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TransformAr

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

Prioritisation of the most vulnerable regions to climate change

Deliverable 2.6

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TransformAr – Accelerating and upscaling transformational adaptation in Europe: demonstration of water-related innovation packages – is an H2020 project funded under the H2020 Programme, coordinated by the University of Antwerp (UA).

The TransformAr project, launched on October 1st 2021, precisely 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 project, funded by the EU Research and Innovation Programme Horizon 2020 under Grant Agreement No 101036683, gathers 22 partnering organisations from 11 Member States. It has an overall budget of approximately €12 million and will run for 4 years, between October 2021 and September 2025.

Abstract

The identification of regions that face higher risk of experiencing the adverse effects of climate change has been the subject of late studies and is of high importance for the design and prioritization of sector and region specific solutions that can potentially alleviate negative consequences, protecting both people and the environment. To help understanding the importance of climate risks for regions we develop a comprehensive Climate Risk Index that ranks EU regions given their individual social, economic, political characteristics and the hazard they face to help characterise and identify the most vulnerable systems and regions across the EU. The index follows closely the definition of IPCC which relates risk to exposure, vulnerability and hazard. The analysis which is performed at the NUTS3 level, is based on the latest ISIMIP 6 data, and the risk index is calculated for four individual impact chains (agriculture, tourism, water scarcity and labour productivity), while we also formulate an aggregate risk index that combines all four elements. The results indicate that South, South-eastern and coastal regions in Spain, Portugal, Italy, Greece and Bulgaria face higher relative risk compared to the regions that are in the Central and Northern Europe. Regional specificities and interactions between impact chains determine the overall value of the aggregate risk index.

1. Introduction

Climate change is one of the biggest threats for humanity, seriously affecting people and nature. Globally, 2023 was the warmest year on record. The global average temperature for 2023 was 1.46 °C above the pre-industrial baseline, making it 0.17 °C warmer than 2016 — the previous warmest year on record in the HadCRUT5 global temperature dataset, which dates to 1850 (Met Office, 2024). Since the 1980s, Europe has been warming at twice the rate of the global average, making it the fastest-warming continent on Earth. In 2023, the impacts of climate change continued to be seen across Europe, with new records in the "number of days with extreme heat stress", largest area of Europe affected by at least "strong heat stress", largest wildfire, and highest December River flows. As a consequence, millions of people were affected by these extreme weather events. The total losses were estimated at €13.4 billion, with 81% of these losses attributed to flooding (C3S and WMO, 2024).

The climate change-related risks can be significantly reduced by effective policies and actions at both European and national levels. The degree to which damages can be avoided will largely depend on the speed at which we reduce global greenhouse gas emissions and how swiftly and effectively we prepare our societies to adapt to the unavoidable impacts of climate change (EEA, 2024). The European Green Deal (EGD), introduced in 2019, aims to overcome the climate change-related threats and to transform the EU into a climate-neutral economy, where the economic growth is decoupled from resource use, while no person and no place is left behind (European Commission, 2024).

The EU and its Member States have also made significant progress in understanding the climate risks they face and in preparing for them, with national climate risk assessments increasingly being used to guide adaptation policy development. However, societal preparedness remains low, as policy implementation has not kept pace with the rapidly increasing risk levels. Given that most climate risks are shared between the EU and its Member States, coordinated and urgent action across all levels of governance is necessary (EEA, 2024).

To help with understanding of the climate risks, Task 2.6 aims to develop a comprehensive Climate Risk Index to help characterise and identify the most vulnerable systems and regions across the EU, with analyses at NUTS-3 level. This synthetic index will integrate multiple dimensions, including climate change impacts, exposure to climate damages, adaptive capacity and socio-economic impacts. For this purpose, four specific "impact chains" will be selected and analysed. Each pathway combines a specific climate-related risks (such as heat stress) with its impact on a particular socio-economic factor (such as labour productivity), and is defined through a selection of hazard, exposure and vulnerability-related indicators. The Climate Risk Index will then be calculated for each impact chain, allowing the policymakers assess the vulnerability of the European regions and prioritise those at the highest level of risk.

