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D3.1 – Climate risk assessment framework

Regions 4Climate

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List of Acronyms

AR	Assessment Report
AST	Adaptation Support Tool
IPCC	Intergovernmental Panel on Climate Change
CDD	Consecutive Dry Days
CLIMAAX	Climate Risk Assessments for every European Region
CRA	Climate Risk Assessment
DG CLIMA	Directorate-general for Climate Action of the European Commission
DRMKC	Disaster Risk Management Knowledge Centre
EEA	European Environment Agency
EUCRA	European Climate Risk Assessment
PCA	Principal Component Analysis
SPAM	Spatial Production Allocation Model
UNDRR	United Nations Office for Disaster Risk Reduction
WASP	Weighted Anomaly of Standardized Precipitation

List of Tables

List of Figures

Keywords list

- Risk assessment frameworks
- Hazard, exposure, vulnerability, response and risk

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Table of Contents

Executive summary

This deliverable is part of the Regions4Climate (R4C) project, in fulfilment of the Grant Agreement number 101093873. Its objective is the provision of the Climate Risk Assessment (CRA) framework (deliverable 3.1) that will establish how risk analysis are developed in R4C's Task 3.1.

The deliverable firstly presents a review and comparison between the most relevant CRA frameworks and highlights new developments in CRA field as well as the evolution of the most relevant concepts during the last decades. The current understanding of risk comes from the IPCC, which understands risk as the dynamic interactions among climate-related hazards, the exposure and vulnerability of affected human and ecological systems, and responses. The latter term of response is the new component introduced in sixth assessment report (IPCC, 2022) and allows climate action to be reflected within the risk framework. In line with this, several frameworks have emerged in the last years, such as the one proposed by the UNDRR, (2022) or the one developed by the European Environment Agency (EEA). Both frameworks locate risk at the center of the framework and propose a common sequence to assess risks, namely risk identification, risk analysis and risk evaluation.

Another framework to highlight is CLIMAAX, which is a Horizon Europe project and is currently under development. CLIMAAX project is not only one of the reference projects in relation to the considered CRA frameworks, but there is a wider collaboration with the project (e.g. by attending its events). The aim of CLIMAAX is to provide a harmonised framework to support European regions in their climate risk assessment. It also makes available a risk analysis tool, that contains models, data and utilities to support regions in their risk assessment. It comprises a total of seven methodologies (the so-called risk workflows), namely floods, drought, exposed drought population, wildfire, storm, blizzard and snowfall.

The R4C framework builds upon the terms and concepts of these frameworks. Risk takes a central role in the framework and is understood in the same way as defined by the IPCC. This means that risk is referred as the potential for adverse consequences for human and ecological systems triggered by the interactions of climate-related hazards with the vulnerability, exposure of human and natural systems, and responses. Besides, climate change is understood as the underlying risk driver in the framework and other underlying risk drivers altering vulnerabilities and exposure are also considered, such as changes in population and land use.

On the other hand, the deliverable identifies a set of key risks to be considered in the risk analysis. This selection builds on several criteria (i.e. alignment with R4C societal challenges, assessment of region gaps and priorities for CRA, alignment with CLIMAAX project and data needs). The proposed key risks correspond to coastal flood on built environment, heat stress on population and droughts on agriculture activity. The final selection of these key risks will be carried out over the next months, and it will depend on the availability of data. The methodology to carry out their risk assessment will be based on the risk workflows of CLIMAAX as well as other European relevant projects, such as the ESPON CLIMATE.

1. Introduction

In the last decades, a variety of frameworks have been developed related to climate risks assessments (CRA). Since the IPCC AR5, conceptual concepts and terms have evolved and therefore, risk assessment frameworks. According to the latest scientific developments in CRA field, a proper design of a CRA depends on several factors, such as the recognition of the complex nature of risks and its uncertainties, the use of multidisciplinary approaches for a more holistic CRA, the assessment of exposure and vulnerability dynamics, among others. Currently, these factors are gradually being incorporated into CRA; however, there are still gaps to be filled.

The objective of this deliverable (D3.1), which falls under the WP3, is to develop the framework for the holistic vulnerability and risk assessment of R4C project. This framework is built on the outcomes of the project funded under HORIZON-MISS-2021-CLIMA-02-01 (CLIMAAX project). CLIMAAX transfers the state-of-the-art of CRA frameworks into a harmonized framework to support European regions and communities to better understand their climate change related risks. Besides, the R4C framework is complemented with other relevant frameworks (e.g. IPCC AR6, 2022) and UNDRR, 2022) and European projects (ESPON CLIMATE Update, 2022 and PESETA IV, 2020; among others); in this sense, new concepts emerging in the field of CRA are incorporated in the framework in line with the latest developments in this field.

The vulnerability and risk assessment of R4C framework puts risk at the centre of the framework and is understood as the dynamic interaction of climate-related hazards (including hazardous events and trends), vulnerability, exposure, and response. The incorporation of the latter term (i.e. human responses to climate change) into the risk analysis, as well as the dynamic nature when characterizing the exposure and vulnerability of regions, make the framework innovative. On the other hand, its linkage to the D4.1 "Regional Resilience Maturity Model and Framework" as well as to the D2.2. “Just transition framework” through indicators that characterize the response component, makes the regional-scale vulnerability and risk assessment of R4C being holistic and just.

The following deliverable is organized as follows. Section 2 presents a revision of the most relevant CRA frameworks highlighting the key conceptual terms and their evolution over the last decades. Within the different frameworks, particular reference is made to the CLIMAAX framework, which provides a robust and coordinated framework at European level for consistent, harmonised, and comparable risk assessments. Section 3 introduces a summary of methodologies to apply CRA frameworks, which depend on the complexity of selected risks and the resources available. Section 4 describes the CRA framework of R4C and the sequence for the development of the framework, which is divided in: scoping, risk identification and risk analysis. Scoping prepares the ground for the assessment, defining several aspects, such the objective, scope, scale of analysis, climatic scenarios, and temporal periods. Risk identification includes a first proposal of key risks. Risk analysis provides the methodologies to carry out the CRA of these potential key risks, which incorporate the last term of the IPCC (i.e. the response component) making the R4C CRA innovative and providing ideas for the development of the next generation of CRA frameworks. Finally, Annex 1 provides an analysis of the potential GAPs and priorities of the R4C regions in their knowledge of risks and vulnerabilities of climate change and Annex 2 presents the questionnaire template.

2. Current CRA frameworks

The assessment of climate vulnerability and risk has undergone conceptual changes and developments leading to a variety of climate risk assessment frameworks. In some cases, this variety of frameworks differs in forms and even in the terminology used, thus it poses a challenge for the different actors and organisations involved in the assessment of climate risks. This section focuses on the most relevant Climate Risk Assessment (CRA) frameworks. It summarises each of them, highlighting the most relevant terms with the aim of establishing the baseline for the development of the Regions4Climate CRA framework.

2.1. IPCC

The CRA proposed by the Intergovernmental Panel on Climate Change (IPCC) is the main framework embraced by the scientific community on CRA. The concepts and definitions of this framework have evolved as knowledge in this field has grown. The early view of CRA reflected in the IPCC's Fourth Assessment Report (AR4) (IPCC, 2007) posed the focus on vulnerability, but since the publication of the IPCC's Fifth Assessment Report (AR5) (IPCC, 2014) the concept of risk has advanced forefront, recognising the diversity of values and objectives associated with human and ecological systems (Figure 1).

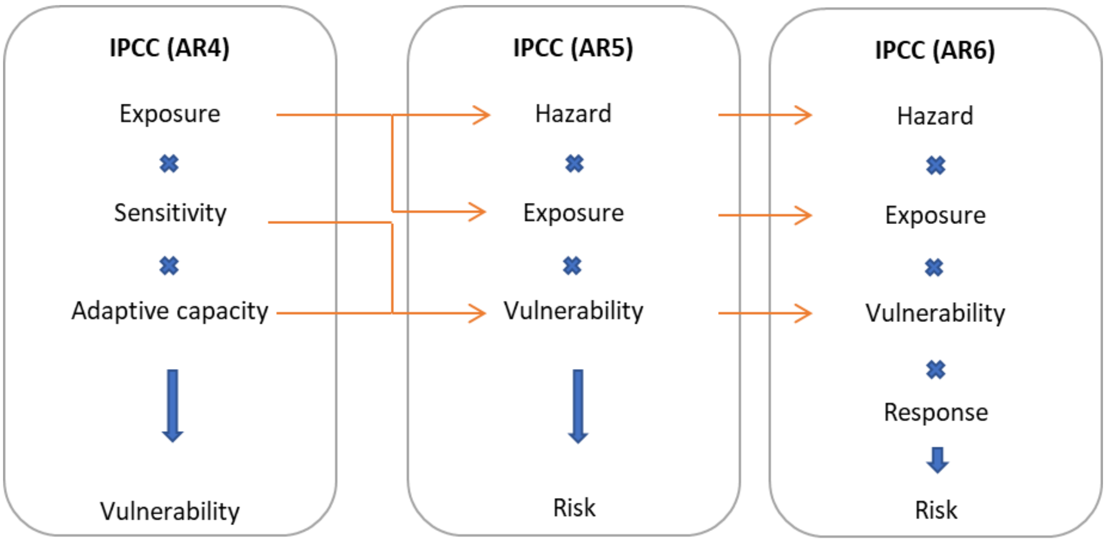

Figure 1. The shift of concepts from AR4 where vulnerability plays an important role to AR5 and AR6 where risk is in the center of the CRA framework.

According to the IPCC, risk, defined as the potential for adverse consequences for human and ecological systems, is resulted from the interactions of climate-related hazards (including hazardous events and trends) with the vulnerability and exposure of human and natural systems. The definitions of these concepts that contribute to the understanding of risk are described below according to AR5 (IPCC, 2014):

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

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

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

Recently, the IPCC Sixth Assessment Report (AR6) (IPCC, 2022) has built on the risk-focused framing of the AR5 and, like AR5, considers that risk results from a variety of interactions among climate-related hazards, the exposure and vulnerability of affected human and ecological systems. Besides, it includes the adaptation-related **responses** within the risk framing to modulate the determinants of risk. These responses vary across regions and sectors, with technology and infrastructure responses being the main types of response recorded in Europe (**¡Error! No se encuentra el origen de la referencia.**). The inclusion of them into the framework provides insight into how climate action contributes to risk reduction. In this sense, it allows monitoring of the actions undertaken and their effectiveness.

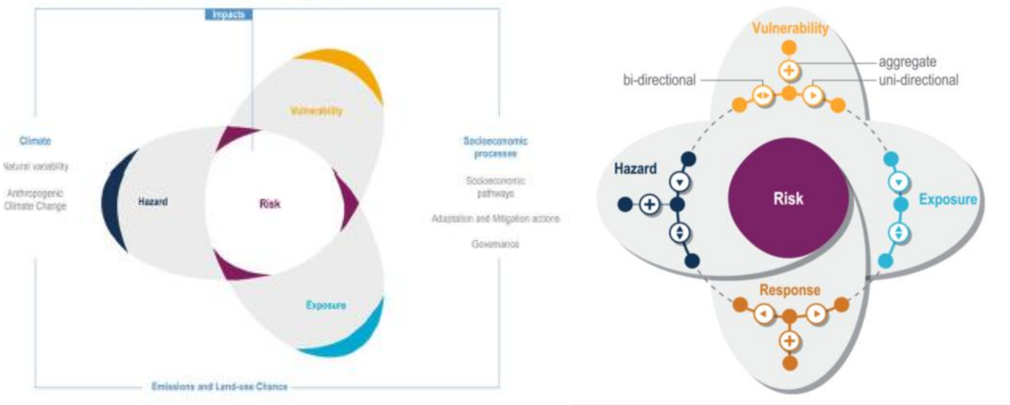

Figure 2. The climate risk assessment frame of AR5 report and the new AR6 framework with response added as a new risk determinant (IPCC, 2022).

On the other hand, AR6 has recognised other concepts that contribute to a proper understanding of risk. These emerging terms refer to:

- **The inherent complex nature of climate risks.** According to AR6, climate risk is inherently complex. Currently risk assessment approaches are beginning to tackle this complexity; however, there is still not a consistent framework and multiple terms have been used to describe complex risk. The complex nature of risk is central in the AR6 and refers to multiple stressors unfolding together, cascading or compounding interactions, and non-linear responses and the potential for surprises.

- **The evaluation of key risks.** The evaluation of key risks in AR6 expands significantly from previous reports. AR6 evaluates key risks across sectors and regions applying four criteria: magnitude of adverse consequences, likelihood of adverse consequences, temporal characteristics of the risk, and ability to respond. On the other hand, there is a more explicit recognition that key risks evolve constantly and can result not only from climate change, but also from changes in the exposure and vulnerability, and from human responses to climate change (e.g., a poorly planned and mismanaged adaptation efforts). Finally, the report clusters key risks into 8 representative key risks, and these are particularly looked at the AR6 report.

