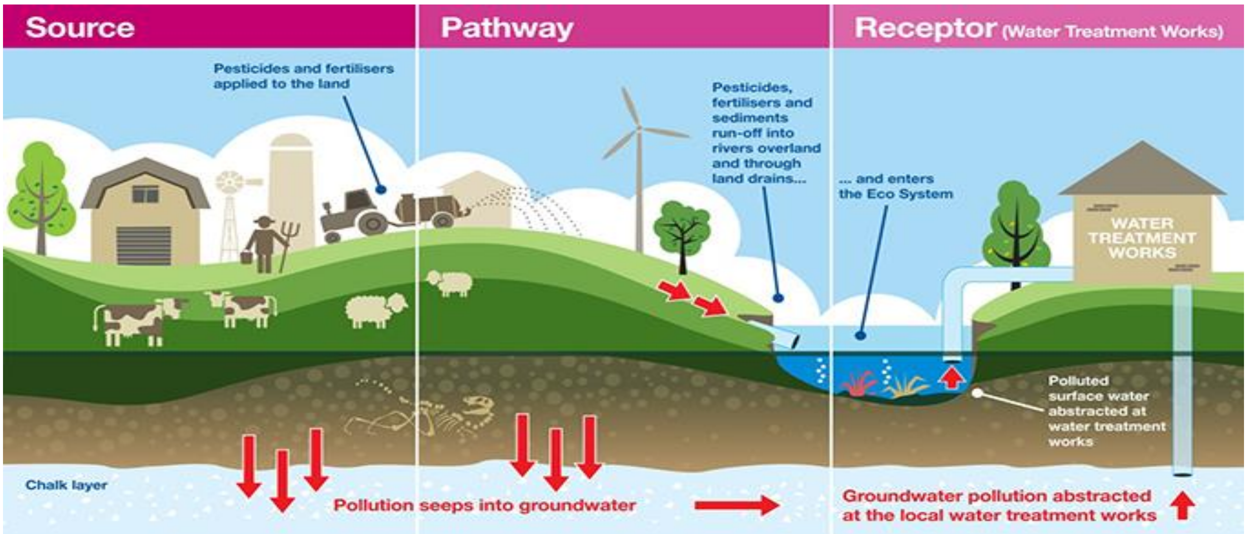
4.2 Adaptation response measures to increase the resilience of water sector to climate change

4.2.1 Incentives/Governance/Management

The development of grey[9] and green[10] adaptation measures to increase the resilience of territories and water systems to climate change is crucial. This however should be supported and complemented by soft adaptation solutions including appropriate legal, policy, management, social, and financial measures.

An integrated Catchment Management (ICM) approach recognises the need for community-based and interdisciplinary collaboration and the alignment of efforts across non-government and government stakeholders to ensure water, land, and biodiversity protection via the adoption of sustainable water and land management in catchment areas (Stewardson et al., 2017). The ICM identifies key issues relevant to stakeholders and integrates different point of views considering cross-disciplinary identification of causal relationships and the development of dynamic simulations of scenarios. Based on the understanding of stakeholders need, community-driven policies and action plans for sustainable development are developed and implement.
The diagram below (figure 4.2) illustrates the need for ICM to address water quality issues by emphasizing how pollution, due to inappropriate land management (in this case: the use of fertilisers and pesticides), can impact groundwater and rivers, increasing the resources needed (i.e. financial and energy resources) for water treatment. The implementation of an ICM is deemed necessary to increase the resilience of water resources by limiting non-climatic stressors (e.g., impact of pollution on aquatic ecosystems) exacerbating the effects of climate change.

Figure 4.2 Diagram illustrating the need for Integrated Catchment Management (ICM) to address water quality issues



Source: Affinity Water Group, n.d. Retrieved April, 6, 2022 from https://www.affinitywater.co.uk/corporate/environment/catchment-management

Similarly, an Integrated Water Resources Management (IWRM) approach, promoting the coordinated management of water and related resources, is crucial to maximize social and economic welfare

[9] Grey adaptation measures refer to engineered solutions.

[10] Green adaptation measures refer to nature-based solutions.

without compromising the sustainability of vital environmental ecosystems in light of climate change as this global phenomenon is likely to have direct and indirect impacts on water resources (GWP, 2000). There has been a growing interest in IWRM which is seen as a process or guiding principles on well-rounded water management practices. For instance, the European Union is also promoting the principles of IWRM across its member states through its Water Framework Directive (WFD) which requires the establishment of catchment or river basin authorities or other institutions dealing with water management and informs them on planning processes (Fritsch & Benson, 2020).

It is also important develop financial and legal incentives to promote water savings and behavioural changes for efficient water usages such **as introducing water pricing considering its economic value** (Acterra consulting, 2021). Other measures and solutions could be adopted such **as encouraging different water-users and stakeholders to fix leaks and install water saving devices** (e.g., water flow regulators, water saving aerators, water among others). For example, laws could be developed requiring hotels to install water saving aerators, workers in the agriculture sectors could be encouraged to modernise irrigation infrastructures, etc.

It is also important **to incite different water users across sectors** (e.g., agriculture, industrial, construction, tourism, and services, etc.) **and recycle and re-use wastewater**; this however should be done without compromising water quality and related health-risks.

4.2.2 Communications & roundtable exchanges

It is important to **raise public awareness on water-usages** (Acterra consulting, 2021) to increase the tolerability of soft, grey and green adaptation measures. Indeed, t**he integration of water users and key stakeholders in the management of water resources and related decision-making** could play a key role in increasing the acceptability of measures, especially when some could implicate increased financial investments or changes of habits. Thus, the importance of organising awareness campaigns and programs as well as roundtable exchanges with key water consumers from various sectors to present to these actors the impacts of climate change on water systems as well as the necessity of preserving water resources in light of climate change.

4.2.3 Research & innovation

Research and innovation could support the development of new tools and technologies allowing to preserve water resources and enhance water quality.

For example, the separation of water at source permits to increase the efficiency in water treatment in terms of energy and costs. Concretely, **water infrastructure systems could be designed to separate grey[11], black[12] and storm water, which would allow for adequate treatments and reuses of water based on contamination levels** (Harder, 2012). Nevertheless, it is important to note that the efforts required for the rehabilitation and the renovation of existing water infrastructure systems are substantial. Also, when adopting this new wastewater infrastructure system, it is crucial to consider public health risks (e.g., contamination of grey water streams by black water) as well as the social support and acceptance of the changes of the current system (that is widely recognised and thew substantial changes within buildings

[11] Gray water designates the wastewater that drains from the sink, washing machine and the shower, with low levels of contamination.

[12] Black water (also referred to as sewage or brown water) is the wastewater containing human waste. This water is highly contaminated and could carry bacteria and disease, requiring chemical or biological treatments and disinfection.

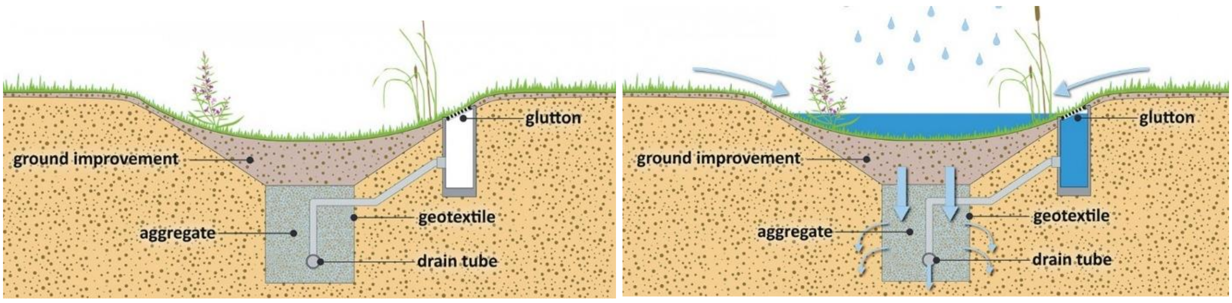
needed). This should be complemented with a comprehensive study of failure modes, vulnerability and robustness of the different systems that could be achieved (Harder, 2012).

4.2.4 Technical/Engineered solutions

To increase the overall resilience of the water sector to droughts as well as pluvial, fluvial, and coastal floods - likely to increase in light of climate change- it is important to **develop water management and infrastructure systems**, **reinforce and rehabilitate water storage**, and **protect hydraulic structures against all forms of pollution** (Acterra consulting, 2021). This includes **the improvement of water treatment facilities and conducting specific treatment by use**.

Sustainable urban Drainage Systems (SuDS) present themselves as environmentally friendly drainage solutions that offer an alternative to the direct channelling of water through sewers and networks of pipes to nearby water courses (Boogaard et al., 2006). The system allows to manage stormwater and increase the resilience of cities to runoff generated by heavy rainfall events. SuDS operate through infiltration using built components that imitate natural features allowing for drainage in a quick and efficient way. Thus, it reduces surface water flooding by increasing water storage capacity, lowering flood rates, and limiting the transport of pollution to the water environment. Concretely, SuDS could take the form of permeable pavements, bioswales[13], wetlands, rooftop reservoirs, green roofs, grassed strips detention basins or other features allowing to retain and slowly infiltrate water (Poleto & Tassi, 2012).

Figure 4.3 Section scheme of a bioswale when its dry (Left) and during rainfall (Right)



Source: Photo by atelier GROENBLAUW, Marlies van der Linden. Retrieved April 5, 2022 from https://www.urbangreenbluegrids.com/measures/bioswales/

The figure above (Figure 4.3) illustrates a section of a bioswale (example of SuDS), both when its dry and during rainfall, where the top layer consists of enhanced soil covered with plants, with a layer of gravel (or comparable material) packed in geotextile (to prevent clogging by roots or sludge) below it allowing for rainwater to drain off. Bioswales are typically designed to be connected to surface water, thus a drain tube is placed to transport water from areas of ground with a weak infiltration capacity to regulate water levels.

The figure below (Figure 4.4) shows a photo of the Kronsberg project (Hannover – Germany) which was designed with a vision to support sustainable urban development through the development of a landscape-based storm-water concept. In the project, rainwater does not directly infiltrate sewage systems, instead, SuDS function as conveyance elements carrying stormwater to retention ponds and allowing for its slow infiltration (Altevers, Groß & Menze, n.d.). This project is an example of a green-blue infrastructure urban system allowing to enhance the resilience of a neighbourhood to heavy rainfalls and floods through which are expected to increase in frequency and intensity in light of climate change,

[13] Trench of vegetation with a porous bottom.

through the optimization of the organization and management of surface water, the promotion of rainwater collection and the strengthening of the artificial recharge of groundwater (Acterra consulting, 2021).