2. Literature review

The concept of vulnerability has been a powerful analytical tool for describing conditions of susceptibility to harm, powerlessness, and marginality in both physical and social systems. It also guides normative analysis aimed at enhancing well-being by reducing risk. Vulnerability assessments incorporate a range of parameters in building quantitative and qualitative pictures of the processes and outcomes of vulnerability (Adger, 2006). The vulnerability frameworks widely used in climate-related vulnerability assessments are often based on the IPCC Third and Fourth Assessment Reports (AR3 and AR4, respectively), used for example in Weis et al. (2016). In this framework, vulnerability is constructed as a function of exposure, sensitivity and adaptive capacity.

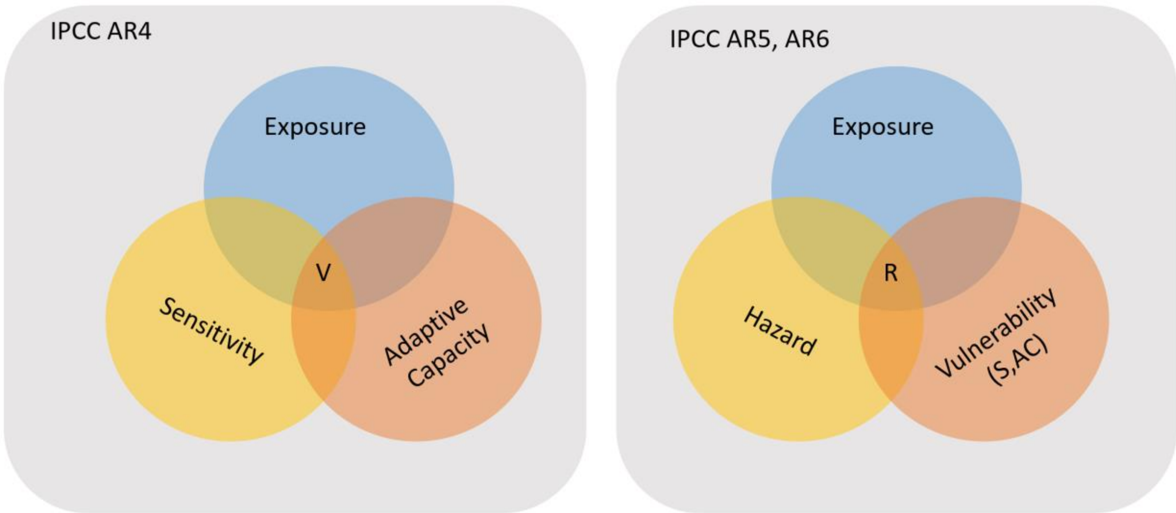
The analysis in Task 2.6 builds on the literature of regional and climate vulnerability assessment using the latest IPCC methodology, as defined in the Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) and Fifth and Sixth Assessment Report (AR5 and AR6, respectively). In these reports, IPCC redefined and separated exposure, which now refers to exposed elements, defined as “the nature and degree to which a system is exposed to climate change” (IPCC, 2019). The concept of vulnerability has been reconceptualized to be a function of sensitivity and adaptive capacity. IPCC defines vulnerability as “the propensity or predisposition to be adversely affected”, and it “encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt” (IPCC, 2019). Sensitivity is defined as “the degree to which a system is adversely affected by climate change” and adaptive capacity as “the capability of a production system or region to better adjust to climate change” (IPCC, 2019).

In addition to vulnerability and exposure, the concept of hazard is introduced, defined as “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” (IPCC, 2019). The dynamic interactions between the climate-related hazard with the vulnerability and exposure results into the climate-related **risks**, which are defined as “the potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems”. Hazard, exposure, and vulnerability each carry uncertainty regarding their magnitude and likelihood of occurrence, and they can change over time and space due to socio-economic changes and human decision-making (IPCC, 2019).