2.2. UNDRR

The CRA framework developed by the United Nations Office for Disaster Risk Reduction (UNDRR, 2022) is built on the concepts of the IPCC and presents the following similarities:

- Risk is located at the **centre of the framework**, and is determined by exposure, vulnerability and hazards, which vary through space and time.

- Like IPCC, risk is understood as the **potential for adverse consequences for human or ecological systems**. Additionally, the UNDRR recognizes the importance of considering the full spectrum of climatic (extreme weather events and slow onset processes) and non-climatic hazards when assessing risks, whereas the IPCC focuses on climatic hazards.

- Risk assessment in the context of climate change requires a **comprehensive**, systemic perspective on risk and its underlying drivers due to the complex and partly systemic nature of climate-related risks.

- **Risk-informed decision making and planning (i.e. adaptation and risk reduction options),** which is related to IPCC's fourth component (i.e. response), is integrated into the framework and linked to the climate assessment.

Figure 3 shows the UNDRR framework for CRA and planning in the context of climate change. In the upper part, the components to make a comprehensive risk assessment are presented, while in the lower part the risk-informed decision making and planning is shown, which is the context to codesign and implement the CRA.

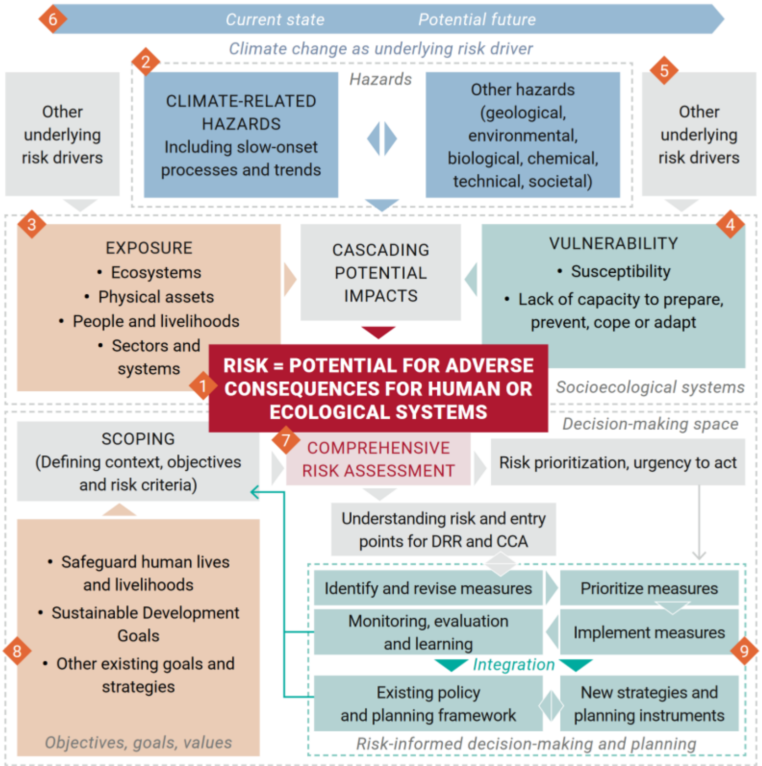

Figure 3. Framework for climate risk assessment of UNDRR (UNDRR, 2022).

According to the UNDRR and in line with the ISO31000, the recommended phases to develop a proper CRA are risk identification, risk analysis and risk evaluation. These phases prepare the ground for risk assessment, which involves selecting and implementing options for addressing and reducing risk (Figure 4):

- **Risk identification**, which is based on existing knowledge (e.g., event databases on losses and damages, expert and stakeholders' input, among others), is about identifying the most relevant hazards, impacts and risks, that will be considered in the risk analysis.

- **Risk analysis** aims at analysing the interrelated determinants of risk (hazard, exposure and vulnerabilities), understanding the resulting cascading impacts and describing the potential for adverse consequences. For this purpose, it is important to recognise the complex nature of risks and is recommended the use of so-called impact chains. Based on cascades and risks conceptualization, the phase ends by assigning risk levels (e.g., from very low to very high). The use of a common classification scheme allows the comparison of risks within a sector and across sectors, regions, and time.

- **Risk evaluation** is the last phase of the risk assessment, and its aim is to support decisions. Currently, this step is underdeveloped in CRA and there are few studies that address, such as the United Kingdom's climate change risk assessment.

Figure 4. Phases to develop a risk assessment (UNDRR, 2022).

2.3. The Adaptation Support Tool

The Adaptation Support Tool (AST) of the European Climate Adaptation Platform Climate Adapt provides a cyclical and iterative process to develop, implement, monitor and evaluate climate change adaptation strategies and plans (Figure 5).

Figure 5. CLIMATE-Adapt adaptation cycle.

CRA is the second step of this process and is built upon the terminology and concepts of the latest report of the IPCC (AR 6). As well as the UNDRR, it recommends the use of impact chains to conceptualize climate risks and proposes a general sequence to carry out the CRA, that slightly differs from the UNDRR. This sequence is based on a five-step procedure. Firstly, the objective, the context and the scope of the assessment are defined (I). Then, a selection and prioritization of risks are made (II). For each selected risk, additional data is acquired (III) and a specific risk assessment is carried out (IV). Finally, overarching risks and risks hot spots are identified (V).

2.4. ESPON CLIMATE

ESPON is an EU funded applied research program that delivers quality expertise regarding actual policy needs. ESPON CLIMATE project is one of the Applied Research Projects that are assessed within the program. It is aim at developing evidence to understand how and to which extent climate change will impact the competitiveness and cohesion of all European regions.

The latest report called ESPON CLIMATE Update (ESPON, 2022) provides a comprehensive risk assessment based on the latest IPCC conceptual framework (Figure 6). . This conceptualization is aligned with the most relevant European initiatives, which are crucial in the new European Adaptation Strategy framework, such as JRC PESETA IV report, the Risk Data Hub of the Disaster Risk Management Knowledge Centre (DRMKC), Climate Adapt Portal and its European Climate Data Explorer or the Climate Data Store from the Copernicus Climate Change Service.

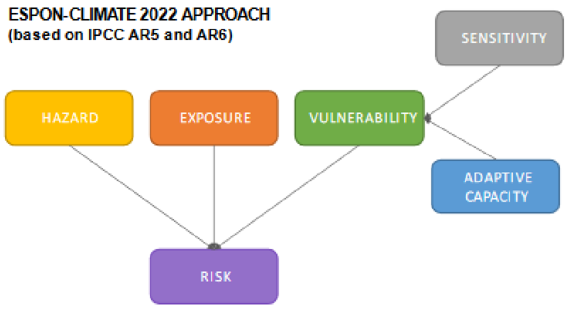

Figure 6. ESPON-CLIMATE risk conceptualization

Recently, ESPON CLIMATE Update has been used as selection criteria within Pathways2Resilience project (a flagship project under the EU Mission on Adaptation to Climate Change) to prioritize regions with higher vulnerability and climatic risks.

2.5. European Climate Risk Assessment

The European Climate Risk Assessment (EUCRA) seeks to complement the existing knowledge regarding climate-related hazards and risks in Europe. The Directorate-general for Climate Action of the European Commission (DG CLIMA) and the European Environment Agency (EEA) are behind this initiative, which will be published in 2024.

The general approach for risk analysis is built on the concepts of the IPCC and follows the UNDRR 2022 framework as seen in Figure 7. It will address current and future climate change key risks for eight selected systems and sectors (e.g. “biodiversity and ecosystems”, “food security”, and “human health”) and it will focus on key compound risks across sectors and regions (e.g. disruption of international supply chains or financial instability).

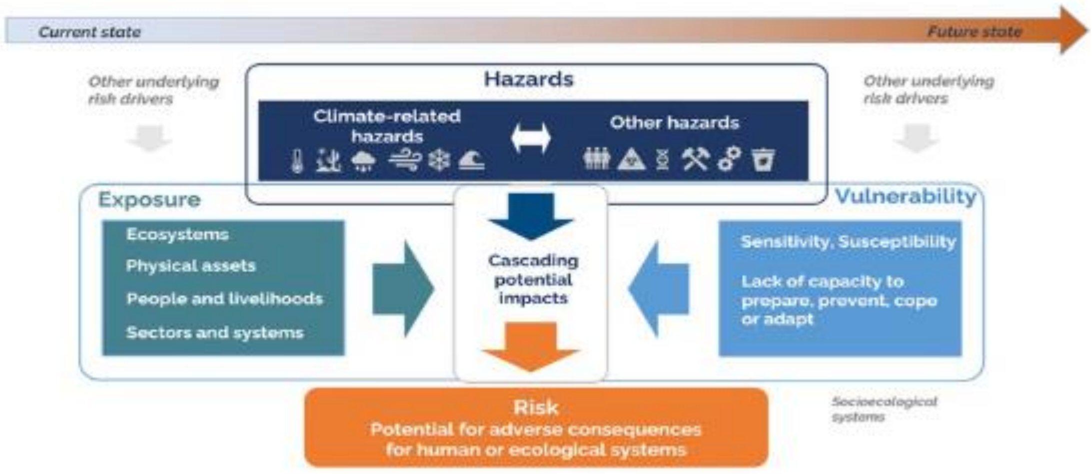

Figure 7. EUCRA's CRA framework

Besides, EUCRA will evaluate the urgency for EU action with the aim of supporting the identification of adaptation-related policy priorities for the next EU policy cycle, informing the further development of EU policies in climate-sensitive sectors and prioritising adaptation-related investments. In this sense, it will follow the sequence proposed by the UNDRR (2022) to develop an appropriate CRA, which as previously mentioned corresponds to risk identification, risk analysis and risk evaluation (Figure 4).

2.6. CLIMAAX Framework

CLIMAte risk and vulnerability **A**ssessment framework and toolbo**X** (CLIMAAX) is a Horizon Europe project, that provides a robust, coordinated, and standardized CRA framework for a consistent, harmonised, and comparable climate risk assessment on a regional scale across Europe.

CLIMAAX builds upon the on state-of-the-art literature and the latest scientific developments related to risk assessment frameworks, methods, and tools. It contributes to the EU Mission on climate adaptation, which aims at supporting EU regions, cities and local authorities in their efforts to build resilience against climate change impacts. By 2030, the Mission will support European regions and communities to better understand, prepare and manage climate risks and opportunities; work with 150 regions and communities to accelerate their transformation towards a climate-resilient future and deliver at least 75 large-scale demonstrations to build deep resilience.

The CLIMAAX project is framed at the base of the pyramid, providing guidance for the development of comprehensive risk assessment, while Regions4Climate project is located at the upper part of the pyramid triggering systemic transformations to climate resilience across European regions.

Figure 8 presents the CLIMAAX framework. This framework proposes five risk assessment steps (scoping, risk identification, risk analysis, key risk assessment and monitoring and evaluation) within an iterative climate risk assessment cycle and highlights three conceptual pillars (principles, technical choices, and participatory processes). Beyond this, CLIMAAX develops in parallel a practical toolbox within the risk analysis phase. This toolbox is structured as a sequence of workflow and comprises a set of risk workflows (i.e. floods, drought, exposed drought population, wildfire, storm, blizzard and snowfall) to carry out regional and local multi-risk assessments.

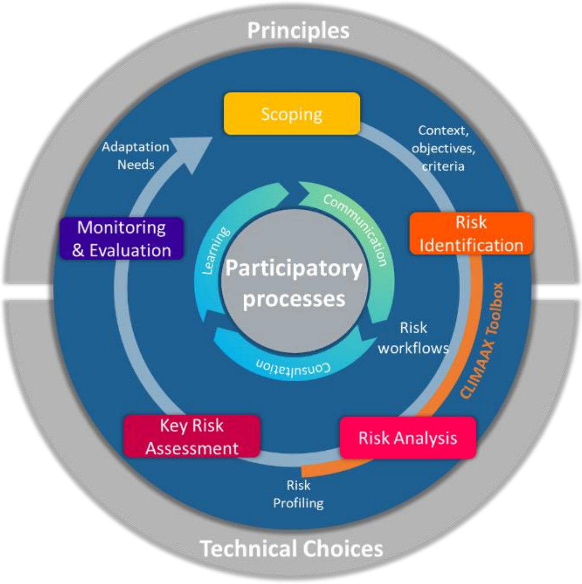

Figure 8. Framework of CLIMAAX

3. CRA methodologies

The application of the previously described frameworks requires a variety of methodologies, which are specific to the key risk being analysed. These methodologies are conditioned by the type of information and studies available for that particular risk. According to UNDRR (2022), methodologies can be divided into:

- **Qualitative**: this approach is used when the knowledge of risk is limited or there is slight information available. It is based on expert judgement or can be built on qualitative research techniques, such as structure interviews or focal groups. This methodology is easier to apply and does not require a high level of specialisation. Results are not spatially explicit (mappable).