Figure 4.4 Bioswales, Kronsberg (Hannover) – Germany

Source: Atelier Dreiseitl Retrieved April 5, 2022 from https://www.urbangreenbluegrids.com/measures/bioswales/

4.2.5 Green/Nature-based solutions

The EEA in its report No 14/2017 'Green infrastructure and flood management — promoting cost-efficient flood risk reduction via green infrastructure solutions,' presented environmental-friendly options to reinforce defences against river flooding which remains to date one of the most recurrent natural hazards in Europe, putting around 20% of European cities at risk (EEA, 2017a). The report asserted that **green infrastructures like wetlands and floodplains present lower investment and more sustainable solutions to address challenges caused by floods** in comparison to traditional approaches (e.g., building dikes, dams or cement barriers and constraining rivers by levees). It presented a series of **Natural Water Retention Measures (NWRM) increasing the resilience of the hydromorpholigical sector including the re-naturalisation of polder areas, the development of basins and ponds, flood plain and wetland management and restoration, lake restoration, restoration and reconnection of seasonal streams, riverbed material re-naturalisation, among others.** The EEA (2017) also emphasized the importance of **coordinating flood management plans between downstream and upstream areas and between different territories and countries** to improve decision-making and enhance the implementation of green infrastructure systems for flood risk management.

As a case in point, the Netherlands developed the Room for the River Programme to restore the natural flood plains of 4 rivers: the Waal, the Rhine, the Ijssel, and the Meuse.

The figure below (Figure 4.5) shows the plan of the Room for the Waal project which "was built based on different simulations and scenarios to increase the resilience of the city to floods. For this project, a dike was repositioned, three bridges and a new quay were constructed, and an auxiliary channel was developed to drain the river when there are high water levels, creating an island" (Khamis, 2021).

Figure 4.5 The Room for the Waal Project during (above) and after its completion (below) (Nijmegen) – the Netherlands

Source: Dirk Oomen/oomenlandschap (above) / Dutch Water Sector (below)

Table 4.1 Proposed adaptation measures to increase the resilience of the water sector

Types of adaptation solutions	Proposed Measures
Incentives/Governance/ Management	• Coordinating flood management plans between downstream and upstream areas and between different territories and countries. • Adopting an Integrated Catchment Management (ICM) approach, for sustainable water and land management in catchment areas. • Adopting an Integrated Water Resources Management (IWRM) approach. • Introducing water pricing.
Communications & roundtable exchanges	• Raising public awareness and education on water-usages.

	• Implicating water users and key stakeholders in the management of water resources and related decision-making. • Inciting different water users across sectors and recycle and re-use wastewater. • Encouraging different water-users and stakeholders to fix leaks and install water saving devices.
Research & innovation	• Improving water treatment facilities and conducting specific treatment by use. • Developing water infrastructure systems designed to separate grey, black and storm water, which allow proper treatments and reuses of water.
Technical/Engineered solutions	• Reinforcing and rehabilitating water storage. • Protecting hydraulic structures against all forms of pollution. • Developing sustainable urban drainage systems (SUDs).
Green/Nature-based solutions	• Developing green infrastructures like wetlands and floodplains. • Developing of Natural Water Retention Measures (NWRM).

5.0 ENVIRONMENT (BIODIVERSITY)

5.1 Impacts of climate change on the environment (biodiversity)

Climate change has various impacts on biodiversity and the environment. These impacts vary by location and ecosystem (EC, 2021). Observed climate change impacts on the environment include direct alteration of abiotic conditions, such as shifts in climatic features (e.g., temperatures, seasonality, extreme weather), the physical environment (e.g., sea level, glacial extent, fire frequency, oxygen concentration) and atmospheric greenhouse gas concentrations (IPBES, 2019). This affects reproductive cycles and growing seasons, species distribution and habitat ranges, and leads to shifts in migration patterns, and changes in the intricate ways in which species interact (predation, pollination, competition, disease, and pest outbreaks), among others. Unprecedented temperature changes are projected to impact 73% of the species by 2100 as it will cross their threshold tolerance (IPBES, 2019). According to a study published in the scientific journal Nature, human-induced climate change could put 15% to 37% of terrestrial plant and animal species at risk of extinction (UICN, 2008).

5.1.1 Wildfires

The frequency and severity of extreme events are increasing, causing a surge in environmental damages, over the last two decades. The extreme event ranges from unprecedented forest fires, storms, and heavy rainfall (IPCC, 2021). Climate change has increased the risk of forest fires across Europe. Indeed, every year, more than 50.000 fires are recorded in Europe, burning more than 0.5 million hectares (San-Miguel-Ayanz et al. 2012). Fire hazards are projected to increase further in most regions in Europe, but specially in the southernmost area including Portugal, Spain, and Greece (Costa, 2020). Fires have direct impacts on species and land and could affect water quality which is vital for the environment and biodiversity (EC, 2021).

5.1.2 Heavy Storms

Another major extreme event likely to increase in light of climate change is the frequency and the intensity of storms, which has direct effect on biodiversity. Storms are responsible for more than 50% of all primary abiotic and biotic damage by volume to European forests from catastrophic events. Concretely, more than 130 separated winds storms have been identified as causing noticeable damage to European forests in the last 60 years. (Barry et al., 2010).

5.1.3 Heat stress & Increased temperatures

During unprecedent 2003 summer heatwave in Europe, the primary productivity of vegetation was sensibly reduced, especially at low altitudes, due to the water stress experienced by the plants with consequences protracted for the successive growing seasons (Abeli et al., 2014). The reproduction performance of many mountainous plants species was also negatively affected (Abeli et al., 2014). In coastal areas and margins, increased thermal stratification may lead to oxygen deficiency, loss of habitats, biodiversity and distribution of species, and impact on entire ecosystems. Changes to rainfall and nutrients flux from land may exacerbate these hypoxic events (IPCC, 2007).

5.1.4 Decrease in water flows and availability

Long-lasting, severe, and frequent droughts cause habitat loss, migration of local species and the spread of invasive alien species resulting in biodiversity loss. Droughts have an impact on water resources, cause soil erosion, reduce carbon sequestration and overall contribute to land degradation (EEA, 2022). In Europe during the past’s decades, forests suffered the most intensive and most frequent impacts, especially in the years 2007, 2013, 2016 and 2019. Between 2017 and 2019, the forest area impacted increased from 60,000 km2 to 160,000 km2 (EEA, 2022).

5.1.5 Floods

Flooding, likely to increase in magnitude due to the intensification of water cycle because of global average temperature increase, accounts for one-third of natural disasters and affects more people and their environment than any other type of disaster (Alfieri et al. 2017; Talbot et al., 2018). Floods have direct impacts on the organisms that inhabit rivers, displacing or destroying wildlife for example. They also have indirect impacts on ecosystems via changes to the shape and form of the river. The structure of rivers determines the quality and quantity of habitat that is available to freshwater organisms. Therefore, structural changes caused by extreme flooding could influence river ecology even more than the direct impact of the flood itself, through changes to habitat availability for example (Death et al., 2015). In this context, it is nevertheless important to underline that flooding could have some benefits on aquatic biodiversity as it could provide some ecosystems services such as food supply, water regulation, water quality and disease regulation (Talbot et al., 2018). Furthermore, the physical force of a flood can expand or clear the floodplain, creating dry areas which provide crucial habitat for birds, reptiles, insects, and plants. More frequent extreme flood events may therefore generate more habitat for certain organisms. (Death et al., 2015).

5.1.6 Sea level rise

Changes in sea level have had major impacts on the abundance and particularly the distribution of both marine and terrestrial environment. Sea level rise occurs due to the thermal expansion of seawater, the melting of glaciers, and changes in the distribution of ice sheets. Coastal environments are predicted to be profoundly affected by sea-level rise. Global forecasts project a 33% area loss in coastal wetlands between 2000 and 2080 with a 36 cm rise of sea level (IPCC, 2007). Furthermore, sea-level rise and saltwater intrusion may limit the regeneration of trees, promoting osmotic stress and sulphide toxicity in sediments that cause tree mortality (Craft, 2012). As forest covers decline due to sea-level rise, salt-tolerant shrubs and herbaceous plants are expected to overtake these environments, leading to a gradual transition from forest to herbaceous marsh land cover (Linhoss et al., 2015). According to the IPCC, dozens of Spain's most beautiful beaches are in danger of disappearing due to rising sea levels (IPCC, 2007).

5.2 Adaptation response measures to increase the resilience of the environment to climate change

The European Commission, on its online platform, described ecosystems services as “our natural capital” and asserted that “they are at the foundation of all civilisations and sustain our economies”. Indeed, protecting ecosystem services is important as they play a vital role in providing food, clean water, maintaining the soil and purifying air as well as supplying important resources and raw materials for medicine, construction, among others. Increasing the resilience of environment and boosting biodiversity is therefore crucial to maintain the healthy functioning of ecosystem services in light of climate change.

5.2.1 Incentives/Governance/Management

To adapt ecosystem services to a changing climate it is important to consider its risks on biodiversity and integrate that into a flexible adaptation planning. This includes **the understanding of impacts of climate change on the environment, biodiversity and ecosystems**, **the determination of sites that are particularly exposed to climate impacts as well as the factors that increase the vulnerability of these sites**, **assuring their conservation**, and **integrating climate change considerations in the management plans of protected areas**. **The creation of a “landscape framework”** could allow for planners **to integrate climate and biodiversity considerations in plans developed at a regional scale**.

Addressing non-climatic factors is crucial, such as regulating urban sprawl, controlling forest logging and deforestation, limiting air, climate, water, and soil pollution as well as curbing luminous pollution that has direct impacts on nocturnal wildfire.

5.2.2 Communications & roundtable exchanges

Organising awareness campaigns and roundtable exchanges on the impacts of climate change on the environment and related socio-economic ramifications is important. These exchanges could take various forms such as events, marches, workshops, roundtables dialogues, brochures, websites, etc. presenting eco-system goods and services and highlighting the value of the environment and its place in human life.

5.2.3 Research & innovation

The introduction or reintroduction of diverse types of species allow to strengthen or improve natural functions and cycles of ecosystems, such as rebalancing the food chain. Comparably**, the control and prevention of invasive species** in light of climate change is crucial to rebalance the ecosystem. As a case in point, Lionfish (a.k.a., Pterois miles) a rapacious meso-predator native of the Indian Ocean has invaded the Mediterranean Sea as seawaters are warming, posing threats to native species of the Mediterranean basin. To address the issue, Cyprus in its EU-funded project RELIONMED-LIFE, **established a corresponding risk assessment** and **formed a surveillance and monitoring system to report the sighting of the invasive species (**Kleitou, et al., 2021). This approach is to allow to estimate the abundance of the Lionfish and share this information to key stakeholders, so they take appropriate actions. In response, a regulated **removal of the invasive species** was conducted in “newly colonised” protected natural areas to preserve the ecosystem (Figure 5.1) (Kleitou, et al., 2021).

Figure 5.1 Removal Action Team (Left) removing lionfish (Right) from various areas of Cyprus marine water

Source: Marine and Environmental Research (MER) Lab; Cyprus

5.2.4 Technical/Engineered solutions

To increase the resilience of ecosystems to floods, **the removal of features that inhibit the natural movement of water** seems critical, i.e., **the removal of manufactured barriers** (e.g., dikes, sea walls, etc.) erected to control coastal sediment movements. Furthermore, **maintaining wetlands and floodplains is** important to address flood issues as well as the **construction of new holding ponds and water reservoirs**. **Multifunctional wetlands can be created to sustain ecosystems** through providing wildlife habitats and assuring flood protection, while providing areas for recreational use (Watts, 2010).