The IPPC’s transition from a vulnerability to risk framework provides new perspectives on assessing climate change impacts and adaptation strategies. By focusing on risk, the IPCC recognizes that a significant portion of climate change impacts are triggered by hazardous events, making the risk concept more appropriate for addressing these impacts, and promotes further research in risk management to better understand the potential consequences of hazardous events. However, in its review of vulnerability assessments, Estoque et al. (2022) found that the IPCC’s revised vulnerability concept has not been well adopted by researchers yet.

The evolution of the concepts of vulnerability and risk in IPCC AR4, AR5 and AR6 are shown in Figure 1, where V stands for vulnerability, R stands for risk, S stands for sensitivity and AC stands for adaptive capacity.

Figure 1: Concepts of vulnerability and risk in IPCC AR4, AR5 and AR6. Source: E3M based on IPCC AR4, AR5 and AR6



Using the IPCC vulnerability framework from AR4, Weis et al. (2016) demonstrate how to apply GIS methods to spatially represent socioeconomic vulnerability in Grenada. Their model combines spatial features representing variables of social sensitivity, community adaptive capacity, and community exposure to flooding in an integrated vulnerability index to measure the vulnerability of communities to flooding by multiplying all the components:

$$V = E * S * AC$$

where V represents vulnerability, E represents exposure, S represents sensitivity and AC represents adaptive capacity. Each sub-index (exposure, sensitivity and adaptive capacity) is composed of indicators, which are averaged to create each sub-index. Each indicator contributes equally to each sub-index, and variables within each indicator are normalised due to physical limits. To spatially represent and visually compare the results, the vulnerability index and its sub-indexes were displayed using a 5 category quantile split.

Using the IPCC framework from AR6, Vrontisi et al. (2024) calculate the Socioeconomic Risk Index (SRI) to identify the European regions at socioeconomic risk of job loss because of the low carbon transition. Similarly to Weis et al. (2016), they combine all sub-indicator with multiplication, while also adding different weighting factors to each sub-indicator:

$$SRI_r = H_r^{wh} * E_r^{we} * V_r^{wv}$$

where SRI_r is the socio-economic index for region r, H represents hazard, E represents exposure, V represents vulnerability, while wh , we and wv stand for the respective weights of each sub-indicator. Each sub-indicator is composed of several indicators, which are also assigned weights. They define seven weighting options for all sub-indicators, resulting in 2,401 combinations. They report the frequency of appearance of regions on the highest risk positions. All sub-indicators and their components are normalised to ensure comparability and enable aggregation of the sub-indicators and their components. The geographical scope of their analysis covers NUTS-2 classification.

A report that is most closely aligned with our approach to Task 2.6 is the final report of the ESPON-CLIMATE project, initially conducted in 2011, that submitted an update in 2022. In the update, it presents a framework for calculating a climate-related risk that is aligned with the IPCC AR5 and AR6. In the analysis, ESPON considers four scenarios (baseline, and low, intermediate and high emissions scenario), covering the EU-27 plus Switzerland, Iceland, Liechtenstein, Norway and United Kingdom at the NUTS3 level in years 2070-2100. They define seven impact chains, which refer to the combination of a particular hazard and receptor, defined through a selection of hazard, exposure and vulnerability indicators. All indicators are rescaled and are subsequently aggregated using equal-weighted geometric mean to obtain the risk components of hazard, exposure and sensitivity. The overall risk score for a particular impact chain is calculated by combining the hazard, exposure and vulnerability components using an equal-weighted geometric mean:

$$R_t = H_t^{\frac{1}{3}} * E_t^{\frac{1}{3}} * V_t^{\frac{1}{3}}$$

Where R_t is the risk for territory t, H_t is the hazard component for territory t, E_t is the exposure for territory t, and V_t is the vulnerability for territory t. The climatic component refers either to biophysical impacts or hazard depending on the impact chain examined. The results are then linked to the NUTS3 geometries. Besides the risks related to the seven impact chains, an aggregated risk is calculated. In ESPON (2022), the hazard is projected to the end of century, while the exposure and vulnerability are not. This means that the report interprets the results as what the effect of the future hazard would be on the present society and environment.