- **Semi-quantitative**: the methodology addresses risks for which quantitative impact models are not available. It is based on the use of indicators to quantify risk and its components. Indicators are derived from available data sources or from expert judgement and they are aggregated through different techniques, such as arithmetic or geometric means (GIZ, 2017). The knowledge to apply this approach depends on the level of detail to be achieved. Results are usually spatially explicit (mappable).

- **Quantitative**: the methodology involves mathematical models (biophysical impact modelling, socioeconomic impact modelling, among others), that require a medium-high level of knowledge. It provides quantitative estimates with respect to a given metric. These estimates are more accurate and are usually spatially explicit (mappable).

- **Hybrid**: it combines approaches, such as the use of mathematical models (quantitative) with indicators (semi-quantitative). It involves a greater effort in terms of knowledge, information and resources, as more than one technique has to be applied. Results are usually spatially explicit (mappable).

4. Regions4Climate CRA framework

As discussed in the previous sections, there are a variety of CRA frameworks. In general, it can be said that there is a broad consensus on the key elements to carry out a CRA, although there are some differences and particularities among them. The proposed framework in Regions4Climate project tries to adapt to the needs of the partner regions and requirements of the project in terms of coherence with the rest of the project tasks as well as with the availability of data and resources.

The CRA framework proposed in Regions4Climate is based on existing international CRA frameworks considering the particularities of the project and the availability of information in the study areas. Therefore, special consideration has been given to IPCC AR6, UNDRR, CLIMAAX and ESPON CLIMATE Update due to their relevance at the scientific community on CRA and at European level. Figure 9 presents the general structure of the R4C framework. Risk is located at the centre of the framework and is understood as the potential for adverse consequences for human and ecological systems triggered by the interactions of climate-related hazards (including hazardous events and trends) with the vulnerability, exposure of human and natural systems, and responses. Climate change is considered as underlying risk driver in the framework; however, there are other underlying risk drivers altering vulnerabilities and exposure, such as changes in population and land use.

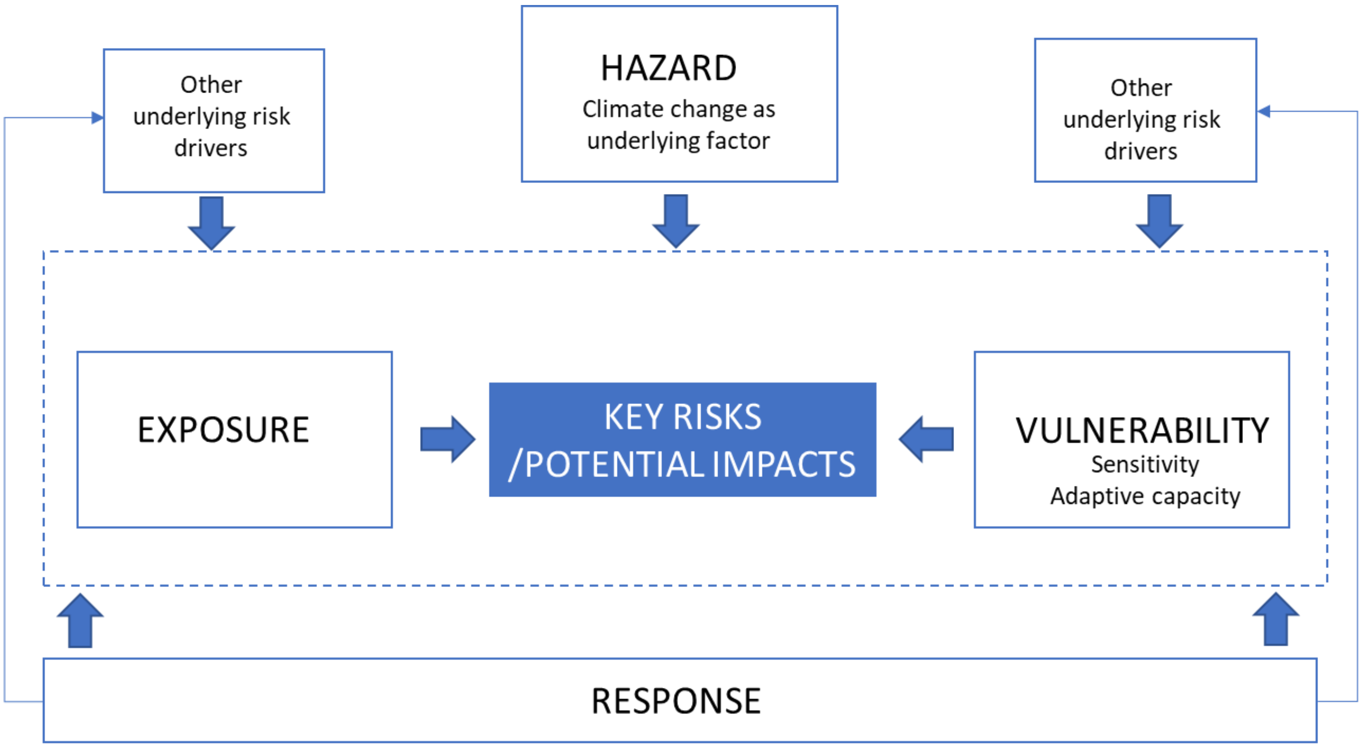

Figure 9. General structure of R4C framework (Adapted from UNDRR, 2022)

The sequence for the development of this framework is divided into three phases (i.e. scoping, risk identification, risk analysis and risk evaluation) in line with the (UNDRR, 2022) approach and CLIMAAX (Figure 10).

- **Scoping**: it is the first phase of the sequence and prepares the ground for the risk assessment.
- **Risk identification**: it is about identifying the risks that will be considered in the risk analysis.
- **Risk analysis**: it is aimed at analysing the risk components (hazard, exposure, vulnerability, and response) of selected key risks, its interrelations and the resulting potential cascading impacts.

Figure 10. Sequence to develop the Regions4Climate CRA framework. Source: (UNDRR, 2022)

4.1. Scoping

Scoping prepares the ground for the risk assessment, designing aspects such as the objective, scope, scale of analysis, climatic and non-climatic scenarios, the temporal periods, and the methodologies to carried out the risk assessment.

4.1.1. Objective

The objective of the R4C climate risk assessment is to provide comparable risk information between the regions to understand the risk under current situation and under different climate change scenarios, improving existing risk assessments and considering information limitations and the scope of the project.

The climate risk assessment is divided in two deliverables. The D3.4 “initial climate risk assessment” in month 24 will assess the climate risk for the reference period and the D3.6 “final climate risk assessment” in month 60 will extend the assessment for the future climate change scenarios.

4.1.2. Spatial units

The spatial units to develop the vulnerability and risk assessment belong to the administrative units. These administrative units correspond with geographical areas for which an administrative authority is empowered to take administrative or strategic decisions. To represent them, the NUTS classification established by Eurostat will be used, which subdivides the economic territory of the Member States. This classification is hierarchical and is divided into three levels: NUTS 1, NUTS 2 and NUTS 3. For this assessment, NUTS3 has been selected, which subdivides the first and second levels. **¡Error! No se encuentra el origen de la referencia.** shows the administrative units corresponding to each partner region. In the case of Troodos network, there is no division for such level.

Table 1. Administrative units corresponding to the NUTS3 classification for each partner region.

Partner region	NUTS3	Partner region	NUTS3
Basque Country	Provinces	**Uusimaa**	Regions
South Aquitaine	Departments	**Pärnumaa**	Groups of counties
Azores	Groups of municipalities	**Sitia**	Prefectures
Tuscany	Provinces	**Castile and Leon**	Provinces
Køge Bay	Municipalities	**Nordic Archipelago**	Regions
Burgas	Oblasts	**Troodos**	-

4.1.3. Spatial coverage

The study area of the CRA consists of the 12 regions that are part of the project: Basque Country, South Aquitaine, Azores, Tuscany, Køge Bay, Burgas, Uusimaa, Pärnumaa, Sitia, Castile and Leon, Nordic Archipelago and Troodos. The locations of these regions are represented in Figure 11.

Figure 11. Partner regions of R4C

Regions 4Climate

4.1.4. Climatic and non-climatic scenarios and temporal reference

Climate change will be assessed by comparing past (1981-2010) and future conditions (2070-2100) under three potential scenarios:

- SSP1- RCP 2.6 (Sustainability) - which is considered a low emissions scenario where emissions start declining beyond 2020. This declining is due to the world shifts gradually toward a more sustainable path.

- SSP2- RCP 4.5 (Middle of the road) - which is a scenario where historical patterns of development are continued throughout the 21st century.

- SSP5- RCP 8.5 (Fossil-Fuelled Development) - which represents a very high emissions scenario where emissions continue to rise throughout the century, as human development will be driven by an energy-intensive, fossil fuel-based economy.

It is worth mentioning that these scenarios will be linked to the qualitative scenarios developed in the R4C project deliverable D2.4 "Just Transition Roadmaps". Those qualitative scenarios will provide the narrative description of the quantitative scenarios analysed in task 3.1.

4.1.5. Methodological set-up: hybrid approach

The hybrid methodological approach (see section 3 for further details) is chosen for developing the described framework in R4C. This approach allows analysing complex risks in a comprehensive manner obtaining the benefits of the quantitative and semi-quantitative approaches.

On the one hand, the **quantitative approach** will be used to assess the selected potential impacts of regions. This approach is normally based on impact models, which are hazard specific, and resulting results are measurable (e.g. number of dead people, damage to buildings or economic losses). An example could be the use of flood-depth damage curves, which relate water flood depth with percentage of damage to buildings. In this study, the assessment of potential impacts will be carried out by considering the impact models proposed in the workflows of CLIMAAX and feeding them with current scenarios as well as with future climate scenarios (see section 4.3 for further details).

On the other hand, **the semi-quantitative approach** will be applied for assessing the adaptive capacity of regions and the response component. The semi-quantitative approach involves a selection of proxy indicators. According to (GIZ, 2017) a good indicator follow the following characteristics: (i) it is reliable, valid and represent adequately the component of risk that is assessing; (ii) it has a precise meaning, and its direction is clear; (iii) it comes from a freely available dataset.

In this study, the methodology and the selection of indicators for the assessment of adaptive capacity correspond to the ones used in the ESPON CLIMATE Update. The indicators are presented in Table 2 and the methodology involves the use of Principal Component Analysis (PCA) for the aggregation of indicators. PCA is a dimensionality reduction method that transforms a set of variables into a smaller ones, named components, preserving as much information as possible, and it has already been applied in many studies related to vulnerability assessment (Cutter et al., 2003; Fekete, 2009; Tapia et al., 2017; Navarro et al., 2023). Some of the indicators from D2.1 “Social & economic vulnerabilities analysis” are aligned with ESPON CLIMATE Update.

Table 2. Selection of indicators to characterize the component of adaptive capacity.

Type of indicator	Selected indicators
Technological capacity	Research staff, patent applications, research and development investments
Social capacity	Investments in education, persons with tertiary education, risk perception, social capital and gender equality index.
Economic capacity	Employment rate, risk of poverty, regional GDP, National GDP
Infrastructural capacity	Medical doctors, Hospital beds, Settlement compactness
Institutional capacity	National adaptation strategies, regional quality of government index, municipalities signatories to the Covenant of Majors

The reason for the inclusion of these indicators is due to the following:

- Within technological capacity, a high level of education and research through tertiary educational attainment, research and development expenditure, and personnel, researchers and patent applications indicate a higher capacity to produce knowledge and develop innovative solutions to new problems (Brooks et al., 2005; Zhang et al., 2018; Medina et al., 2020).

- Social capacity is also relevant. Risk perception is a sociocultural phenomenon affected by social organisation and values, which guides the behaviour of people in prevention and response actions related to hazards; generally speaking, the higher the risk perception the lower the vulnerability (Douglas & Wildavsky, 1982; Grothmann & Reusswig, 2006; Oliver-Smith, 1996; Wachinger et al., 2013; Birkholz et al., 2014; Martins & Nunes, 2020; Medina et al., 2020; Wu, 2021).

- Social capital captures the level of cohesion, trust and access to resources based on social networks; the higher the social capital is, the lower the vulnerability (Pelling, 1998; Wisner, 2003; Nakagawa & Shaw, 2004; Newman & Dale, 2005; Murphy, 2007; Myers et al., 2008; Morrow, 2008; Varda et al., 2009; Ainuddin & Routray, 2012).

- The impacts of disasters are not evenly distributed in society; when there is a high level of inequality among social groups, the impacts are higher. It is also true in the case of gender inequality, which has been captured with the gender equality index (Bashier Abbas & K. Routray, 2014; Jamshed et al., 2020; Martins & Nunes, 2020; Medina et al., 2020).