5.2.5 Green/Nature-based solutions

The **development of green-blue infrastructure** systems allows to preserve biodiversity while addressing key issues such related to the fragmentation of natural environments. This approach aims on **restoring**

and maintaining a natural network of exchanges between plant and animal species, so that they can feed, circulate, rest, and reproduce, which is crucial to their continuity. The maintenance of a good connectivity between these species and the environment favours their ability to resist, or even re-establish themselves considering global changes, including climate change. **Increasing habitat connectivity in urban areas** is important to enable the migration of all species in light of climate change, thus the importance of providing advice to policy makers.

It is important to **align mitigation and adaptation efforts when managing natural environments**. For instance, **the restoration of blue carbon ecosystems** (e.g., coastal ecosystems such as tidal marshes, mangroves, and seagrass meadows for carbon storage) "allows to sequester and store more carbon per unit area than terrestrial forests" (IUCN, 2017) while conserving biodiversity as well as providing coastal defence and food security for coastal communities (Ocean and Climate, 2021). As a case in point, the Elkhorn Slough Tidal Marsh Restoration project was developed to build coastal resilience through elevating drowned salt marshes so that they can keep up with projected sea level rise (Figure 5.2). The habitat restoration project has a twofold objective, on the one hand, it aims on playing a role in GHG reductions as marshes allow for absorbing carbon dioxide. On the other, the revegetation of the marsh and the restoration of the site is expected to attract sea otters to settle in, enriching biodiversity.

Figure 5.2 Elkhorn Slough Tidal Marsh Restoration Project – South of San Francisco Bay (California)

Source: Photos by the Elkhorn Slough National Estuarine Research Reserve's Tidal Wetland Program Retrieved April 13, 2022 from https://www.elkhornslough.org/tidal-wetland-program/hester-marsh-restoration/

The landscape could also be reconverted to increase its climate resilience, concretely communal forests could be re-converted to climate-tolerate mixed forests, arable land in flood-prone areas could be converted to waterlogged grasslands, etc.

Figure 5.3 Installation of cages of oysters off the greenspace's marina

Source: Steven DeWitt, 2020 - Witness Tree Media

Various projects and initiatives have embraced **a nature-based or landscape-based adaptation approach to restore coastal ecosystems**. As a case in point, the "Billion Oysters Project" has been established to restore oyster reefs in New York Harbour. The project's aim is to provide habitat for species while protecting the impacts of the rise of sea level and storm damages (Figure 5.3).

In the Netherlands, the Sand Motor project in the Delfland Coast is implemented to assure the preservation of the shoreline and its protection against flooding while ensure nature development. The Dutch project is an example of a BwN approach using natural processes to manage the coast (Figure 5.4). Such initiatives allow to provide a natural buffer zone between the sea and the shoreline preventing erosion.

Figure 5.4 Sand Motor Project - Netherlands

Source: Rijkswaterstaat/Jurriaan Brobbel; Source: www.flickr.com/photos/zandmotor - CC licensing

Table 5.1 Proposed adaptation measures to increase the resilience of the environment/biodiversity sector

Types of adaptation solutions	Proposed Measures
Incentives/Governance/ Management	• Setting up a risk assessment and monitoring system to report invasive species sightings. • Regulating urban sprawl, controlling forest logging and deforestation, limiting air, climate, water, and soil pollution. • Integrating climate change considerations in the management plans of protected areas • integrating climate and biodiversity considerations in plans developed at a regional scale. • The creation of a "landscape framework" to integrate climate and biodiversity considerations in plans developed at a regional scale
Communications & roundtable exchanges	• Associate mitigation and adaptation efforts when managing natural environments
Research & innovation	• Introduction or reintroduction of diverse types of species. • Controlling and preventing invasive species • Continuous assessing the impact of climate change on the environment biodiversity and ecosystems
Technical/Engineered solutions	• Removal of features that inhibit the natural movement of water. • Constructing new holding ponds and water reservoirs.
Green/Nature-based solutions	• Development of green-blue infrastructure. • Increasing habitat connectivity in urban areas. • landscape-based adaptation approach to restore coastal ecosystems.

6.0 INFRASTRUCTURE

6.1 Impacts of climate change on infrastructure systems

Infrastructure systems are seen as the basic organizational and physical structures needed for the operation of societies and territories such as roads, power supplies, buildings, Information and Communications Technology (ICT), among others. They are considered as “the backbone” of the global economy as they are crucial for enhancing the quality of life, connecting people, and promoting health and safety. Under climate stress, the vulnerabilities of infrastructure systems are revealing due to both technical and non-technical issues (Purwanti & Nurmuntaha, 2018). Individual assets have various hazard exposures depending on their geographical location since climate change consequences are exhibited locally (Forzieri et al. 2018). The impacts of weather extremes on strategic infrastructure are significant. Concretely, European countries spend around 3.4 billion euros annually on damage due to climate change. This amount is expected to rise sharply to around €19.6 billion by 2050, and €37 billion euros by 2080 (WHO, 2017b).

Climate-related extreme events such as storms, landslides, hurricanes, windstorms, hail, and heavy precipitation have become more frequent and intense in Europe due to climate change, increasingly impacting and damaging buildings, transportation, and energy infrastructure systems (EEA, 2017b). For example, energy infrastructure systems can be inundated, the efficiency and output of solar and hydropower generation systems, also insufficient cooling water could perturb the generation. To add to that, the transmission and distribution are likely to be impacted due to damages to transmission lines and substations in light of climate change. Not to mention, energy demand for both cooling and heating are expected to increase, adding pressure on the existing system (OECD, 2018).

6.1.1 Heavy Storms

Storms have been Europe's most costly natural hazard in terms of insured losses, with the most severe effects in north-western Europe, especially along the coastline (EEA, 2017b). Heavy precipitation associated with landslides is expected to be more severe in Europe, leading to major damages to construction, buildings, and other assets such as bridges. In fact, these events can lead to water intrusion, damage to foundations and basements, destruction of buildings and infrastructure, overflowing sewers, land- and mudslides (COM, 2013). Heavy storms could affect ports, airports, power plants, above ground transmission infrastructures (e.g., radio masts) as well as flood barriers. Compounded and cascading climate risks, such as tropical cyclone storm surge damage to coastal infrastructure and supply chain networks, are expected to increase by 2100 (IPCC, 2013).

6.1.2 Floods

The damaging effects of floods are complex. Floods frequently cause major infrastructure damage, including disruption to roads, rail lines, airports, electricity supply systems, water supplies and sewage disposal systems. Flooding affects more people in Europe than any other risk. Central, Eastern and South-Eastern European are affected by rivers floods. While flash floods are common in Southern Europe (EEA, 2017b). A projected increase in the occurrence of heavy precipitation and snowmelt, in light of climate change, are expected to result in more frequent and severe floods in Europe (IPCC,2012). Almost 1,500 floods have been reported in Europe since 1980, of which more than half have occurred since 2000 (EEA, 2017b). Many European cities have been built along a river; and these rivers will respond to extreme rainfall or snowmelt events with extreme discharges, threatening the cities with floods (COM, 2013). As a case in point, the 2007 summer floods in the UK dramatically affected electricity power substations, water and sewage treatment works, and the road and rail network. Because of this event 750,000 people lost electric power and 350,00 lacked drinkable water for 17days (Kees van et al., 2016).

6.1.3 Sea level rise

Sea level has risen globally by around 20 cm between 1901 and 2010 at an average rate of 1.7 mm per year (IPCC 2013). The rise of sea level presents a significant pressure on critical infrastructure services, properties and lives in coastal towns and cities which accommodate more than one-third of the European population (Crespi, 2020; EEA, 2017b). Coastal infrastructure such as roads, ports, railways, generation transmission, among others could be inundated. Projections show a dismal future for many coastal communities as sea levels could rise as much as 2 meters by 2100 leading to coastal erosion, saltwater intrusion, deterioration of water quality, with knock-on effects on infrastructure and key ecosystem services (Williams, 2013). Norway's coastline is found to be one of the most vulnerable regions as approximately 110,000 buildings are situated less than 1m above normal sea level rise. (Almås & Hygen, 2012).

6.1.4 Heat stress & Increased temperatures

Europe has experienced intense heatwaves since 2000, with notable impacts on human health and socio-economic systems (EEA, 2014b). In addition to that, heatwaves can have significant impacts on infrastructure and essential services (Chhetri et al. 2012). Concretely, heat places electricity generation and transmission systems under considerable stress, significantly testing their ability to withstand the pressure of increasing energy demand (McEvoy et al. 2012). Furthermore, heatwaves affect electricity communication, and the transmission lines can become so hot that they expand and can hang dangerously low. When this occurs, energy flow is reduced to allow transmission lines to cool and contract (Will et al., 2014). For example, in Australia, on the 30th of January 2009, around 500,000 residents in central and western Melbourne experienced a blackout lasting from one hour up to two days (Will et al., 2014). The recorded heatwave recorded led to electrical shortcomings causing technical failure in rail signalling. Consequently, trains were cancelled leaving many commuters stranded (Will et al., 2014).

6.1.5 Decrease in water flows and availability

Due to climate change, Southern European countries are experiencing their worst drought in decades, the frequency and severity of drought events is expected in increase all across Europe (IPCC, 2012). Precipitation deficiency results in water shortages impacting infrastructure systems that depend on water resources. For example, drought conditions may result in low water levels in rivers and other waterways which could damage waterborne transportation infrastructure (U.S DPH, 2015). The lack of water availability could also impact hydroelectric power generations affecting sustainable energy resources. Concretely, in 2012, a severe drought hit more than one-third of United States of America, hampering the functioning of power plants and other energy-generating operations (U.S DPH, 2015).

6.1.6 Wildfires

Drought accompanied by heats waves also increases the risk of wildfire which has both direct and indirect consequences on critical infrastructure systems (CIs). Fires could eat up CIs, impacting respective services and endangering the safety of the people (UNECE, 2012). Furthermore, the smoke resulting from wildfires could affect the functioning of infrastructure systems. For instance, the smoke can affect road visibility and lead to airport closures.

6.2 Adaptation Response measures to increase the resilience of infrastructure systems to climate change

6.2.1 Incentives/Governance/Management

Savonis (2008) presented three main ways to ensure more climate resilient infrastructure systems: 1) **developing risk and vulnerability assessments,** determining infrastructure failure risks due to climate stressors and the potential for major damages or disruption based on its structural integrity and strength ; 2) **establishing a planning timeframe incorporating the long-term climate change effects into the**

planning process; and 3) **assessing adaptation solutions in terms of cost-effectiveness, taking into account public perceptions and priorities**. The **development and implementation of a toolbox allowing to assess the resilience of CIs** allow to determine the vulnerability, exposure and critical thresholds in light of climate change. **An adaptation action plan compiling effective and feasible solutions to address climate impacts and vulnerabilities**. For example, the Blue Plains Wastewater Facility in Washington DC adopted an adaptation plan to increase its flood resilience based on its understanding that storms may become more frequent and intense (NCPC, 2014).