There are several indexes that ranks countries (in most of the cases), or regions according to their probability of experiencing adverse effects of climate change (Table 1). Most indexes are based on a similar context as the one defined in the IPCC report, i.e., combining elements of hazard (or biophysical impacts) with elements from the socioeconomic and political and political spectrum to capture vulnerability and exposure to climate change.

For example, the European Climate Risk Assessment by EEA (2024), is a comprehensive assessment of climate risks the EU regions, which follows the IPCC AR6 methodology. EEA identifies 36 climate risks and evaluates the risks in the contexts of risk severity, policy horizon, policy readiness and risk ownership. Climate risks are clustered into the following categories: ecosystems, food, health, infrastructure and economy and finance. EEA develops a comprehensive methodological framework where climate-related hazards (e.g. heatwaves) and non-climatic risk drivers (e.g. unsustainable agricultural practices) impact the risk categories (e.g. food). Climate impacts can either be direct or can cascade from one system or region to another, including from outside of Europe to Europe and vice versa. Cascading climate risks can lead to system-wide challenges affecting whole societies, with vulnerable social groups particularly affected. EEA further identifies priorities for EU policy action, based on a structured risk assessment while also considering some qualitative aspects, such as social justice.

The Climate Risk Index (CRI), developed by Germanwatch, calculates the aggregate country risk associated to seven hazards. These are classified as hydrological, meteorological and climatological. Hazards are translated into economic losses, fatalities and affected people based on historical data and the relative indicators are assigned weights equal to 50%, 30% and 20% respectively in the calculation of the CRI index. The ND-GAIN Country Index considers six dimensions regarding potential influence of climate change: food, water, health, ecosystem services, human habitat and infrastructure. These constitute the pillar of vulnerability and are defined over exposure (linked to biophysical impacts or hazards), sensitivity and adaptive capacity. The other pillar of the index, readiness, is composed of economic, social and governance elements. All inputs are transformed into indexes and aggregated using a simple arithmetic mean. The U.S. Climatic Vulnerability Index which performs an assessment of risk for U.S.A at the state level (and even goes to the sub-state level), includes two pillars: the baseline vulnerability which consists of health, social & economic, infrastructure and environment components which determines regional resilience and climate risks which include hazards and impacts categorized in extreme events, social and economic and health. At each nest a weighted average approach is adopted to calculate the overall score.

In summary, and from a methodology perspective, most developed indexes receive as inputs biophysical hazards and combined with other socio-economic components, using in most cases a weighted average approach compute the overall risk for a territory.

Table 1: List of risk indexes

Indicator	Country/Team	Climatic inputs	Aggregation method
U.S Climatic Vulnerability Index	US	Temperature, precipitation, wildfires, droughts, storms, flooding	weighted average
Notre Dame Global Adaptation Initiative's (ND-GAIN) Country Index	University of Notre Dame	Impacts: Projected change of cereal yields, projected change of annual runoff, projected change of annual groundwater recharge, freshwater withdrawal rate	summation, linear formula for aggregate index
Climate Risk Index	Germanwatch	Hydrological (flood, mass movement wet), meteorological (storm, extreme temperature), climatological (wildfire, drought, glacial lake outburst flood)	weighted average
Climate Change Performance Index (CCPI)	Germanwatch, New Climate Institute, Climate Action Network International	-	weighted average
ESPON	ESPON	heat stress, coastal flooding, river flooding, droughts, flash floods, wildfire	weighted average