- The economic capacity of a territory has a strong influence on the number of resources that may be mobilised to implement mitigation actions and to facilitate the recovery process after a hazard (Cutter et al., 2003; Brooks et al., 2005; Myers et al., 2008; Zhang et al., 2018; Rufat et al., 2019).

- The health system is also an important indicator of the capacity to respond to a hazardous event; in this case, indicators referring to the number of hospital beds and practising physicians are considered (Cutter et al., 2003; Myers et al., 2008; Fekete, 2009; Finch et al., 2010; Yoon, 2012; Chen et al., 2013; Zhang et al., 2018; Maletta & Mendicino, 2020).

- Governance dimension is also an important aspect of the adaptive capacity, which influences the effectiveness of the implementation of disaster risk reduction policies. This is included in the assessment through the quality of government index and the percentage of municipalities signatories to the Covenant of Mayors (Brooks et al., 2005; Kotzee & Reyers, 2016; Medina et al., 2020).

Regarding the response component, the selected indicators will be based on the D4.1 "Regional Resilience Maturity Model and Framework" indicators (Table 3), which are linked to the D2.1 “Social & economic vulnerabilities analysis” and D2.2. “Just transition framework” as they have informed the indicator selection of D4.1. In this sense, just transition will be included in the framework and the fulfilment of the proposed actions in the roadmap will be reflected in the response component and thus, in the risk analysis.

Table 3. List of indicators of the Regional Resilience Maturity Model and Framework

Dimensions	Indicators
1. Regional Governance and Institutional capacity	1.1 Political support for a just transition to climate resilience 1.2 Regional governance structures for cross-sectoral coordination 1.3 Governance structures for multi-level (vertical) coordination 1.4 Governance structures for cross-border cooperation (across administrative boundaries) 1.5 Engagement in networks 1.6 Anticipatory governance 1.7 Region's monitoring and evaluation system
2. Plans and policy instruments	2.1 Regional plan or strategy for climate resilience 2.2 Integration of planning and regulatory framework for climate resilience 2.3 Policy instruments supporting regional resilience-building. 2.4 Mainstreaming of climate resilience into other regional sectoral plans and strategies 2.5 Regional plan or strategy for emergency response. 2.6 Alignment of existing policy instruments with regional ambitions for a

	socially just transition to climate resilience. 2.7 Assessment of region's progress towards relevant SDGs. 2.8 Identification of local/regional targets that align with macro-regional S3/S4+ strategies
3. Human resources and technical skills	3.1 Staff assigned to the planning and implementation of climate change resilience actions 3.2 Flexibility in staff contracting and allocation 3.3 Staff's competencies, knowledge and skills to understand and use climate change data and information 3.4 Staff's competencies, knowledge and skills to design and conduct effective participatory and stakeholder engagement processes 3.5 Staff's competencies, knowledge and skills to successfully implement the planned climate resilience and adaptation strategies and measures 3.6 Staff's competencies, knowledge and skills to successfully engage in climate change mainstreaming 3.7 Staff's capacity building 3.8 Staff's competencies, knowledge, and skills to make use of multiple financing opportunities
4. Participatory governance and stakeholder engagement	4.1 Identification of purpose and clear objectives for stakeholder engagement 4.2 Identification of opportunities and challenges for stakeholder engagement 4.3 Mapping of stakeholders 4.4 Identification of stakeholders most affected by climate change 4.5 Development of a stakeholder engagement plan 4.6 Participatory governance to enhance coordination and agenda-setting 4.7 Engagement with the private sector 31 4.8 Engagement with citizens 4.9 Engagement with organised civil society 4.10 Engagement with academia and research community
5. Public support, awareness and climate change communication	5.1 Climate risk communication strategies 5.2 Dissemination of scientific information and good adaptation practices 5.3 Alignment of regional communication and marketing strategies with climate resilience priorities 5.4 Analysis of public perception of climate change 5.5 Analysis of public perception and acceptance of policies

6. Financial capabilities	6.1 Financial resources availability 6.2 Budget allocation and distribution at local level 6.3 Budget allocation for planning 6.4 Budget allocation for implementation 6.5 Incentives for private sector
7. Vulnerability and Risk Assessment	7.1 Ability to conduct risk and vulnerability assessments 7.2 Risk assessments 7.3 Integrated vulnerability and risk assessments 7.4 Alignment of vulnerability and risk assessments with justice and equity principles 7.5 Comprehensiveness of indicators 7.6 Use of vulnerability and risk assessments' results
8. Innovation Potential Assessment	8.1 Framework conditions - Education & Lifelong learning 8.2 Framework conditions - Research System 8.3 Framework conditions - Digitalisation 8.4 Public investments in innovation 8.5 Innovation activities in SME 55 8.6 Collaboration 8.7 Economic impact of innovation 8.8 Environmental sustainability

Once indicators have been selected, they will be aggregated to compose an index of adaptive capacity and an index of response, which is usually in the range of 0 to 1. Finally, a common assessment frame will be developed by combining both approaches.

4.2. Risk identification

Once the context and set-up have been defined in the scope phase, risks will be identified. Risk identification phase is about identifying the risks that will be considered in the risk analysis. In this project, this selection builds on several criteria (i.e. assessment of region needs for CRA, alignment with R4C societal challenges, alignment with CLIMAAX project and data needs). Firstly, it is ensured that the selected hazards and sectors are a necessity for the regions and meet the societal challenges of the project. Then, it is verified that the methodology for impact assessment is available in CLIMAAX. Finally, the data needs criterion adjusts the final selection of the key risks. A description of each criterion is given below:

- **Alignment with R4C societal challenges**. The regions in R4C project are grouped in three different clusters which shares common challenges. The first cluster identified sea level rise, coastal erosion, storm surge and ocean warming as common hazards. The second cluster highlighted extreme storm events, flooding, higher temperatures and droughts. Finally, the third one identified heat waves, water scarcity, rural depopulation and pressure on agriculture as challenges.

- **Assessment of region needs for CRA**: this criterion is built on the conclusions of the gap analysis report developed in WP3, which contributes to a revision of the state of the question in relation to the risk assessment in the R4C regions (Annex 1). According to this, the needs of regions in selecting key risks for in-depth analysis are relatively similar. In general, heat stress, drought and coastal flood are the three most prioritized hazards.

  Regarding sectors, agriculture sector raises the biggest concern when studying the drought hazard, while a set of sectors are prioritized for coastal floodings (i.e., built environment, population, biodiversity and commerce and services sectors) and heat stress (i.e., population, social services, agriculture, forestry, biodiversity and built environment).

- **Alignment with CLIMAAX project**: this criterion refers to the selection of the risks based on the workflows elaborated in CLIMAAX. As described in section 2.6, CLIMAAX has developed seven risk workflows based on state-of-the-art literature and latest scientific development to support European regions in their climate risk assessments. These risk workflows, entitled as floods, drought, exposed drought population, wildfire, storm, blizzard, and snowfall, describe risks and its components following a harmonized framework.

- **Data needs**: the needs for risk assessment revolve around the availability of hazard data for historical and future scenarios, as well as the availability of information to characterize exposure, vulnerability, and response. Thus, the final selection of key risks will depend on the availability of information (i.e., high resolution data in raster or vector format) at NUT3 for the study area.

Based on the previous criteria, Table 4 presents a preliminary identification of key risks.

Table 4. Potential key risks for risk assessment with each corresponding acronym.

Potential Key Risk	Acronym
Coastal flood on built environment	CF_BE
Heat stress on population	HE_PO
Drought on agriculture activity	DR_AA

4.3. Risk analysis

This phase is aimed at analysing the risk components (hazard, exposure, vulnerability, and response) of selected key risks, its interrelations and the resulting potential cascading impacts. It applies the methodologies described in section 4.1.5, which are specific for each key risk. It is worth mentioning that these key risks are preliminary. The final selection of them will depend on the availability of data.

4.3.1. Coastal flood on built environment

This key risk will be assessed by using a hybrid methodology. On the one hand, a quantitative approach is proposed to characterize the impact of coastal flood on urban sector. This approach follows the workflow proposed in CLIMAAX, which follows a "stepwise" data processing scheme to calculate the damage of floods on the built environment[1]. The potential datasets to quantify this flood damage are summarized in Table 5. Regarding the depth-damage curves, the global consistent database of depth-damage curves, available at the Journal Research Centre, will be used.

Table 5. Potential datasets to quantify the impact of coastal flood on built environment.

Potential datasets to be used in the impact analysis	
Coastal inundation	Extreme sea levels are available from the Journal Research Centre and coastal flood maps are available from the European Coastal Flood Awareness System
Land-use information	The land cover map is available from the Copernicus Land Monitoring Service.

On the other hand, the adaptive capacity and response components will be assessed following a semi-quantitative approach. The former will be considered holistically through a selection of 18 indicators representing the social, economic, institutional, infrastructural, and technological nature of the vulnerability (Table 2). These indicators have been previously considered in ESPON CLIMATE Update and are able to influence the distribution of any of the proposed key risks.

Concerning to the response component, the indicators of the D4.1 "Regional Resilience Maturity Model and Framework", will be considered (Table 3), which are linked to the D2.2. "Just transition framework".

4.3.2. Heat stress on population

The heat stress on population key risk will follow, as the previous one, a hybrid methodological approach. Currently, the CLIMAAX workflow of heat stress is under development, thus a quantitative approach, through a distributed lag non-linear model (Gasparrini et al., 2015) is proposed provisionally to estimate heat related mortality for reference period and future climate change scenarios. This initial proposal may be subject to change once the CLIMAAX heat stress workflow is published.

The potential datasets to be used to estimate mortality are included in Potential datasets to quantify the impact of heat stress on population.

[1] https://handbook.climaax.eu/notebooks/workflows/FLOODS/FLOOD.html

Table 6. Potential datasets to quantify the impact of heat stress on population.

Potential datasets to be used in the impact analysis	
Temperature	Temperature from ERA5 available from Copernicus Climate Change Service.
Population	Population information from EUROSTAT.

Finally, the adaptive capacity and response components will be integrated through a semi-quantitative based approach to the quantitative results of mortality in the same way as previous key risk.

4.3.3. Droughts on agriculture activity

This key risk will be assessed following an adaptation of the semi-quantitative approach described in CLIMAAX advanced drought workflow, which quantifies drought risk by combining indicators of drought hazard, exposure and vulnerability. CLIMAAX workflow follows the methodology proposed by (Carrão et al., 2014) and has a multi-sectoral approach; however, the methodology proposed for R4C focuses specifically on the agricultural sector due to the interest of the regions.

Drought hazard will be estimated considering climatic indexes, which are indicative of drought conditions. For instance, CLIMAAX proposes the weighted anomaly of standardized precipitation (WASP) index, which is a severe precipitation deficit indicator. WASP considers the annual seasonality of precipitation cycle and is computed by summing weighted standardized monthly precipitation anomalies.

$$WASP_j = \sum_{P_{n,m}<T_m}^{P_{n,m}>=T_m} \left(\frac{P_{n,m} - T_m}{Tm}\right) * \frac{T_m}{T_A}$$

Where $P_{n,m}$ is each region's monthly precipitation, T_m is a monthly threshold defining precipitation severity, and T_A is an annual threshold for precipitation severity. These thresholds are defined by dividing multi-annual monthly observed rain using the 'Fisher-jenks' classification algorithm.

Another potential climate indicator could be the Consecutive Dry Days (CDD), which has been previously used in the European latest initiatives (e.g. ESPON CLIMATE Update) together with the annual mean precipitation.

Regarding exposure component, the agricultural the R4C regions will be considered following the specifications of CLIMAAX drought workflow. In this sense, the global crop distribution model of Spatial Production Allocation Model (SPAM) will be used, which provides an estimation of crop distribution for 42 crop species based on land-cover information.

Similarly, sensitivity component will be characterized collecting and aggregating indicators, which represent the degree to which the agriculture is affected (either adversely or beneficially). The selection of indicators will be based on the ones proposed in ESPON CLIMATE Update (Table 7)

Table 7. Potential indicators to characterize the sensitivity of agriculture.

Potential indicator	Potential data source
Primary sector employment	Proxy available at Eurostat.
Primary sector Gross Value Added (GVA)	Proxy available at Eurostat.
Share of irrigable and irrigated areas in utilized agricultural area (derived from Landuse information)	Proxy available at Eurostat.

Finally, the adaptive capacity and response components will follow the same approach as the methodology proposed for the key coastal flood risk on the built environment.

5. Conclusions and way forward

Risk assessments across Europe employ a diverse of frameworks and approaches as they are typically developed at local or national level and are customized and context specific. In general, these frameworks share common concepts (e.g., the IPCC risk components); but, in some cases, differ in the form (e.g., they assess climate impacts quantitatively without considering adaptive capacity) and even in the terminology used; thus, they pose a challenge to achieve a comprehensive risk assessment at different EU regions.