Crisis and disaster management measures also allow for quick intervention following extreme climate-related events and ensure the rapid resumption of activities. This approach requires **the development of contingency, recovery and crisis management plans as well as the establishment and training of emergency structures** (Sanchez, 2021).

6.2.2 Communications & roundtable exchanges

***S*everal organisms need to work together to prepare an adequate adaptation strategy to increase the resilience of CIs**. These organizations include governmental bodies, the private sector, investors, infrastructure owners and operators, economic regulation, insurance and reassurance providers, local authorities and/or local enterprise partnerships, the engineering profession, and the research community.

The impact of climate change on the critical infrastructure systems including energy, transport and Information Communication Technology (ICT) sector is likely to be significant. For an adaptive action to be set up, **continual awareness of the need to design and implement adaptation strategies** allowing to better prepare for, respond and adjust to the impacts of short- and long-term climatic manifestations are necessary (Ospina et al, 2014).

6.2.3 Research & innovation

Given that infrastructure systems provide services crucial for the functioning of society and are perceived as the backbone of healthy economy, increasing their climate resilience is crucial. Successful adaptation solutions for critical infrastructure systems (CIs) are ones that are effective: allowing to reduce climate vulnerability, efficient: with benefits outweighing costs of adaptation, following an equitable distribution, and evidence-based: informed by the latest research data and practical experience (DEFRA, 2011). Therefore, it is important to **understand the ramifications of climate change on CIs**, and to **integrate adaptation in asset management in collaboration with climate experts and meteorological services**.

In response, some technologies, tools and solutions could be explored to increase the resilience of CIs to climate change. For instance, RENFE, the Spanish rail service operator, has **established a tool for the prediction of adverse weather events, which can help develop pre-and post-crisis strategies in real-time** (CEDEX, 2013). This approach allows for **fleet changes, slowdowns, salt application, preheating units, covered parking at the station, or working with extra trains** to clean catenaries when there are below-freezing temperatures, ice accumulations or heavy snowfall (CEDEX, 2013).

6.2.4 Technical/Engineered solutions

Maintenance schedules could be updated and revised in function of climate impacts, frequency and severity (OECD, 2018). **Adaptation concerns taking into account future climate projections should be well embedded and integrated in the renovation, rehabilitation and design of new CIs.**

Building norms can be developed and readjusted to include climate resilience aspects including elevation of critical infrastructure services in flood prone areas, limiting or banning the use of inflammable materials in areas that are susceptible to wildfires, and **the use of materials that do not intensify or exacerbate the urban heat island effect**. It is also important to **consider new building materials** (e.g., chalk, hemp, raw earth, bamboo, etc.) for the construction of infrastructure systems that have a limited impact on the environment and biodiversity, however, when doing so, it is crucial to **assess the climate resilience of these material** (OECD, 2018).

I- Energy Systems

To increase the resilience of energy systems, and to cope with the impact of rising temperatures and heatwaves on energy transmission, system operators need to **adapt overhead lines to high temperatures**. Not to mention, **the amount of electricity that flows through overhead power lines under high ambient temperatures needs to be reduced to prevent equipment from overheating** (EEA, 2019). Whereas the demand on electricity for cooling increases when temperatures rise. In the UK, to address these concerns, the Western Power Distribution (WPD) has cooperated with the Energy Network Association (ENA) to operationalize adaptation measures in its transmission and distribution infrastructure (EEA, 2018e). Furthermore, knowing that extreme events can lead to the collapse of power line infrastructure, resulting in temporary power outages for users and elevated utility repair costs overhead, **transmission lines could be replaced with underground cables**. This would allow **to protect transmission and distribution systems from the most common severe weather events**, especially storms and heavy snow and ice loads. As a case in point, Elenia, Finland's second-largest distribution system operator, is investing heavily in underground wiring to adapt to Finland's increasingly frequent and expected extreme weather events (EEA, 2018b) (Figure 6.1).

Figure 6.1 Elenia in Finland replacing overhead transmission lines with underground cables.

Source : Allianz SE (2017) Retrieved 25 April, 2022 from https://www.allianz.com/en/press/news/financials/stakes_investments/171213_Allianz-Macquarie-Valtion-acquire-Elenia

Furthermore, to address flood risks on energy systems, France's largest electricity producer, Electricité de France (EDF), has **adopted the Piano Key Weir (PKW) system[14] to improve flood flow from hydroelectric dams during heavy rains** (EEA, 2018d). The main advantage of this technology is that it

[14] An overflow control structure permitting to increase the storage capacity and/or the capacity of clearing the floods of the existing dams.

protects hydropower plants from damage while reducing operating costs compared to alternative gate systems. **Positive impacts due to current or projected climate variations should also be taken into account when managing CIs**. For instance, Landsvirkjun, Iceland's state-owned energy company, **has incorporated climate change adaptation into the management, design, upgrade, and expansion of hydropower plants** given that ice melting is expected to intensify due to rising temperature. This could benefit and boost hydropower potential, yet reservoir management needs to be adapted to accommodate this increased flow (EEA, 2018b).

II- Transport

Modern design standards have been developed in Copenhagen to address floods affecting urban transport systems (Figure 6.2). Contractors unravelled ways to keep water out of exposed station tunnels by predicting the worst scenario of water levels in the streets around seventeen new subway stations during extreme rainfall (EEA, 2014b).

Figure 6.2 Measures adopted to increase the resilience of subway stations to floods and keep metros operating in the events of heavy rainfalls: Flooding gates (Right) and Elevated Metro Entrance (Left)

Source: EEA (2014b).

To address the impact of storms and sea level rise on the Dawlish railroad in the UK, some coping short-term solutions have been considered such **as installing temporary breakwaters made from concrete-filled shipping containers**. However, in this context it is important to mention that long-term measures to increase rail resilience against could be more transformative such as **building a second line and reroute the mainline** (EEA, 2014b). Indeed, **building new transport infrastructure that is climate-resilient** will, in most cases, save costs due to avoided damages and necessary upgrading at a later stage. For example, the Slapton Line in South Devon (England) running along the coast, is vulnerable to floods and storms. In response, the Devon County Council developed a plan to **reroute roads further inland**, to reduce the risk of resulting damage (UN, 2013). Similarly, France engages in an ambitious **systematic review of transportation infrastructure standards, including climate parameters that may be affected by climate change** (EEA, 2014b).

Adaptation actions have been examined and developed to render the largest port in Europe, the port of Rotterdam, and its industrial infrastructure more resilient to sea-level rise. The strategy adopted to increase the resilience of the port includes preventatives measures, measures to adapt the space as well as crisis management responses. These measures can be combined with each other (Sanchez, 2021). In prevention, the strategy proposes **the raising of barriers, land, and banks** through interventions on retaining walls and quay walls. Also, two water squares have been built to hold excess water with a capacity of 750 cubic meters and 1800 cubic meters, respectively (Climate Adaptation Platform, 2019)

(Figure 6.3). To adapt the space, flood risk is managed by **developing adequate sites and adapting equipment for instance, elevating vulnerable structures or site, making buildings and equipment watertight, moving stored goods to higher floors** (UNCTAD, 2020).

Figure 6.3 Water squares constructed to counter excess water in Rotterdam - the Netherlands

Source: Climate Adaptation Platform (2019). Retrieved April 25, 2022, from https://climateadaptationplatform.com/climate-change-adaptation-transportation-infrastructure/

Addressing the impact of heavy infrastructure on road infrastructure (pavement performance) is also crucial. Adaptation solutions include the **development of new heat resistant materials**, **the stabilization of unsealed roads**, **sealing of cracked and damaged areas**, **more track and/or wear-resistant resurfacing**, **surface treatments** as well as **micro surface treatments** (Tsamboulas, 2012).

III- Information Communication Technology (ICT)

Current actions to make the ICT sector more resilient to climate change are divided into two categories. Firstly, it is crucial to **protect the value of existing assets and systems**. Secondly, it is important to **create value through innovation** and **meet new needs that are likely to arise considering climate change** (Wong & Schuchard,2011).

Value protection in ICT entails **assessing site and asset risks as well as planning for continuity**. Climate-related hazards are frequently assessed as part of standard risk assessments, with follow-up activities incorporated into business continuity planning. For example, Motorola, a multinational telecommunication company, undertakes regular risk assessments throughout Asia to detect and prepare for high-risk events (Wong & Schuchard,2011). In this context it is however important to emphasize the need to **ensure that climate risks on ICT are well developed and integrated in standard risk assessment developed by telecom companies, or even incite concerned partners to establish distinct climate risks assessments**. **Continuity and readiness strategies need to be developed and tested based on identified threats**. Furthermore, firms are investing in existing network infrastructure and factoring such concerns into plans for future networks to cope with and minimize the disruption and damage to services and networks caused by sudden weather occurrences (Wong & Schuchard,2011).

To create value, companies are working on solutions for the rapid deployment of new networks. Verizon, for example, is **incorporating fibre optic technology and advanced electronics into its network to increase redundancy and allow network traffic to be rerouted when a portion of the network is down**

(Wong & Schuchard, 2011). ICT companies are also **developing products and services that allow businesses to identify and address vulnerabilities in their operations, systems, and processes** (Ospina et al, 2014). **Early warning and disaster-response systems are being developed by telecommunications companies** particularly. Finally, **technological solutions are being established and applied to collect, analyse, and disseminate data related to the effects of climate change** (Wong & Schuchard, 2011).\

6.2.5 Green/Nature-based solutions

The development of green-blue infrastructure systems to increase the overall resilience of the territory and CIs. Concretely, solutions that are examined and found in the literature review to increase the resilience of CIs are focused on technical and engineered solutions. This stresses the need to further consider, test and demonstrate nature-based adaptation measures as solutions permitting to increase the resilience of the energy, transport and ICT sectors.

Table 6.1 Proposed adaptation measures to increase the resilience of the infrastructure sector

Types of adaptation solutions	Proposed Measures
Incentives/Governance/ Management	• Building and readjusting norms to include climate resilience aspects. • Incorporating climate change adaptation into the management, design, upgrade, and expansion of hydropower plants. • Developing contingency, recovery and crisis management plans as well as the establishment and training of emergency structures. • Ensuring climate risks on ICT are well developed and integrated in standard risk assessment developed by telecom companies. • Developing action plans compiling effective and feasible solutions to address climate impacts and vulnerabilities.
Communications & roundtable exchanges	• Assuring the coordination among different organisms to prepare an adequate adaptation strategy. • Raising continual awareness on the need to design and implement adaptation strategies for the ICT sector.
Research & innovation	• Understanding the consequences of climate change on CIs. • Developing risk and vulnerability assessments. • Developing tools for the prediction of adverse weather events. • Assessing adaptation solutions in terms of cost-effectiveness, taking into account public perceptions and priorities. • Developing new heat-resistant materials, as well as the stability of unsealed roads, the sealing of cracked and damaged regions.
Technical/Engineered solutions	• Elevating vulnerable constructions. • Raising of barriers, land, and banks. through interventions on retaining walls and quay walls. • Building new transport infrastructure that is climate-resilient • Protecting the value of existing assets and systems.