European Climate Risk Assessment (EAA)	European Environmental Agency	mean temperature, heatwaves, total precipitation, heavy precipitation, meteorological drought, agricultural drought	No aggregate Index
ESCB - Physical Risk statistical indicators	European System of Central Banks	coastal flooding, river flooding, wildfires, landslides, subsidence, windstorms, water stress, droughts and rainfall variation	No aggregate Index
INFORM Climate Change Risk Index	Joint Research Center (JRC)	river floods, coastal floods, droughts, epidemics, earthquakes, tsunami	Multiplicative (C-D), geometric average
World Risk Index	Bündnis Entwicklung Hilft, Ruhr University Bochum – Institute for International Law of Peace and Armed Conflict (IFHV)	earthquakes, tsunamis, cyclones, coastal flooding, riverine floodings, droughts, sea-level rise	unweighted geometric mean

3. Methodology

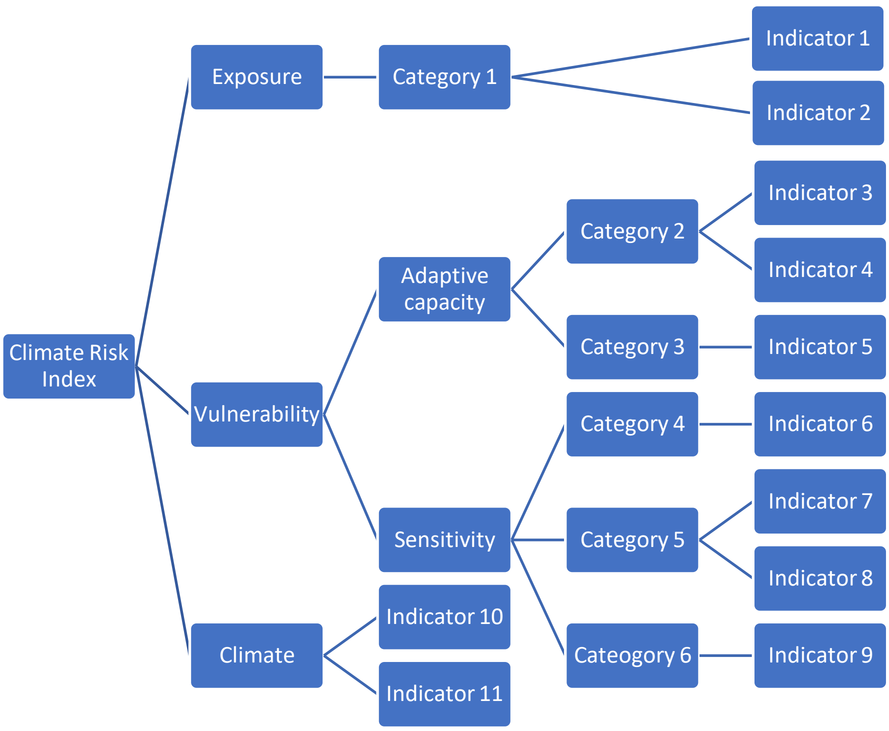
The methodology in Task 2.6 aims to identify and prioritise European regions that are the most vulnerable to climate change-related risks, focusing on four specific impact chains, i.e. combinations of a particular hazard and a receptor. The impact chains considered are the specified in Table 2 below:

Table 2: Impact chains analysed in Task 2.6

Impact chain	Acronym
Wet Bulb Global Temperature (WBGT) on labour productivity	LABOUR
Heat stress and number of wet days on tourist arrivals	TOURIST
Heat stress, precipitation and water balance on agriculture	AGRI
Water balance and water flow on water scarcity	WATER

Our analysis is informed by the literature presented above, especially in terms of the specific indicators that feed into the Climate Risk Index components. The risk index framework is in line with the latest IPCC Assessment Report (AR6). We follow the latest definition of risk as included in the IPCC Glossary (2019), where risk is defined as "potential for adverse consequences for human systems, recognizing the diversity of values and objectives associated with such systems". The Climate Risk Index (CRI) is defined as a combination of Exposure, Vulnerability and Hazard. Each CRI component consists of multiple indicators, which are grouped into thematic categories, as shown in Figure 2 below. For each impact chain, only the relevant indicators are selected, as shown in Table 6, while more details are also provided in the Annex.