This deliverable provides a robust and standardized CRA framework for a consistent, harmonised, and comparable climate risk assessment on a regional scale across Europe. The proposed framework is based on current CRA frameworks (e.g. IPCC AR6, 2022 and UNDRR, 2022) and is aligned to CLIMAAX framework, which provides guidance for the development of comprehensive risk assessment across European regions. Besides, it incorporates the latest scientific developments related to risk assessment frameworks, such as the emerging concept of response proposed by the IPCC AR6 (2022). This response component involves the consideration of risk-informed decision making and planning (i.e., adaptation and risk reduction options) into the CRA; thus, the efforts of the regions are considered in the framework and modulate the determinants of risk (i.e., hazard, response, and vulnerability).

On the other hand, the alignment of the framework with several tasks of R4C project (i.e., the D2.2. “Just transition framework” when selecting climatic scenarios and the D4.1 "Regional Resilience Maturity Model and Framework" and D2.1 “Social & economic vulnerabilities analysis” when characterizing vulnerability and response components) makes the R4C regional-scale vulnerability and risk assessment holistic. In the future, this holistic approach could be improved assessing complex risks (e.g., aggregate risks, cascading risks, compound risks), as well as transboundary risks, which do not respect borders and impact across different distances and time scales. In this way, a more systemic perspective will be adopted in the assessment of climate risks.

Regarding the proposal of key risks, a preliminary selection has been made based on several criteria (i.e., alignment with R4C societal challenges, assessment of region gaps and priorities for CRA, alignment with CLIMAAX project and data needs). This proposal corresponds to coastal flood on built environment, heat stress on population and droughts on agriculture activity. Over the next months, data will be gathered and depending on its availability the final selection will be done.

Once key risks have been finally chosen, the vulnerability and risk assessment will be conducted. By December 2024 (M24), an initial climate vulnerability and risk assessment will be developed for the reference period. By January 2027, the final climate vulnerability and risk assessment will be carried out considering future climate and non-climate scenarios.

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Annex 1. Analysis of the potential GAPS and priorities of the R4C regions

Identifying impact chains and their regional variations is relevant for developing effective adaptation strategies, to mitigate different risks and climate change consequences. Each region has its own geography, socioeconomic conditions, and climate which can influence the way hazards unfold. By exploring impact chains specifically region by region, policymakers and experts can identify vulnerabilities and tailor adaptation strategies. Impact chains are the result of combining a threat with a receptor sector.

This analysis corresponds with a milestone, that falls under the WP3 activities. It includes the analysis of the potential GAPs and priorities of the R4C regions in their knowledge of risks and vulnerabilities of climate change. This information was extracted from a questionnaire that was prepared and shared with the representatives of the regions. The questionnaire (available at Annex 2) gathered information of the availability of data regarding different impact chains and identified the priorities for the regions concerning climate risk assessment.

In the GAP Analysis, different hazards are listed: heat stress, fluvial flood, pluvial flood, coastal flood, wildfires, drought, storms, winds, landslides, and erosion. Regions can be compared regarding which hazard or hazards affect them, and cartography can be done by searching for their spatial location and possible patterns. There are also different sectors to watch out: agriculture, biodiversity, built environment, commerce and services, cultural heritage, energy, industry, population, social services, transport and supply chain and, finally, water management.

In this document a compilation of the main conclusions and results of the forms filled by the regions is presented. The result of this analysis will be a reference for the conceptualization of the Deliverables 3.1 and 3.4 regarding the Vulnerability & risk assessment framework and the Initial climate V&R assessment.

The Annex includes a first section about the hazard and sectors that have been assessed by the Regions and the ones that are considered as priorities for their resilience. Secondly, the scale and spatial resolution of the data that are available in each region is analyzed and finally, the methodologies that have been applied and the data sources that have been considered are presented. This contributed to a revision of the state of the question in relation to the risk assessment in the R4C Regions. The R4C Regions that are included in this GAP analysis are the following.

REGION	GEOGRAPHICAL DEFINITON
Basque Country (PV)	Autonomous community of Basque Country
South Aquitaine (FR)	158 municipalities

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Azores (PT)	Azores islands
Tuscany (IT)	Tuscany Region
Køge Bay (DK)	Eleven municipalities
Burgas (BG)	Burgas municipality
Helsinki-Uusimaa (FI)	Uusimaa
Pärnumaa (EE)	Pärnumaa County (7 municipalities)
Sitia (EC)	Sitia municipality Lasithi prefectural unit
Castile and Leon (ES)	Autonomous community of Castile and Leon
Nordic Archipelago (SE/FI)	Huge cross-border region
Troodos (CY)	Several rural municipalities

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HAZARDS AND SECTORS

Comparing regions to identify spatial patterns of hazards is a crucial aspect of deploying strategies at the community level and identifying potential mutual knowledge between regions that share impact chains. This comparative analysis helps in understanding the underlying factors, such as geographical, climatic, or geological conditions, that contribute to the prevalence of certain hazards in particular regions. For instance, coastal areas may be more susceptible to hurricanes and flooding, while arid regions might face greater risks of drought and wildfires. Identifying these spatial patterns enables the development of targeted mitigation strategies, the allocation of resources for preparedness and response efforts, and the formulation of region-specific policies to reduce vulnerability and enhance resilience. Sectors affected by hazards can be listed in 13 categories. There is one "none" category which means that the region has not specified any or the option that the region can point out one that is not listed. In general, regions can assess the sectors affected by hazards and, additionally, can highlight the priority they give to each sector by "low", "medium" or "high" levels.

Among the regions, heat stress, drought and coastal flood are the three most prioritized hazards to be analysed.

- ### Heat stress hazard

In ten out of twelve heat stress is assessed, which implies the relevance of creating strategies for mitigating heat stress, such as improving green infrastructure, implementing heat action plans, and promoting sustainable building practices. Additionally, comparing regions allows for the identification of areas that have the will to develop targeted interventions to protect those at the highest risk, particularly during heatwaves, which are becoming more frequent and severe due to climate change. Heat stress is prioritized by regions mostly in sectors such as population, built environment, biodiversity, and social services (**Map 1**). Almost all regions give high priority to assessing heat stress effects in population and Atlantic and Baltic regions give high priority to analysing heat stress regarding the built environment. Biodiversity is seen as a high-priority sector in island regions: Sitia, Troodos and Azores, plus in Burgas and in northern ones such as Uusimaa or Køge Bay. Social Services are listed as important sectors when studying heat stress in four regions with geographic diversity: Aquitaine, Castile and Leon, Køge Bay and Uusimaa. Heat stress is sometimes given a high priority, but regions did not address it in the past. This is the case of Aquitaine, Sitia, Køge Bay and Uusimaa. Each of them failed to study heat stress in some sectors even though they gave it importance. Heat stress in population and in agriculture is highly important for Aquitaine and Sitia but there is no data available. The same for heat stress in social services and in the built environment for Aquitaine and Køge Bay, and in forestry for Aquitaine and Troodos. Furthermore, the effects of heat on biodiversity is a common concern in Aquitaine, Sitia and Troodos that has not been addressed.

Moreover, other sectors and the number of regions that give them a high priority are: agriculture (four), forestry (three), commerce and services (two) and fishery (one). As heat stress poses significant challenges to agriculture, Aquitaine, Castillla-León and Sitia give it a high priority in the GAP Analysis. Commerce and services have a big concern in Troodos and Uusimaa. Finally, as heat stress can disrupt the delicate balance of the marine environment and affect fishery, Aquitaine has this sector with high relevance.

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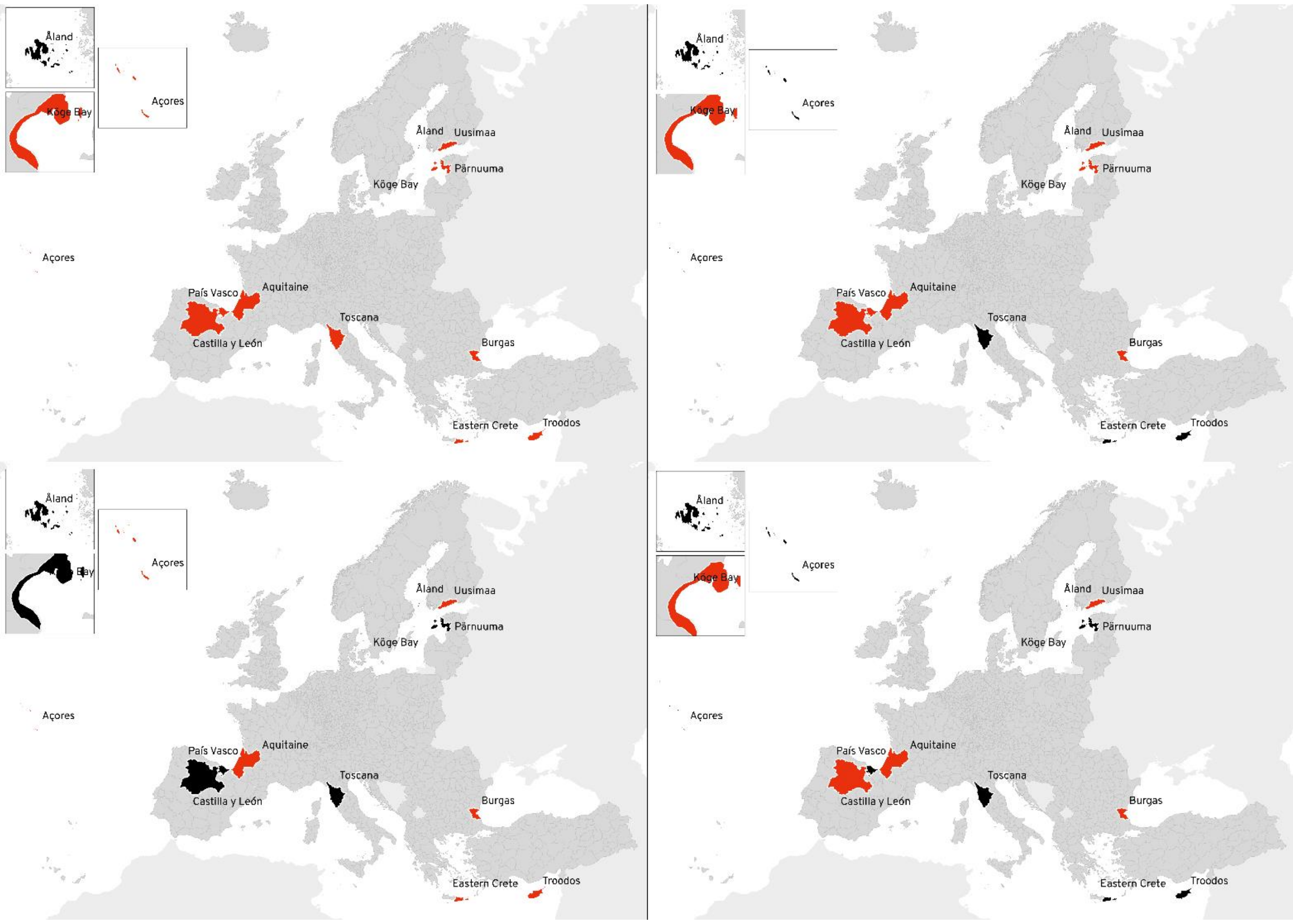
Looking for the regions with the most concern about this hazard, it can be highlighted the fact that Aquitaine listed eight sectors that can be affected by heat stress with "high" priority, followed by Burgas with seven, Uusimaa with five sectors and Azores, Sitia and Castilla-Leon with four each.



***Map 1**. In red regions that tackle heat stress with high priority in population sector (above, left), built environment (above, right), biodiversity (down, left) and social services (down, right).*

- **Drought hazard**

The second most highlighted hazard among all regions is drought. It is pointed out in eight out of twelve regions (Aquitaine, Azores, Basque Country, Castile and Leon, Sitia, Køge Bay, Pärnumaa and Troodos). Comparing regions to discern spatial patterns of drought is essential for understanding the complex dynamics of water scarcity across different areas. By analyzing concerns about drought, it can be identified vulnerable regions and recurrent drought hotspots. This information is invaluable for developing targeted drought management strategies, enhancing water resource planning, and implementing mitigation measures. Furthermore, comparing regions allows for the sharing of best practices and collaborative efforts to build resilience in drought-prone areas, given the increasing global concern about water scarcity driven by climate change and growing demands on freshwater resources.