	• Developing products and services that enable businesses to discover and address flaws in their operations, systems, and procedures. • Incorporating fibre optic technology and advanced electronics. • Developing technical solutions to collect, analyse, and disseminate data related to the effects of climate change on CIs
Green/Nature-based solutions	• Developing green-blue infrastructure systems to increase the overall resilience of CIs.

7.0 URBAN PLANNING

7.1 Impacts of climate change on urban environments

Climate change poses significant challenges to urban systems around the world including increased floods, heavy storms, heatwaves, among others. These impacts are likely increase in the coming decades due to both projected surge in urbanization and the anticipated increase in the frequency and intensity of hazards because of climate change (Khamis, 2021). In fact, over the last three decades, the number of natural disasters worldwide has nearly quadrupled, increasing the deaths rate and economic losses (UNISDR, 2012).

Urban systems are extremely vulnerable to the impacts of climate change due to the concentration of population, capital, and resources (IPCC, 2019; Khamis, 2021). The degree of vulnerability and exposure varies across cities in function of their scale, their geographical location, their population, the dominant economic sector, and the availability of resources (Lehner et al., 2016) Khamis, 2018; Khamis, 2021). In Europe, much of the population lives in urban areas and is projected to increase from 74% to 83% by 2050 (EEA, 2020a).

In an urban context, infrastructure systems are extremely intertwined and cascading effect can potentially “paralyze the entirety of a city” (ITU et al., 2019). Concretely, heavy rainfall events could perturb transportation systems which could impede people from reaching their jobs and have further ramifications on services and economic systems within the city and beyond. As a case in point, Hurricane sandy which hit New York in 2012 resulted in direct damages devastating the city and causing the stock exchange to shut for two business days costing the city more than 70 billion US dollars in financial losses and taking the life of 159 people (NCEI, 2018; Khamis, 2018).

7.1.1 Heat stress & Increased temperatures

In Europe, heatwaves have significant consequences, including increased burden on infrastructure (e.g., increased energy demand), risk on human health and increased mortality rates, which can exacerbate social unrest (EEA, 2020a). As a case in point, the 2003 heatwave struck the whole of Europe, leading to the death of 70,000 people due to heat-related health issues (Robine et al., 2008). Forecasts predict strong heat waves to occur every two years until 2050 (Rosso et al., 2014). By the end of this century, the summers of southern, central, and north-western Europe are expected to be warmer than any summer from 1920 to 2014. Southern Europe and the Mediterranean coast are the most vulnerable due to dense urban areas (Lehner et al., 2016). Indeed, urban areas are critical points as they are exposed to more extreme heat than rural areas due to the urban heat island (UHI) effect (Wouters et al., 2017). Peak electricity demand for cooling during intense heat waves is projected to increase across Europe, with the largest increase expected in Italy, Spain, and France (EEA, 2019).

7.1.2 Decrease in water flows and availability

Most European cities are projected to experience an increase in severe droughts by 2050 due to reduced precipitation and increased evapotranspiration. Concretely, the lack of water during droughts can lead to reduced water flow in sewers, resulting in increased odours, and higher concentrations of pollutants in wastewater (Sofoulis, 2015). Southern and central Europe show a trend toward increased duration and severity of droughts in the future (EEA, 2020a). In fact, cities in southern Europe are likely to experience fourteen times more drought in comparison to the 1951-2000 reference period (IPCC, 2019). Mediterranean cities are expected to suffer from water shortages, particularly due to high water demand and the overexploitation of existing water resources, which are exacerbated during droughts. For example, in the summer of 2015, rainfall amounts decreased by 10%, resulting in a 20% reduction in freshwater renewable resources compared to the same period in 2014 (EEA, 2022).

7.1.3 Wildfires

Wildfires commonly occur in areas with warm and dry climates, such as the Mediterranean and in northern Europe's boreal forests (Xanthopoulos, 2015). The increase in wildfires observed in the Mediterranean since the 1970s has been attributed to climate change along with increased urbanization and urban sprawl (EEA, 2017). The concentration of human exacerbates both the likelihood and the impacts of wildfires, which make cities particularly vulnerable. In fact, over 26 000 km2 of the administrative areas Mediterranean cities were burnt over the course of 19 years, affecting nearly 68 000 people in total (EEA, 2020a). Fire danger is expected to keep on increasing in the future owing to increased incidence of droughts and reduced soil moisture. There are currently sixty-three million Europeans living close to wilderness and exposed to at least 10 days of high and extreme fire risk per year. This number is expected to increase to sixty-eight million with a 1.5°C increase of average global temperature and seventy-eight million with a three degrees Celsius global warming (Feyen et al., 2020). European cities with the highest numbers of population numbers by wildfires are Coimbra (Portugal), Vigo (Spain), Palermo (Italy), Marseille – Aix-en-Provence Metropolitan area (France) and Split (Croatia) (EEA, 2020a).

7.1.4 Heavy Storms

The number of extreme weather events recorded in Europe has increased (IPCC, 2019). European coastal areas are highly exposed to severe wind damage, also Southern European territories are projected to face an upward trend in **windstorm** intensity (Spinoni et al., 2020). The increase in intensity and frequency of severe winds is likely to impact urban infrastructure systems causing physical damage the built environment and in extreme cases the injury and death of people (due to their exposure to falling elements). Urban green infrastructure systems are also vulnerable to intense winds and can cause damage to infrastructure and property as well as to human lives. In 2014, Hurricane Ela removed more than 20,000 trees from its roots in Dusseldorf, Germany, and Hurricane Xavier, in 2017, damaged thousands of trees in northern Germany (Gross, 2018). Also, on the night of Saturday the 19th of February 2022, Storm Eunice caused sixteen deaths: four in each of Poland and the Netherlands, three in England, two in each of Belgium and Germany and one in Ireland. The reported deaths were mostly caused by trees falling on vehicles (Euronews & AFP, 2022).

7.1.5 Floods

Europe already experiencing a decrease in summer precipitation and an increase in winter precipitation (EEA, 2020a). Heavy rainfall events are expected to increase across much of the continent. Urban areas and cities are more susceptible to flooding from heavy rainfall events due to the development of floodplains, the straightening of canals as well as the abundance of impervious surfaces in cities. Not to mention, the size and condition of urban storm sewers also affect the risk of flash floods (EEA, 2020a). In fact, the average age of sewer networks in thirty-six cities included in the Atlas of Urban Waters in Europe is 40 years and the average age of London's sewers is 90 years, making these cities especially vulnerable to flooding (Gawlik et al., 2017). For example, flash floods hit Copenhagen in 2011 where 135 mm of rain were recorded in two hours. The event costed more than €800 million in damages (EEA, 2020a). In addition to that, the location of new urban areas and the accumulation of assets in low-lying areas near rivers have increased sensitivity to riverine floods. For instance, in January 2018, floods on the Seine and Marne rivers in France affected the Paris metropolitan area, with overall damages ranging between EUR 190 million and EUR 350 million despite flood control measures (CCR, 2018).

7.1.6 Sea level Rise

Rising sea levels pose a significant risk coastal regions in Europe due to the exposure of the territories and the concentration of resources. In fact, “The EU coastline is 68 000 km long — more than three times longer than that of the United States and almost twice that of Russia.” (EEA, 2020b). Not to mention, around half of the EU population lives within 50 km from the sea with a majority concentrated in coastal cities (EEA, 2020b). Climate change projections assume the range of 0.29-0.59 m of sea level rise in the 21st century for the low emission scenario and 0.61–1.10 m for the high emission scenario (IPCC, 2019). In consequence, losses from sea floods in coastal cities in Europe are expected to be amplified. As a case in point, in February 2014, the coastal city of San Sebastian (Spain) was hit by a heavy storm with intense waves exceeding ten meters in height. Tidal flood water reached the city's old town. The event caused damages to coastal roads of the city, the destruction of walkways, as well as the flooding of various commercial shops and buildings (Khamis, 2021).

7.2 Adaptation Response measures to increase the resilience of cities and urban environments to climate change

"Until the beginning of the 21st century, the role of cities in global climate governance was rather narrow and symbolic. Nonetheless, cities are progressively gaining a significant role in the global response to climate change and the emergence of transnational systems for climate governance" (Khamis, 2021). In fact, the Paris agreement (UNFCCC, 2015) emphasized the role of cities and subnational authorities in addressing the global issues, also the Council of the European Union (2013) asserted that the European Commission supports adaptation in urban environments through various initiatives like the "Covenant of Mayors". Following the global and European support of urban climate adaptation, many cities of different scales have understood the urgency of addressing the global issue of climate change at an urban level and have developed strategies and solutions to increase their adaptability and climate resilience (Khamis, 2018; Khamis, 2021).

7.2.1 Incentives/Governance/Management

The EEA (2016), in a report on urban climate adaptation in Europe, asserted that the intricacy of climate change requires the involvement and the collaboration of various levels of governance. Thus, the importance of **establishing collaboration and vertical communication lines between city governments, regional and national authorities to align adaptation efforts**. Also, the World Bank (2011) affirmed that adaptation "must be location-specific and tailored to local circumstances". Hence, **developing adaptation strategies and action plans at an urban scale in response to assessed impacts and vulnerabilities** is crucial to determine ways forward and increase a city's climate resilience (Khamis, 2021). Implementing the developed strategies is the step that transforms vision into reality, however, it requires **dedicating adequate technical, financial, and human resources**.

Furthermore, individuals and businesses need to be incited to invest in climate adaptation. The **local government could therefore provide subsidies or other financial incentives (e.g., reduction of taxes) for individuals and businesses retrofit buildings or develop other projects** to increase their climate resilience to floods, and other extreme weather conditions. Lastly, it is important to make sure that human with the right expertise and knowledge are involved in decision making process.

7.2.2 Communications & roundtable exchanges

The communication of developed scientific knowledge is also crucial thus the importance of **making climate knowledge accessible and understandable by the public through organizing events and developing communications for the dissemination of climate data**. When doing so, it is important to spark the interest of people by **creating links between climate change and its impact on the day-to-day life**. **Workshops could be organized to have discussions with key stakeholders on the impacts of climate change they are currently feeling and their concerns considering projected impacts.** As a case in point, in Rouen (France), a physical workshop (Atelier Cop 21) was established at the heart of the city centre (Figure 7.1), with public access, communicating climate and environmental-related knowledge through the organization of exhibitions, workshops, the distribution of brochures, etc. (Khamis, 2021).

Concretely, technologies should be developed and made available to address key climate issues, thus, it is important that actors in the public and private spheres **support research and innovation to promote the development of technological and scientific urban climate solutions**.

Figure 7.1 Atelier Cop 21 – Rouen (France)

Source: Khamis, 2021

The collaboration of city planners, urban developers and policy makers with environmentalists, meteorologists and climate experts is crucial to **integrate scientific knowledge and climate projections in the design of the** city, especially that urban infrastructure systems are designed and built to stand for decades. Also, **developing horizontal communication and working lines between a city's different departments** (e.g., transportation, construction and maintenance, sustainable development, health, etc.) is important to avoid working in silos, especially that urban systems are increasingly intertwined (Khamis, 2021). As a case in point the city of San Sebastian **established a local adaptation technical commission ensuring the mainstreaming of adaptation efforts across various city departments**. Also, the city of Leuven developed the "Leuven 2030" initiative **– a city wide organization bringing together city actors, researchers at the local university and people working in different sectors to work together** to achieving sustainable development, a net zero city and increasing Leuven's climate resilience by integrating the environment to the heart of the city's various operations and development projects.

Cities could also learn from the experience of other cities that are developing and implementing adaptation goals **through joining city networks and initiatives** (e.g., ICLEI, Covenant of Mayors, EIT Climate-KIC etc.) **promoting environmental and sustainable development and emphasizing the importance of making adaptation efforts**. City networking has proved to be crucial, especially in a context where cities are becoming increasingly connected at a global scale (Acuto, 2013). In fact, cities demonstrated to be taking remarkable action when developing links and partnerships with governments, cities, businesses, civil society, and organizations (40 cities & Arup, 2015). This underlines the importance **of adopting a bottom-up decision-making approach based on roundtable exchanges and discussions bringing together various stakeholders.** Concretely, the city of Leuven collaborated with EIT Climate-KIC to draw up a strategic plan for the city's climate action and accelerate the implementation of its climate-neutral roadmap (Figure 7.2). The collaboration allowed to secure subsidy permitting to make the city's climate ambitions more concrete (Leuven 2030, n.d.).

Figure 7.2 The city of Leuven's collaboration with EIT Climate-KIC and its partners to accelerate climate action at a territorial scale.

Source: Leuven 2030.

The participation of city residents, locals and key stakeholders in the design and conception of urban climate adaptation solutions allow to increase the acceptability of measures. As a case in point, in the Nijmegen, the room for the Waal project -which is an appropriation of the national room for the river program giving more space for rivers to address flood risks- initially faced oppositions as the destruction of houses was necessary for the implementation of the project. **Elaborate discussions and collaboration with a wide range of stakeholders allowed to address the public's concern and increase the acceptability of the project**, which "not only improved flood protection and adaptability to climate change but also created opportunities for new housing developments Additionally, it ameliorated the spatial quality of the city as it offered a new river park for recreational use and for the citizens to enjoy" (Khamis, 2021).

7.2.3 Research & innovation

Given that cities are complex dynamic systems, **the development of knowledge, maps and data at a territorial scale** is a steppingstone for increasing their climate resilience. The **understanding of impacts** should cover both short-term and long-term effects of climate hazards on urban systems. This includes **the development of maps determining areas that are vulnerable to pluvial, fluvial, and coastal floods, zones in which the UHI effect is intensifying heat stress as well as areas that are at risks of various extreme weather events** such as wildfires, heavy storms, among others (Khamis, 2021). **When developing these maps, it is crucial to pay a particular attention to geographical and socio-economic factors increasing the vulnerability and exposure of the city**, such as the existence of fragile infrastructures as well as the concentration of people with low income in certain neighbourhoods as these could be more vulnerable due to a lower investment capacity to adapt to climate change.

The adoption of a 15-minutes city concept could allow to increase the climate resilience of a city. Concretely, the 15-minutes city concept emphasizes the importance **of decentralization within a city and having easy access to the main functions and needs of city residents.** This concept remains confusing to some as the scope of the "15-minutes" depends largely on adopted transport modes (i.e., 15 minutes by car is not the same as 15 minutes by bike). However, the concept usually focuses on soft or sustainable modes of transport. Indeed, one of the survivors of Christchurch Earthquake which took place in February 2011, advocates decentralization within a city. The survivor affirmed in a press review that "one thing the earthquake taught us is that you can't always rely on central services to survive"; adding, "you have to rely on things within walking distance, without a car or a laptop. If you build with that in mind, you build in a lot of resilience." (Anderson, 2014). This also applies to developing climate resilient cities, as due to extreme weather events, critical infrastructure systems such as transport, ICT, electricity, could be damaged.

7.2.4 Technical/Engineered solutions

Increasing the resilience of built cities and old towns is more challenging than building new climate-resilient neighbourhoods or structures (Khamis, 2021). **The maintenance of existing urban infrastructure systems is crucial** to assure resilient cities, especially that climate stressors undermine the efficiency of exposed systems, not to mention, cascading effects can "paralyze" an entire city (ITU et al., 2019). This stresses the importance of **developing knowledge and models depicting potential cascading effects. stakeholders.**

Figure 7.3 Metropol Parasol – Sevilla (Spain)

Source: Photo retrieved May 2, 2022, from https://www.vanupied.com/seville/monument-seville/metropol-parasol-ou-las-setas-a-seville-superbe-construction-organique-centre.html

Some measures could be integrated in the development of climate-resilient cities such as **the use of materials with high infrared emittance and solar reflectance) on pavements, roofs, and facades** (EEA, 2020a). Also, **shading devices or installations could be fitted across a city,** like the Metropol Parasol which was designed and constructed to shade the Plaza de la Encarnación in Sevilla (Spain) (Figure 7.3). **Other cooling features could be integrated to upgrade the existing urban systems in a way that permits mitigating UHI effects such as the installation of cooling fogs (Figure 7.4) or fountains, however it is important to make sure that these features do not increase water stress**. Not to mention, **buildings and facades could be renovated to integrate improved insulation**, however, the main challenge that lies in adopting this measure includes is inciting residents to invest thermal insulation as the city hall or a local government does not own all buildings within a city. Thus, the importance of the commitment of various actors.

Figure 7.4 Cooling fog systems

Source: Filtertech Company (Left) / Yonhap News Agency (Right)

7.2.5 Green/Nature-based solutions

The development of green-blue urban infrastructure systems has been advocated by many urban planners, climate researchers and environmentalists to increase the resilience of cities to various climate risks. Green infrastructures systems designate **green roofs, walls and fields, parks and pocket parks, fields and vegetation cover, among other green areas**, whereas blue infrastructure systems refer to **water elements in urban spaces such as canals, rivers, ponds, wetlands, or other**. Indeed, the development of blue-green infrastructure systems allow to attenuate the impacts of the UHI effect by reducing heat storage capacity and decreasing air temperatures through increased shading and evapotranspiration provided by greeneries and the cooling effect of water elements (EEA, 2020a). **Blue-green infrastructure systems also allow to increase the permeability of the ground, limiting flood risks**.

Figure 7.5 Big U Proposal – New York City (USA)

Source: Photo by Bjarke Ingels Group Architects

Also, to address sea level rise, some measures could be implemented such as the **stabilization of coastlines with beach nourishments and the adoption of the Living Shoreline Approach** (LSA) which consists of incorporating natural habitats and natural vegetation, sand and rocks to protect shorelines as an alternative approach to hard defences such as flood walls or other artificial flood defences.
As a case in point, to increase its resilience to heavy storms, floods, and sea level rise, and following the occurrence of hurricane Sandy which caused severe damages, the U.S. Department of Housing and Urban Development decided to launch an urban planning competition "Rebuild by Design" (Demeure, 2017). One of the winners of this competition aimed at finding solutions to preserve New York City is the BIG U project (Figure 7.5). The latter aims on protecting the sixteen kilometres of shoreline in lower Manhattan through the development of a "green ribbon" wrapping around the coastline and providing a floodable park acting as a buffer zone. The proposal considers **a revisited approach to protection from sea level rise, softening hard edges and replacing built flood barriers by nature-based solutions and green-blue infrastructure systems** providing spaces for social interactions. The project's plan was generated with inputs from the locals and residents.

In light of an increase urbanization**, the expansion of cities should be seen as an opportunity to increase their climate resilience through the development of new city districts that are climate resilient**. This includes the **use of new materials as an alternative to heat-trapping materials** like asphalt and concrete and **the inclusion of green-blue infrastructure systems in the design and conception of spaces** (Khamis, 2021). Also, **urban configuration changes could be considered such to limit urban heat island effect such increased building height and optimised street orientation. The reduction in building density also allows for that while limiting the mineralization of surfaces**. As a case in point, the municipality of Växjö (Sweden) cooperated with experts from the academic sphere and an international advisory company for the development of a new city district "Bäckaslöv," to accommodate residents in a constantly growing city. While the initial plan considered a traditional design approach with a road for vehicles and sidewalks for pedestrians, the landscape designer suggested **developing and adopting new city-design approaches promoting green-blue infrastructure systems**. Consequently, "**the traditional street plan was substituted by an asymmetric esplanade prioritizing social places and greenery in the streetscape"** (Khamis, 2021). For greening the Bäckaslöv city district, tree species were selected in discussions with experts and scientists at the Swedish University of Agricultural Sciences (Khamis, 2021). This stresses the importance of **selecting the right species when greening cities to avoid undesired effects** such as increased need for irrigation (especially in light of amplified stress on water resources and drought risks), and the introduction of invasive species to urban contexts.

Comparably, to increase the climate resilience of the city of Rouen, quartier Zac Luciline, **a new city "eco district",** covering an area of 9 hectares, **was developed integrating climate adaptation measures like the development of urban biodiversity, protection against flood risks, the reduction of UHI effect and increased reliance on renewable energy** (Moiroud-Musillo, 2014, Khamis, 2021) (Figure 7.6). **The projected increase in heavy was considered when designing the neighbourhoods, accordingly, various water retention basins, several channels and green areas were developed in the district**. The project integrates an environmental approach to urban planning centred on **transforming an industrial site to make it an attractive urban hub.** This approach to urban planning considers opportunities for sustainable urban development while limiting the impact of urban sprawl. As the project proved to be successful, the initiative is to be "replicated and scaled up to cover a brownfield of 90 hectares in the neighbourhood of Flaubert on the South Bank of the Seine River" (Khamis, 2021). This stresses the importance of **testing urban adaptation approaches at a street scale or a neighbourhood scale and replicating successful ones across the city**. Indeed, cities are seen and presented as laboratories for climate and environmental experimentations (Gordon & Johnson, 2017).

Figure 7.6 Ecoquartier Zac Luciline – Rouen (France)

Source: Khamis, 2021

In addition to governing climate change differently at a city scale, deploying efforts to engage various stakeholders, developing green-blue infrastructure systems, and changing the way cities are managed or conceived, other measures could be implemented to increase the climate resilience of urban infrastructure systems. Concretely, to increase the climate resilience of hospitals located in cities, and the health of city residents, measures listed in chapter 1 are to be considered. To increase the resilience of water systems to climate change, measures listed in chapter 4 could be adapted to an urban environment. Similarly, measures to increase the climate resilience of infrastructure systems as listed in chapter 6 could be tailored to an urban context. These measures include **investing in early warning systems**, **revising maintenance schedules**, **upgrading sewer systems**, **developing sustainable urban drainage systems**, **rainwater harvesting and the reuse of grey water, increasing the resilience of urban transport and ICT systems,** among others.

Table 7.1 Proposed adaptation measures to increase urban resilience

Types of adaptation solutions	Proposed Measures
Incentives/Governance/ Management	• Providing subsidies or other financial incentives to promote the development of technological and scientific urban climate solutions (by national, regional, and local governments. • Establishing collaboration and vertical communication lines between city governments, regional and national authorities to align adaptation efforts. • Developing horizontal working lines between a city's different departments. • Developing adaptation strategies and action plans at an urban scale. • Promoting decentralisation.