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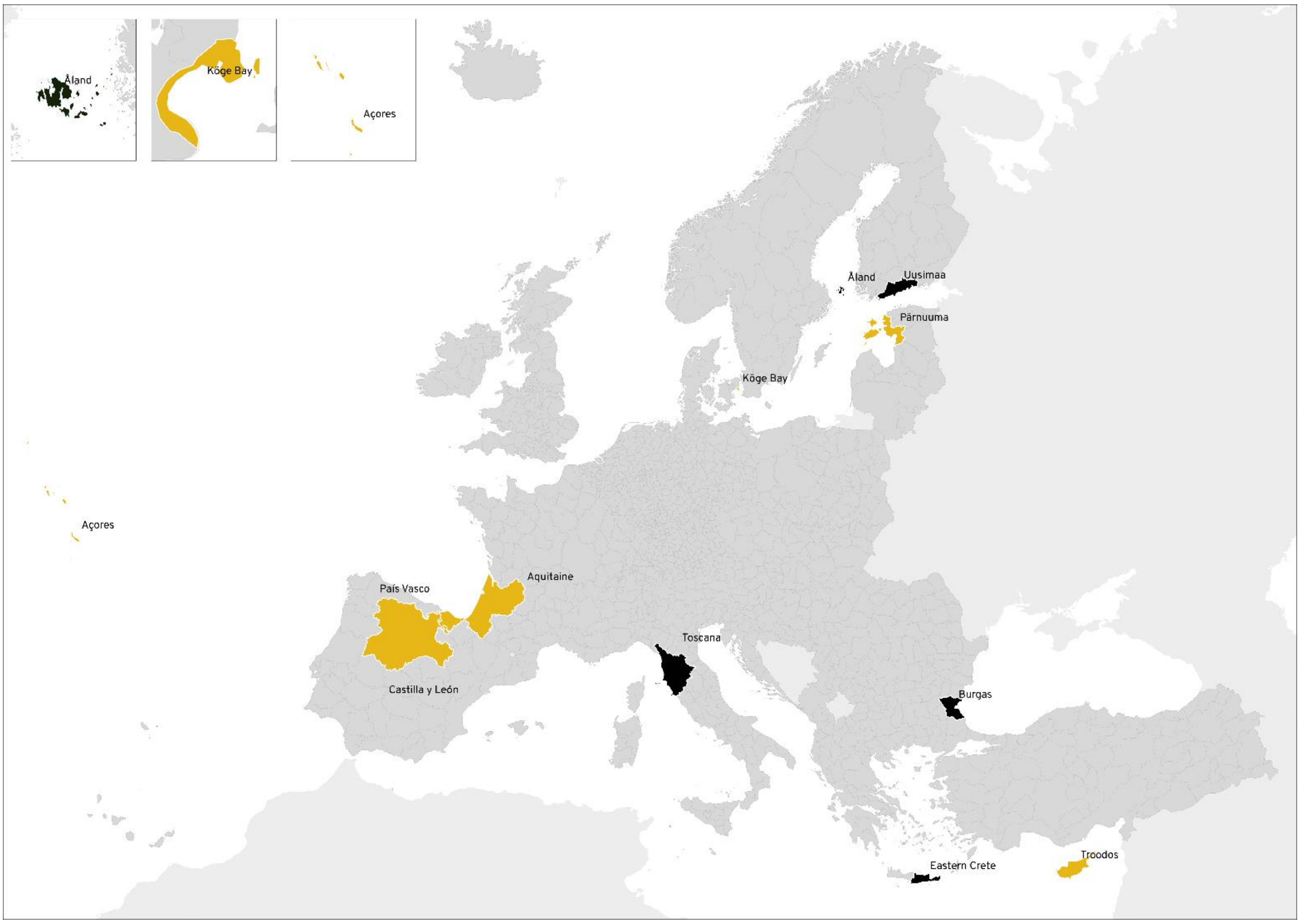
Regarding drought, regions could list different sectors as high prioritized. Seven regions (**Map 2**) have agriculture as the main sector, followed by biodiversity (three regions), and water management (three regions). Drought presents a formidable challenge to agriculture, as it can have severe and far-reaching impacts on crop production and food security. Prolonged periods of insufficient rainfall or water stress can lead to reduced crop yields, withering of plants, and even crop failures. Livestock farming is also affected as pastures and water sources dry up, making it harder to provide adequate feed and water for animals. Moreover, the economic consequences of drought in agriculture are substantial, often resulting in financial losses for farmers and increased food prices for consumers. In Aquitaine, Azores, Basque Country, Castile and Leon, Sitia, Køge Bay and Pärnumaa is seen as a high relevant sector in which to increase efforts.



***Map 2**. In yellow regions that declared agriculture as a high-priority sector in drought hazard.*

Furthermore, drought hazard is related to other sectors by the regions. Biodiversity, and the effects water scarcity could have, is listed by Azores, Castile and Leon and Troodos as highly relevant. Water management is important for Aquitaine, Castile and Leon and Pärnumaa. Following, drought effects in population, forestry and energy are seen as highly important by two regions each. The first and the last ones for the biggest regions (Aquitaine and Castilla-Leon) and the second for island regions (Troodos and Azores). Aquitaine is the region with the most sectors listed as “high priority” when studying drought. Eight sectors are considered relevant: agriculture, water management, population, energy, social services, industry, cultural heritage and transport or supply. It is followed

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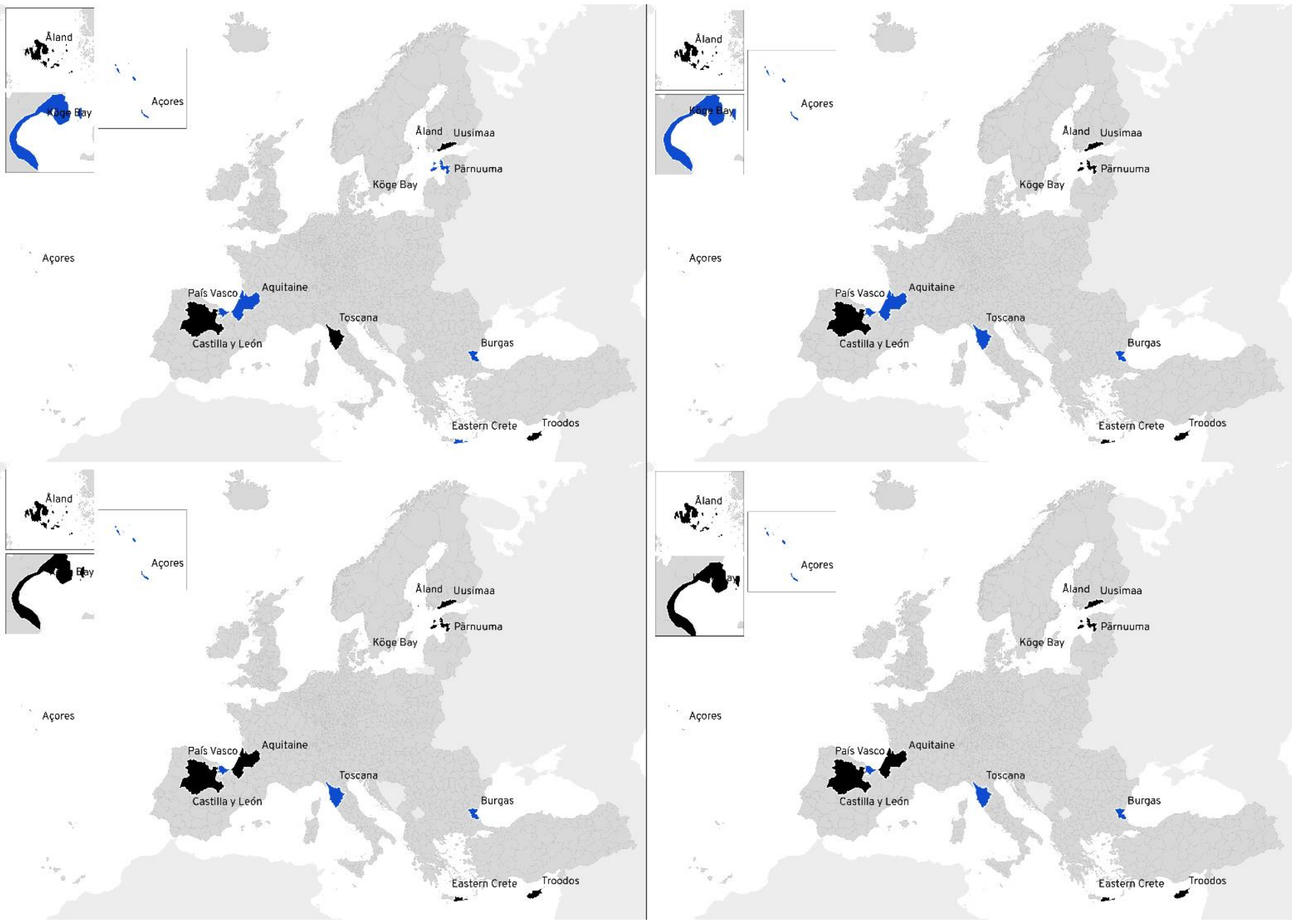
by Castile and Leon with six sectors (agriculture, biodiversity, water management, population, energy and fishery) and by Azores with three (agriculture, biodiversity and forestry). Aquitaine and Castile and Leon share the concern about the effects of drought in the energy sector and have not already addressed it.

- ### Coastal flood hazard

The third most mentioned hazard by the regions is coastal flood. Specifically, Aquitaine, Azores, Basque Country, Sitia, Køge Bay, Burgas, Pärnumaa and Tuscany show interest in tackling coastal flood. Comparing regions to identify the interest in tackling coastal floods' effects is crucial for understanding the vulnerability of coastal areas to rising sea levels and extreme weather events. Sharing knowledge about spatial patterns of coastal floods among regions also fosters collaboration in developing comprehensive, effective measures to protect coastal communities and critical infrastructure from the increasing threat of coastal flooding exacerbated by climate change. The sectors in which regions put more interest, pointed as "high priority" are the built environment, population, biodiversity and commerce and services **(Map 3)**.



***Map 3**. In blue regions that put "high priority" regarding coastal flood in different sectors: built environment (above, left), population (above, right), biodiversity (down, left) and commerce and services (down, right).*

Coastal floods pose a substantial threat to the built environment, encompassing a wide array of structures, infrastructure, and urban developments along coastlines. First, can make buildings and infrastructure weaken,

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erode, or even collapse. Erosion is another significant concern, as the repetitive onslaught of floodwaters can gradually wear away coastlines, endangering the stability of nearby structures and necessitating costly protective measures. Coastal floods can also introduce contaminants like sewage, chemicals, and debris into urban areas, creating health hazards and necessitating extensive clean-up efforts. Furthermore, the disruption of essential utilities, such as electricity, water supply, and sewage systems, can cripple the functionality of urban regions, with far-reaching consequences. Aquitaine, Azores, Basque Country, Burgas, Sitia, Køge Bay and Pärnumaa listed as highly important the effects of coastal floods on the built environment. The effects in population are also a big concern between the regions, being the second most pointed sector. Sectors such as biodiversity and commerce and services follow them.

- **Other hazards**

Apart of heat stress, drought and coastal flood, there are other hazards mentioned that need to be analysed. Erosion is seen as a threat also in seven regions: Aquitaine, Azores, Burgas, Castile and Leon, Basque Country, Køge Bay, Pärnumaa and Tuscany. Pluvial flood is interesting for seven regions: Aquitaine, Azores, Burgas, Sitia, Køge Bay, Pärnumaa and Uusimaa. Wildfires also for six administrations: Aquitaine, Castile and Leon, Sitia, Køge Bay, Pärnumaa and Troodos. Fluvial flood, by six regions, and storms and landslides are listed as important by five regions each. Finally, wind is the least mentioned hazard (four regions). The complete information can be seen in **Table 1**.

HAZARD	AQ	AÇ	PV	BG	CL	EC	KB	NA	PÄ	TO	TR	UU
Heat stress	✓	✓	✓	✓	✓	✓	✓		✓		✓	✓
Drought	✓	✓	✓		✓	✓	✓		✓		✓	
Coastal flood	✓	✓	✓	✓		✓	✓		✓	✓		
Pluvial flood	✓	✓		✓		✓	✓		✓			✓
Wildfires	✓				✓	✓	✓		✓		✓	
Erosion	✓	✓	✓		✓		✓		✓	✓		
Fluvial flood	✓	✓	✓	✓			✓		✓			
Storms	✓	✓			✓				✓			✓

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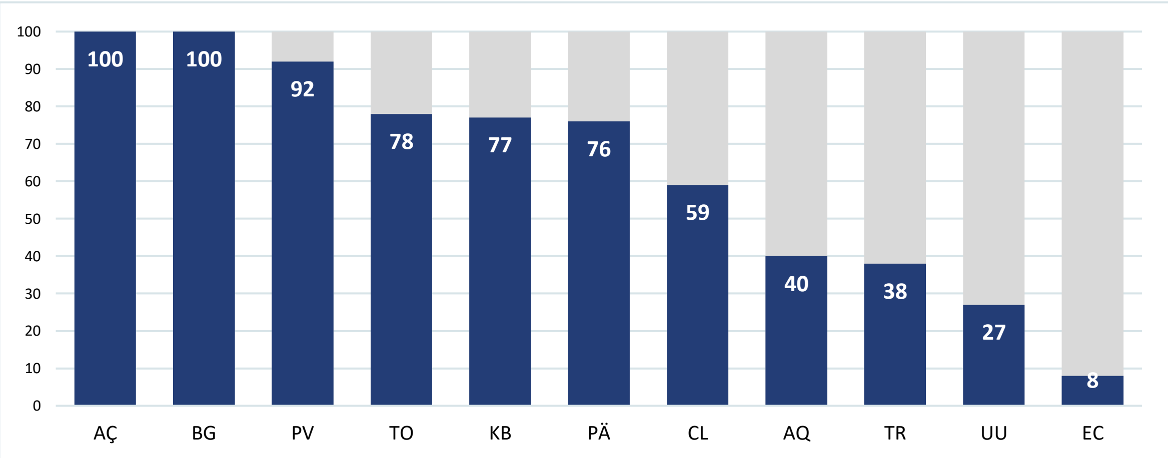
Landslides	✓	✓	✓						✓		✓	
Wind	✓	✓					✓		✓			

Table 1. *Hazards in region's GAP Analysis. AQ= Aquitaine, AÇ= Azores, PV= Basque Country, BG= Burgas, CL= Castile and Leon, EC= Sitia, KB= Køge Bay, NA= Nordic Archipelago, PÄ= Pärnumaa, TO= Tuscany, TR= Troodos, UU= Uusimaa.*

When detailing the highly prioritized impact chains sector by sector and region by region some of them come up as relevant for the territories. Some of them have already been studied and some have not. It is relevant to list them to focus the work during the project on those elements. Some regions have already studied all the highly relevant sectors affected by their relevant hazards: Azores and Burgas. Basque Country has almost prepared information for all of them and some regions have been working on the highly important impact chains during the last years. However, in other territories, there is a lack of information regarding impact chains that need to be resolved. For instance, Sitia has completed only 8% of the impact chains that they see as important. For further information, see Graphic 1 below.



Graphic 1. *Percentage of highly prioritized impact chains that have been already assessed by region. AQ= Aquitaine, AÇ= Azores, PV= Basque Country, BG= Burgas, CL= Castile and Leon, EC= Sitia, KB= Køge Bay, NA= Nordic Archipelago, PÄ= Pärnumaa, TO= Tuscany, TR= Troodos, UU= Uusimaa.*

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SCALE AND SPATIAL RESOLUTION

Understanding the temporal dimension is crucial for comprehending the intricate dynamics of climatic hazards. Short-term temporal horizons are essential for immediate response and preparedness, as they allow us to forecast and respond to imminent threats. On the other hand, longer temporal horizons are essential for assessing the broader context of climatic hazards, including historical patterns, future projections, and the underlying drivers of climate change. Recognizing the interconnectedness of short-term and long-term temporal scales is pivotal in developing comprehensive strategies to mitigate and adapt to climatic hazards. In the GAP Analysis, the regions have offered the information they have regarding scale and temporal horizons. There can be historical data, data from the near future (until 2039), future which comprehends 2040-2069 and further future which goes above 2070. Two regions have historical data (Basque Country and Pärnumaa) and one has data simulated for 2100 and more years (Aquitaine). The most used temporal horizon among the region's data is the 2040-2069 scenario. It is used in Aquitaine, Azores, Basque Country, Castile and Leon, Sitia, Køge Bay and Pärnumaa for different hazards (**Map 4)**. Seven regions use the before-2039 scenario: Azores, Burgas, Castile and Leon, Køge Bay, Pärnumaa, Troodos and Uusimaa. Five of them has data for the 2070-2099 scenario: Azores, Basque Country, Castile and Leon, Køge Bay and Pärnumaa. Azores, Castile and Leon, Køge Bay and Pärnumaa have data for different hazards for all three RCP scenarios. Tuscany, on the other hand, does not have future data predicted.

The different climate scenarios are applied to study the future evolution of the hazards. In this case, the regions utilize the RCP scenarios mostly to explore heat stress. Those seven regions are: Azores, Basque Country, Burgas, Castile and Leon, Sitia, Køge Bay and Pärnumaa. Furthermore, also in six regions RCP scenarios are used to explore droughts: Azores, Basque Country, Castile and Leon, Sitia, Pärnumaa and Troodos. Moreover, fluvial, pluvial and coastal flood are studied in different RCP scenarios also by six regions: Azores, Basque Country, Burgas, Sitia, Køge Bay and Pärnumaa, all regions with coastline. Four regions study erosion in different scenarios: Azores, Basque Country, Castile and Leon and Pärnumaa. Four regions also consider wildfires and different temporal ranges: Castile and Leon, Sitia, Pärnumaa and Troodos. Finally, Azores and Pärnumaa study storms and wind in different temporal scenarios, and Azores also mentions landslides in different climatic temporal frameworks.

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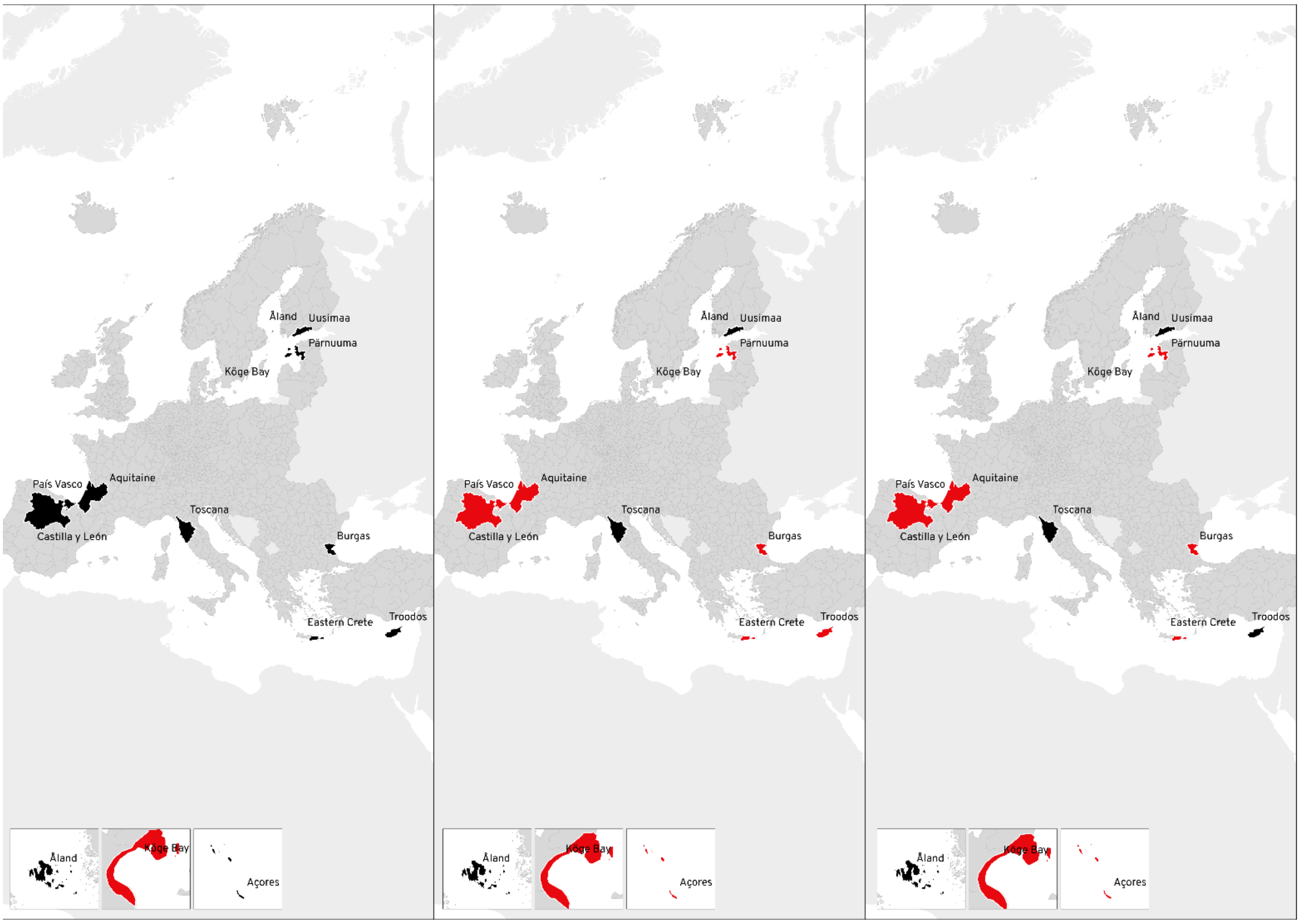

Map 4*. Most RCP scenario used by region when studying hazards. In orange regions that consider climate scenarios when studying hazards. RCP 2.6 left, RCP 4.5 middle, RCP 8.5 right.*

The most used scale is the regional one, especially in Azores, Burgas, Uusimaa and Basque Country. The national one is the one widely used in Castile and Leon, Køge Bay, Pärnumaa and Troodos and, finally, the municipal information is gathered mostly in Aquitaine and Sitia.

METHODOLOGIES AND DATA SOURCES

Risk associated with climate change can be studied using various methodological approaches. They are used to understand and evaluate the potential impact of hazards over a receptor sector. The techniques used vary from purely qualitative to wholly quantitative, with hybrid and semi-quantitative methods used by combining different methods. The qualitative approaches rely on descriptive assessments, without using numerical indicators. They emphasize the narrative of stakeholders, and experts and try to capture the reality that might be difficult to quantify by numerical approaches. Semi-quantitative vision assesses the risk by using indicators to characterize the hazard, exposure and vulnerability components of risk. These models often involve statistical treatments and estimations. On the other hand, quantitative ways of studying risks are characterized by their reliance on numerical data and mathematical models to estimate the impact in a precisely numerical way. When the method takes approaches of several of the previous approaches (qualitative, semi-quantitative and quantitative) they are called hybrid. This enriches the results as they combine numerical metrics and personal descriptions. It often acknowledges the limitations of full quantification. The choice of approach varies from region to region in the project.

While the majority uses the quantitative methods there is a combination between methods depending on the hazards. In **Map 5** there is information regarding which type of methodology is mostly applied when regarding hazards. As it is shown there, the quantitative method is mostly used in the Atlantic and Iberian areas: South Aquitaine, Basque Country, Castile and Leon, Uusimaa Burgas and Køge Bay. In fact, three regions only use quantitative approaches (South Aquitaine, Basque Country and Køge Bay). The semi-quantitative approach is mostly used in island regions: Sitia and Troodos. Lastly, the hybrid method is mostly used in Azores and Pärnumaa.

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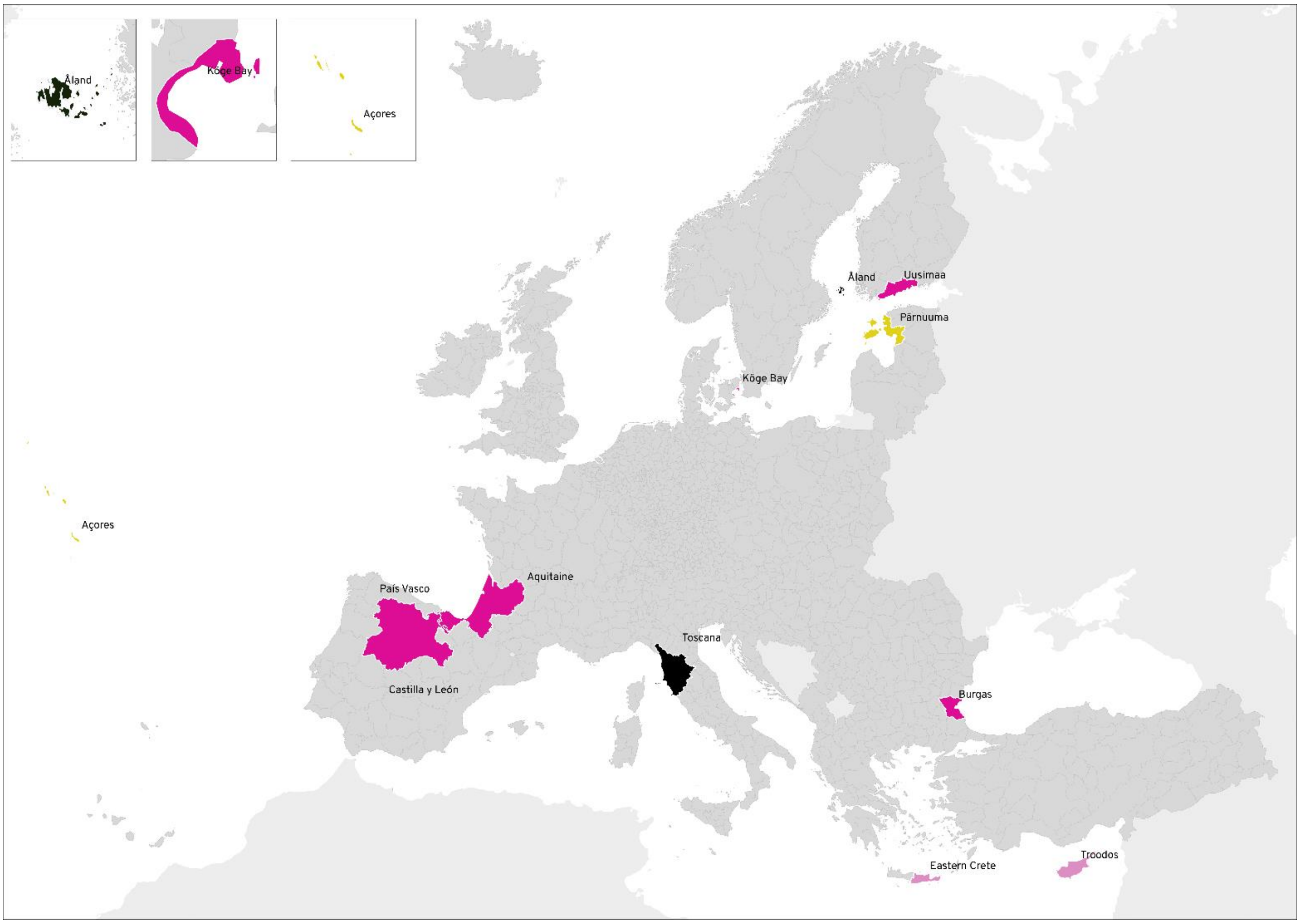