Communications & roundtable exchanges	• Making climate knowledge accessible and understandable by the public. • Organizing workshops with key stakeholders on the impacts of climate. • Bringing together city actors, researchers at the local university and people working in different sectors to work together.
Research & innovation	• Developing knowledge, maps, and data at a territorial scale. • Integrate scientific knowledge and climate projections in the design of the city • Developing knowledge and models depicting potential cascading effects. • Testing urban adaptation options at the street or neighbourhood level and replicating successful ones throughout the city. • Investigating and adopting the 15-minutes city concept to increase climate resilience of a city, through decentralisation inside a city and having quick access to the city's most important function.
Technical/Engineered solutions	• Maintaining existing urban infrastructure systems. • Installing materials with high infrared emittance and solar reflectance. • Installing and fitting shading devices across a city. • Developing cooling features to upgrade the existing urban systems. • Developing new city districts that are climate resilient (to accommodate new urban residents and anticipate projected expansions of cities). • Increasing building height and optimized street orientation to limit urban heat island. • Developing sustainable urban drainage systems.
Green/Nature-based solutions	• Developing of green-blue urban infrastructure systems. • Developing asymmetric esplanades prioritizing social places and greenery in the streetscape. • Stabilizing coastlines with beach nourishments and the adoption of the Living Shoreline Approach (LSA).

8.0 TOURISM

8.1 Impacts of climate change on Tourism

Tourism is a large and important economic sector, accounting for 9% of the world's GDP and an annual output value of over 5.5 trillion euros while providing livelihoods for more than 225 million people worldwide (Nicholls et al., 2014). Europe is the continent attracting the largest number of tourists globally every year (Amelung et al., 2009). Climatic factors affect the temporal distribution of tourists throughout the year and determines the environmental context (e.g., fauna, flora, resources such as snow, etc.) in which tourism activities develop (Moro et al., 2013). For some destinations, certain climatic features are marketed as attractions in themselves and are the main reason for tourists to visit the area.

Given the strict link between tourism and climatic factors, the tourism sector and associated leisure activities are particularly sensitive and can be directly and indirectly impacted by climate change (Drius, 2018). The direct impacts affecting the sector include extreme weather events, increasing temperatures, changes in precipitation patterns, damaging touristic complexes and facilities and making the destination less attractive to tourist. Indirect impacts of climate change consist of environmental changes such as loss of biodiversity and reduced landscape aesthetics (Thomas et al., 2011).

The tourism and leisure industry "falls among the most vulnerable industries worldwide" (Abbas et al., 2021). In fact, the COVID-19 crisis showed how the tourism sector is vital to the global economy and how it can be affected in light of crisis or changes. Concretely, because of the pandemic, travel, leisure, and inbound tourism activities dropped drastically causing around 2.86 trillion US dollars in deficits and more than 50% losses in revenues (Abbas et al., 2021). This underlines the importance of increasing the adaptive capacity of this sector considering various stresses, including climate change and linked environmental crisis.

8.1.1 Sea level Rise

The coast -particularly vulnerable to the rise of sea level- is an important part of the European cultural heritage accommodating many coastal historical sites that attract international and local visitors and tourists. As sea levels rise increases the risks of coastal erosion, tourism infrastructure and attractions are likely to be inundated. Concretely, thirty-seven of the forty-nine cultural heritage sites in the Mediterranean lowlands are at risk of flooding this century and forty-two are at risk of coastal erosion (Reimann et al. 2018). By 2100, coastal flooding may occur at least once a year along the Mediterranean and Black Sea coasts, and at least once a decade on the remaining European coasts, even under low-emission scenarios. (Vousdoukas et al. 2019). In Venice in November 2019, a 187 cm sea-level rise caused by a combination of high tide, heavy rain and wind flooded over 85% of the city. Venice could lose its World Heritage status if it does not have adequate flood protection, decreasing its tourist appeal (Scholz-Carlson, 2019). The rise of sea level is also linked to the deterioration of marine biodiversity and habitat destruction, such as coral bleaching (EEA, 2020a). This could make some travel destinations with beach sports and activities such as diving less appealing to tourists.

8.1.2 Floods

Flash flood risks may increase in the future due to changes in precipitation patterns and heavy rainfalls (EEA, 2020a). Flooding is a growing global problem, increasing in frequency and leading to property damage, economic losses, and fatalities. According to climate change projections, the population affected by floods yearly is estimated to increase by 530,000 people for a two degrees Celsius increase in global temperature and by 717,000 people for a high warming scenario. The expected annual damage is projected to increase to 12.5 billion euros and 17.5 billion euros in the respective future scenarios (Ciscar et al., 2018). The impact of floods on tourism has become an important and urgent issue worldwide. Floods can cause turbulence in the tourism industry and make tourism activities difficult and less profitable, for example, the 2002 flood in Prague reduced the number of visitors by a third and cancelled 30,000 domestic airline flight reservations (Mercia & Clinton, 2018).

8.1.3 Decrease in water flows and availability

In Europe, severe drought associated with rising temperatures and increased evapotranspiration is expected to have several consequences for the tourism sector (EEA, 2020a). Water resources play a key role in various forms of recreational activities. Drought directly affects winter sports, such as skiing and snowmobiles, because of reduced snow peaks. Snow cover in most European ski resorts, especially in lowland areas, is expected to deteriorate due to drought-related events with anomalous temperature rises (EEA, 2020a). Indeed, Studies conducted in France, Italy and Germany show a general decrease in the length and thickness of snow cover (IPCC, 2019). This change is not uniform and depends on the geographical location of the territory, its altitude, and other local factors. Yet, overall, the flow of tourists and overnight stays in most skiing areas in Europe is likely to witness a decrease (Nicholls et al, 2014). Furthermore, droughts are expected to have impacts on river flow with ramifications on rivers and lakes activities, such as boating, rafting, canoe rowing, fishing, and swimming (Thomas et al., 2011). It is also likely to lead to damages to the environment and biodiversity, making some touristic places and hiking trails less attractive, leading to a reduction or shift seasons for these activities.

8.1.4 Heat stress & Increased temperatures

Climate change is expected to increase the frequency and intensity of heatwaves in Europe by the end of the century, resulting in hotter days and nights (IPCC, 2014). This is expected to have considerable effects on tourism, especially in the south of Europe and the Mediterranean coast due to elevated atmospheric humidity values, as it could lead to the discomfort of tourists and influence the demand on destinations (Nicholls et al., 2014). Although the Mediterranean Region might experience a decrease in tourism activities in summer months, this decrease is likely to be offset by a growth of visitors in the spring and autumn (Nicholls et al., 2014). Northern countries could probably benefit from increasing temperatures as it could offer new opportunities due to milder weather conditions (Obrador et al., 2009; Shihan & Kirilenko, 2019).

8.1.5 Wildfires

Extreme weather events such as wildfires, windstorms and landslides have become more frequent and are projected to increase in frequency and intensity the coming decades due to climate change (IPCC, 2019). Extreme and climatic disasters impact the tourism sector as it affects transport facilities, critical infrastructure systems, attractive landscapes, and tourists' safety, which could eventually lead to reducing the flow of tourists (Becken, 2010).

Concretely, hot temperatures exacerbated by extreme drought could lead to more severe forest fires. For example, in southern Europe, the fire season is expected to be longer, and the number of fire days are likely to increase. Wildfires can result in fewer visits, cancelled hotel stays, and fewer vacation bookings (Otrachshenko & Nunes, 2019). Fires also deteriorate the natural environment making the territory less appealing to visit. The Mediterranean basin is the most vulnerable region to wildfires in Europe. In fact, about half of the largest fires in Europe over the past decade have occurred in Spain and Portugal, destroying about 90,000 hectares of forest each year (Hoinka et al. 2009). Portuguese authorities expect the impact of the wildfires to cost local tourists between €17.03 and 24.18 million and inbound tourists between €18.26 and 38.08 million by 2030 (Otrachshenko & Nunes, 2019).

Figure 8.1 Blaze spreading up the hill in the Aegean coastal town of Oren (Turkey)

Source: STR/AFP

8.2 Adaptation Response measures to increase the resilience of the tourism sector to climate change

8.2.1 Incentives/Governance/Management

The development of adaptive capability helps sectors and organizations to capitalize on climate change opportunities or benefits, such as a longer growing season or improved tourism potential (Simpson et al., 2008). Climate adaptation in the tourism and leisure industry is a complex collection of adjustments done at various geographical and temporal dimensions by many stakeholders. It can be undertaken by communities, organizations, individuals, and governments and can be driven by economic, social, or environmental factors (Njoroge, 2015). It is important to keep in mind that tourists and travellers have different purposes to visit a destination, it could be summer-based or winter-based recreation tourism, to practice a specific sport, ecotourism, cultural, urban, or even health tourism. This stresses the importance of **adopting a systemic approach when increasing the resilience of the sector**. **Increasing the capacity of local tourism operators (e.g., casinos, parks, ski areas, etc.), communities, resorts and hotels, tours operators, transport providers, travel agents and tourism is needed**. Some adaptation measures require short response time (e.g., coping measures of tourists, changes in destination choices, etc.) while others require long-term investments such as infrastructure modification and policy changes for transformational adaptation sector (Scott et al., 2009)

The development of adaptation strategy permits to determine the efforts needed to maintain commercial viability of tourism and leisure businesses considering the impacts of climate change. Concretely, businesses can **develop an analysis or adopt another strategic and planning management techniques to identify the opportunities and threats of the business or activity considering climate**

change. In this context it is important to underline that some climate impacts could have positive effects on businesses and adapting to climate change entails **profiting from opportunities that may arise**.

The preservation of the environment is a key feature to maintaining the aesthetic of the territory while increasing its climate resilience. The implementation of this measure requires the **collaborative effort of various stakeholders**. Concretely, the government have the responsibility to **develop regulations protecting ecosystems** and tourism operators and businesses need to **invest in sustainable operations that respect the environment while assuring the implementation of regulations in place.** They could for instance **monitor tourist visits and activities in natural areas** so to prevent their degradation and to limit forest fires risks. Also, tourists have the duty to protect the natural spaces they visit. **Some incentives or dis-incentives could be put in place to nudge tourists to adopt the right practices such as the adopting of a fining system for the enforcement of regulations, the promotion of eco-systems underlining the importance of natural environments, billboards, signs, and educational campaigns/**

In the south of France, the Massif des Calanques is considered an attractive touristic destination for beach and nature lovers. When weather conditions create unfavourable visiting conditions (e.g., high winds, risks of forest fires, etc.) **visitors are alerted ahead of time**. When the risk is considered high, **the access is prohibited by a prefectural decision**, limiting the demand, thus the exposure of tourists to risks (Figure 8.2). **A mobile application and a website are in place to communicate on climate risks** and the access to the Massif des Calanques conditions in real time.