***Map 5**. Most methodological approach used by region when studying hazards. In dark purple quantitative, in purple semi-quantitative and in yellow hybrid.*

Regarding how many times each approach is used in the sector of each hazard (**Table 2**), the quantitative one is applied to 108 sectors of the different regions. The hybrid method is the second most applied methodology when studying sectors. Azores applies it to 50 sectors, and Pärnumaa to 39. Then, the semi-quantitative method is used in 43 sectors, especially in Sitia and Troodos. Finally, the qualitative approach is less used by the regions when detailing the methodology of each sector inside the hazards. It is used in 12 sectors, but the majority are the ones from Uusimaa. On the other hand, it should be highlighted that Azores and Uusimaa has assessed risks in much more extent than other regions, such as South Aquitaine, which considers all hazards relevant (**Table 1**).

METHODOLOGY	AQ	AÇ	PV	BG	CL	EC	KB	NA	PÄ	TO	TR	UU	TOTAL
Quantitative	5		11	33	9		18		6			26	108
Hybrid		50		7	6				39				102

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Semi-quantitative					2	23					16	2	43
Qualitative						2						10	12
Total	5	50	11	40	17	25	18		45		16	38	265

Table 2. *Times each methodology is used in sectors when studying hazards. AQ= Aquitaine, AÇ= Azores, PV= Basque Country, BG= Burgas, CL= Castile and Leon, EC= Sitia, KB= Køge Bay, NA= Nordic Archipelago, PÄ= Pärnumaa, TO= Tuscany, TR= Troodos, UU= Uusimaa.*

CONCLUSIONS

The study of risks associated with climate change in different European regions is relevant as they pose significant threats to human life, infrastructure, and the environment. By conducting a comparative analysis as it has been done in this exercise, it can be identified different patterns and variations in the ways of studying them. Moreover, such studies can reveal disparities in sectors to attend, scale, and resolution of the data or methodologies applied. By comparing the regions' answers in the GAP Analysis, different conclusions can be underlined regarding hazards:

- **The regions prioritize some hazards over others and heat stress, drought and coastal flood are the three most prioritized.** Nine out of twelve study heat stress, eight out of twelve study drought and seven regions study coastal flood.

- **Aquitaine, Uusimaa, Azores and Castile and Leon listed the *most sectors affected by heat stress.*** These regions pointed out the biggest number of sectors as "high priority" when studying the heat stress effect in different sectors.

- **Agriculture sector raises the biggest concern when studying the drought hazard.** Seven regions have agriculture as the main sector and prioritize the efforts in the effects drought could have in this economic sector.

- **Coastal flood is an important hazard for the regions near the coastline.** The regions near the coastline emphasize the relevance of coastal flood in the built environment, population, biodiversity and commerce and services sectors.

When comparing their concerns about different sectors, hazards and impact chains it can be seen how they advanced in the last years. For instance, some have already assessed all the impact chains, but there are some lack of information such as:

- The impact of heat stress has priority for some regions, but information has not been assessed for sectors such as biodiversity in three territories. Other relevant impact chains are heat stress in the population, social services, agriculture, forestry and built environment.

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- There is a lack of information also regarding the effects of storms in population, social services, commerce and services, transport/supply chain, and water management in two regions.

- Wildfires and their effect in forestry needs to be studied for Castile and Leon and Sitia, their effect on agriculture in Sitia and Troodos and, finally, their impact on biodiversity in Castile and Leon and Troodos.

- Fluvial flood and water management is relevant in Aquitaine and Pärnumaa but has not been detailed in any study yet.

- Aquitaine and Castile and Leon prioritize the study of droughts in energy sectors but have not addressed it yet.

For detailed information, see Appendix 1.

When comparing the regions' answers in the GAP Analysis, different scales and spatial resolutions are used. Not all the regions have the same base data, have done the same future scenarios simulations, or dispose of the information at different administrative levels. Some conclusions can be underlined regarding scale and spatial resolution:

- **The temporal horizon that is most used for studying hazards is the 2040—2069 scenario.** It is used in seven regions for different hazards. In this case, the regions utilize the RCP scenarios mostly to explore heat stress.

- **The regions have available data mostly at the regional scale.** The regions use the regional scale to characterize the sectors involved in each hazard.

When comparing the regions' answers in the GAP Analysis, the four types of methodology approach are used among the regions. Some conclusions lay under:

- **Quantitative methods are the most common ones used.** The regions quantitatively study hazards, implying the use of numerical methods. It is used mostly in the Atlantic and Iberian areas. The semi-quantitative approach is mostly used in island regions.

- **When studying risks, the hybrid approach is used more.** The different sectors in which a hazard has implications are studied from a hybrid view. Azores and Pärnumaa study 95 sectors with this approach.

The study of risks demands a consideration of which hazards and sectors are implied, temporal ranges, scale, and methodologies as these factors influence its understating and management. Each approach offers unique advantages and limitations, underscoring the importance of methodological diversity to comprehensively address the complex nature of risks. In conclusion, the relevance of all that is described in the GAP Analysis cannot be overstated, as it shapes the ability to assess risks, plan mitigation measures, and ultimately safeguard communities and ecosystems. This GAP analysis will guide the following actions of Task 3.1 on risk assessment in the context of the R4C project.

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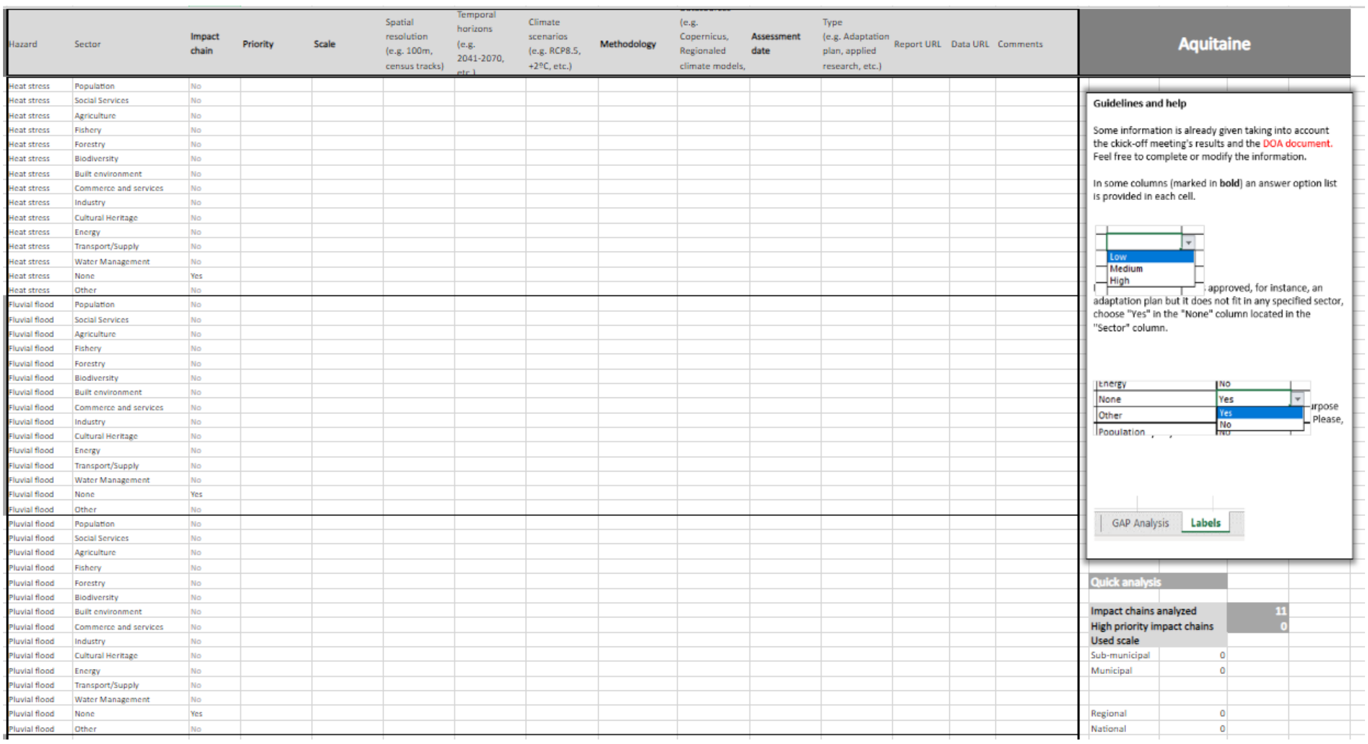
Annex 2. Questionnaire for the analysis of the potential GAPS and priorities of the R4C regions



Hazard	Sector	**Impact chain**	**Priority**	**Scale**	Spatial resolution (e.g. 100m, census tracks)	Temporal horizons (e.g. 2041-2070, etc.)	Climate scenarios (e.g. RCP8.5, +2ºC, etc.)	**Methodology**	(e.g. Copernicus, Regionaled climate models,	**Assessment date**	Type (e.g. Adaptation plan, applied research, etc.)	Report URL	Data URL	Comments
Heat stress	Population	No												
Heat stress	Social Services	No												
Heat stress	Agriculture	No												
Heat stress	Fishery	No												
Heat stress	Forestry	No												
Heat stress	Biodiversity	No												
Heat stress	Built environment	No												
Heat stress	Commerce and services	No												
Heat stress	Industry	No												
Heat stress	Cultural Heritage	No												
Heat stress	Energy	No												
Heat stress	Transport/Supply	No												
Heat stress	Water Management	No												
Heat stress	None	Yes												
Heat stress	Other	No												
Fluvial flood	Population	No												
Fluvial flood	Social Services	No												
Fluvial flood	Agriculture	No												
Fluvial flood	Fishery	No												
Fluvial flood	Forestry	No												
Fluvial flood	Biodiversity	No												
Fluvial flood	Built environment	No												
Fluvial flood	Commerce and services	No												
Fluvial flood	Industry	No												
Fluvial flood	Cultural Heritage	No												
Fluvial flood	Energy	No												
Fluvial flood	Transport/Supply	No												
Fluvial flood	Water Management	No												
Fluvial flood	None	Yes												
Fluvial flood	Other	No												
Pluvial flood	Population	No												
Pluvial flood	Social Services	No												
Pluvial flood	Agriculture	No												
Pluvial flood	Fishery	No												
Pluvial flood	Forestry	No												
Pluvial flood	Biodiversity	No												
Pluvial flood	Built environment	No												
Pluvial flood	Commerce and services	No												
Pluvial flood	Industry	No												
Pluvial flood	Cultural Heritage	No												
Pluvial flood	Energy	No												
Pluvial flood	Transport/Supply	No												
Pluvial flood	Water Management	No												
Pluvial flood	None	Yes												
Pluvial flood	Other	No												

Aquitaine

Guidelines and help

Some information is already given taking into account the ckick-off meeting's results and the DOA document. Feel free to complete or modify the information.

In some columns (marked in **bold**) an answer option list is provided in each cell.

Low
Medium
High

approved, for instance, an adaptation plan but it does not fit in any specified sector, choose "Yes" in the "None" column located in the "Sector" column.

Energy No
None Yes
Other Yes
Population No

irpose
Please,

GAP Analysis | Labels

Quick analysis

Impact chains analyzed	11
High priority impact chains	0
Used scale	
Sub-municipal	0
Municipal	0
Regional	0
National	0