Figure 8.2 Board underlining elevated risk of forest fires and banning entry to the Massif des Calanques – Marseille (France)

Source: AFP/ Gerard Julien

8.2.2 Communications & roundtable exchanges

The understanding of impacts of climate change is crucial, thus the importance of **raising the awareness of tourism business owners on the ramifications on climate impacts on the sector.**

Climate change is likely to impact the global travel economy, resulting in both winners and losers. When compared to locations and tourist providers, consumers are seen to be the most adaptable to climate change. The competitiveness of businesses will depend largely on tourist preferences, their travel patterns as well as the activities in which they indulge in (Njoroge, 2015). **Communicating key information on climate risks and increasing the awareness of tourists** (demand-side) can increase their awareness their coping capacity in the event of climate-related events. This could take the form of **awareness campaigns on likely risks, billboards, and maps identifying areas of interests, protected areas, and areas with high risks.**

Figure 8.3 Sign indicating for visitors to limit their impact on the environment

Source: Photo retrieved May 6, 2022, from https://www.enicbcmed.eu/crossdev-what-sustainable-tourism-definition

8.2.3 Research & innovation

Tourist operators need to continue developing strategies to satisfy changing market demands in various places. For example, to adapt to reduced ski season and compensate for the linked losses, **businesses can diversify their offers and provide all-year round tourist activities**, such as the hiking, camping, paragliding, rock climbing, mountaineering, among others. Similarly, to adapt to monsoon or hurricane seasons, increased temperatures, or the increase in frequency and intensity of extreme weather events, **indoor and non-climate sensitive touristic activities could be promoted.** As a case in point, in Thailand, tourism operations have focused on developing non-climate sensitive tourism attractions to maintain touristic attractivity even during monsoon season, such as health and wellness spas, study tours on Thai culture (e.g., cooking, religion, and language classes), indoor entertainment complexes with Thai cultural performances, and shopping (Scott et al., 2009).

Furthermore, the scientific community play a key role in developing studies and research allowing for the sustainable development of the tourism sectors. The **monitoring of biodiversity** is also essential, such as **examining the evolution of species frequenting the territory** (flora and fauna), to limit the risks of parasites and invasive species (e.g., Figure 8.4).

To cope with the impact of extreme sea surface temperature, impacting the occurrence and severity of coral bleaching. The great barrier reef marine park authority and the Australian ministry of tourism the development of the coral bleaching response plan to: **improve the ability to forecast bleaching risk**, **provide early warnings of major coral bleaching events**, and **evaluate the implications of bleaching events for tourism management policy and strategies**.

Figure 8.4 Survey of bleached reef done by diver – Great Barrier Reef (Australia)

Source: Centre of Excellence for Coral Reef Studies

8.2.4 Technical/Engineered solutions

The development of the tourism sector should not create a conflict of interest with residents such as increased drought risks due to high water consumption for tourism and leisure activities. To address these conflicts, **hotels and resorts should adopt systems limiting the waste of water**. For example, they could **upgrade their drainage to a sustainable drainage system (SDU) separating grey water streams from black water stream**s, they could **update their sanitary devices and systems to ones that permit to save water (e.g., dual flush triggers, sensor-based faucets, low flow faucet aerators and shower heads, etc.).** Tourism complexes could also **retrofit their buildings to integrate thermal insulation increasing the comfort of users while avoiding maladaptation practices such as the high reliance on heating and cooling systems**. Businesses could not be motivated to make these investments as they could seem hefty, thus the importance of highlighting and underlining the link between climate adaptation investments and financial savings, while developing incentives (e.g., aid schemes and free consultations).

The development of new tourism and leisure complexes should consider climate change. Concretely**, developments should be discouraged in high-risk areas** (e.g., areas at flood risks, areas at risk of forest fires, etc.). **Also, an appropriate orientation of new tourism buildings and complexes should be considered to increase the potential for natural ventilation and achieve thermal comfort without the need for artificial cooling or heating. Furthermore, SDU as well as other systems, fixtures or mechanisms allowing to limit the stress on water resources should be integrated in the design of tourism facilities.**

Some adaptation solutions have been considered by various businesses and tourism operators to address climate challenges such as installing air conditioning units to increase the climate comfort of tourists in summer months or artificial snowmaking to extend ski season. However, these solutions are not sustainable ones as they only aggravate the situation because of their high carbon footprint. Therefore, it is important to develop sustainable adaptation solutions, considering the long-term viability of the sector; especially that climate and the environment are key determinant factors of a territory's attractivity for tourists. **The development of sustainable solution to tourism adaptation seeks the**

maintenance of environmental integrity, social justice and economic growth for local community and their involvement in the decision making is key.

8.2.5 Green/Nature-based solutions

Figure 8.5 Beach nourishment in Florida (USA) for attraction of tourists

Source: Photo retrieved May 6, 2022, from https://www.martin.fl.us/beach-nourishment

It is also important to mention that measures allowing to increase the adaptive capacity of the territory could serve to increase the aesthetics and appeal of the territory attracting tourists. For instance**, beach nourishment and sand replenishment allow on one hand to address the impacts of coastal erosion and storm surge**s, while providing and developing an area for recreational and tourism purposes. This adaptation approach involving the artificial placing of sand or gravel on eroded beaches to protect the coast has been adopted in various countries, notably the Netherlands, the USA, Italy, and Croatia (Figure 8.5) (Brand et al., 2022).

To conclude, it is important to consider that the adaptability of the tourism sector is strictly linked to other sectors, thus the importance of **adopting a systemic approach**. **A climate resilient health system could increase the potential of health tourism**, **the development and implementation of good adaptation and environmental practices attract visitors interested in eco-tourism**, and **the adaptation of agriculture, fisheries and aquaculture systems is crucial for assuring food security for restauration**. Indeed, gastronomy and exploration of food is a vital component for tourism as the purpose of tourism. It is considered a vital component of the cultural-tourism experience. For instance, in Galicia, fisheries and aquaculture have a substantial impact on local economic and tourism (García Negro et al., 2018). To add to that, **adapting water and critical infrastructure systems to climate change and developing climate resilient cities is essential to ensure the continuity of essential services that are crucial for tourism**. Therefore, the adaptation measures listed in all the chapters above allow to increase the climate resilience of tourism in each territory.

Table 8.1 Proposed adaptation measures to increase the resilience of tourism sector

Types of adaptation solutions	Proposed Measures
Incentives/Governance/ Management	• Adopting a systemic approach to managing the activities of the tourism sector. • Developing regulations protecting ecosystems.

	• Inciting investments in sustainable operations that respect the environment while assuring the implementation of regulations in place. • Planning for climate resilient cities to ensure the continuity of essential services that are crucial for tourism. • Discouraging new touristic site development in high-risk areas. • Developing incentives or dis-incentives to nudge tourists to adopt the right practices such as the adopting of a fining system for the enforcement of regulations. • Inciting hotels and resorts to adopt systems limiting the waste of water (e.g., water pricings, subsidies for retrofitting of water fixtures, etc.).
Communications & roundtable exchanges	• Raising the awareness of tourism business owners on the ramifications on climate impacts on the sector. • Communicating key information on climate risks and increasing the awareness of tourists. • Promoting eco-systems and underlining the importance of natural environments through billboards, signs, and educational campaigns.
Research & innovation	• Identifying the opportunities and threats of the business or activity in light of climate change. • Developing indoor and non-climate sensitive touristic activities could be promoted. • Investigating the potential of businesses offer diversification to provide all-year round tourist activities. • Improving the ability to forecast climate risks and provide early warnings for major events and evaluating the implications of these events on tourism management policy and strategies. • Monitoring biodiversity, for example assessing the evolution of species frequenting in the territory.
Technical/Engineered solutions	• Retrofitting of hotel buildings and touristic complexes. • Considering appropriate orientation fir new tourism buildings and complexes to increase the potential for natural ventilation (passive cooling architecture). • Integrating thermal insulation increasing the comfort of users while avoiding maladaptation practices. • Adapting water and critical infrastructure systems to climate change.
Green/Nature-based solutions	• Promoting and developing eco-tourism. • Developing and protecting natural areas, wildlife and marine reserves. • Enhancing coastal areas through beach nourishments and sand replenishments allow to address the impacts of coastal erosion and storm surges. • Adapting agriculture, fisheries and aquaculture systems is crucial for assuring food security for restauration.

9.0 CONCLUSION

To summarize things, the different sectors of the economy and key community systems are impacted by climate change, with cascading effects that could paralyze territories, regions and have serious ramifications on the local and international economy. To increase the climate resilience of these sectors various measures are needed. Adaptation solutions could be managerial, governmental, technical or nature based. Some adaptation measures are implemented to cope and recover following the occurrence of extreme weather events, which are expected to increase in frequency and intensity due to climate change. Nonetheless, changes in practices and transformational adaptation measures are crucial to avoid being locked in a situation in which doing the same things will yield to same results.

A systemic approach to increasing adaptation is important as the sectors are interdependent. For instance, ensuring climate resilient water sector and critical infrastructure systems is crucial across all sectors. Similarly, adapting ecosystems and natural environment to climate change is essential for increasing the climate resilience of health, agriculture, fisheries, and aquaculture sectors. Not to mention, the preservation of natural environments permits to increase the resilience of cities and assure the sustainability of tourism sector.

The catalogue proposes solutions that are particular for each sector. However, it is important to note that many of the proposed solutions are transversal and have co-benefits. For instance, the stabilization of coastlines with beach nourishments increases the climate resilience of coastal territories, cities, infrastructures systems, aquifers, agricultural fields while boosting the potential of tourism. Thus, the importance of moving away from working in silos and the creation of synergies across various sectors. The promotion of co-benefits of climate adaptation measures allows on one hand to increase the acceptability of adaptation measures, to increase the efficiency of measures and make investment more attractive (Khamis, 2021).

Although some measures are particular to specific sectors, a general methodology can be laid out that corresponds to all different sectors. This methodology, consists of 7 critical steps as determined by Khamis (2021) including: 1) understanding impacts and vulnerabilities (scientific knowledge and awareness raising) , 2) developing adaptation strategies (laying out adaptation options), 3) implicating and mobilizing actors (collaborative governance), 4) implementing developed strategies (prioritizing actions, mobilizing investments), 5) monitoring and evaluation (to determine the need for corrective actions), 6) understanding success and limiting factors (to scale up successful initiatives and address challenges) and 7) improving the governance system in place.

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Climate change impacts are here and now. The impacts on people, prosperity and planet are already pervasive but unevenly distributed, as stated in the new EU Blueprint strategy (European Commission-EC, 2019). To reduce climate-related risks, the EC and the IPCC agree that transformational adaptation is essential. The TranformAr project aims to develop and demonstrate products and services to launch and accelerate large-scale and disruptive adaptive process for transformational adaptation in vulnerable regions and communities across Europe.

The 6 TransformAr lighthouse demonstrators face a common challenge: water-related risks and impacts of climate change. Based on existing successful initiatives, the project will develop, test and demonstrate solutions and pathways, integrated in Innovation Packages, in 6 territories.

Transformational pathways, including an integrated risk assessment approach are co-developed by means of 9 Transformational Adaptive Blocks. A set of 22 tested actionable adaptive solutions are tested and demonstrated, ranging from nature-based solutions, innovative technologies, financing, insurance and governance models, awareness and behavioral change solutions.

TransformAr

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