Figure 2: Generalized form of the Climate Risk Index



For each impact chain, two different risk scenarios have been analysed considering two representative concentration pathways (RCP): the low emissions (RCP 2.6) and high emissions (RCP 8.5) scenarios in 2050.

The geographical scope of our analysis covers the Eurostat NUTS-3 classification of territorial units for statistics. As a base year of our analysis, we take 2020 as it is well covered in the existing data for the vulnerability and exposure. The data for hazard are provided as projections to 2050. Therefore, our results can be interpreted as what the effect of the future hazard would be on the present society and environment.

4. Components of the climate risk index

The exposure, vulnerability and climate components consist of specific categories and indicators. The indicators were selected and gathered based on the literature review and data availability. The data sources for the indicators are Eurostat[1], ESPON Database[2] and Quality of Government (QoG) Institute[3]. Several indicators from the Risk Data Hub database[4] were identified as relevant, however, the data could not be accessed from the database.[5] The overview of the indicators used, together with the unit of measure, category, data source and resolution are presented in Table 3 (for exposure), Table 4 (for adaptive capacity), Table 5 (for sensitivity) and Table 6 (for climate).

The indicators were either readily available in the relevant databases or were computed, in which case the calculations are shown in the sections below. Mapping from the NUTS-0 and NUTS-2 levels to the NUTS-3 level was performed to convert all indicators to the NUTS-3 level. Most of the indicators were expressed in relative terms, such as percentages. For these indicators, if data were not available at the NUTS-3 level, it was assumed that the NUTS-0 or NUTS-2 level values were applicable to all the corresponding NUTS-3 level regions. There was only one case where an indicator was not expressed in relative terms ('Touristic arrivals'), for which the calculation is shown under Table 3 below.

4.1. Exposure

The IPCC definition of exposure is adopted, which states that exposure is "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" (IPCC, 2019). In line with ESPON (2022) and EEA (2024), we consider the relevant social (population), economic (employment rate, touristic arrivals, and agriculture area) and physical (roads, railways, settlements) categories to be the key determinants of exposure in the regions. The indicators for exposure are presented in Table 3.

Table 3: Exposure Indicators

Indicators	Unit	Category	Data Source	Resolution
Population	Number	Social	EUROSTAT	NUTS-3
Employment	Thousand persons	Economic	EUROSTAT	NUTS-3
Employment (share)	%	Economic	EUROSTAT	NUTS-3
Nights spent at tourist accommodation establishments	Number	Economic	EUROSTAT	NUTS-3

[1] https://ec.europa.eu/eurostat/en/

[2] https://database.espon.eu/

[3] https://www.gu.se/en/quality-government/qog-data

[4] https://drmkc.jrc.ec.europa.eu/risk-data-hub/

[5] Upon e-mail exchange with the Joint Research Centre of the European Commission, we were informed that Risk Data Hub (RDH) shares only information related to disaster losses and disaster risk (and its components hazard, exposure, and vulnerability), therefore we were not able to access data on the individual indicators. The specific indicators of interest were the following: data on roads (ktonnes) at NUTS-3 level, railways (ktonnes) at NUTS-3 level, settlements (km^2) at NUTS-3 level, industrial areas (km^2) at NUTS-3 level, National Adaptation Strategies at NUTS-0 level. These indicators were replaced by similar indicators from EUROSTAT, except for industrial areas and National Adaptation Strategies.

Indicators	Unit	Category	Data Source	Resolution
Touristic arrivals	Number	Economic	EUROSTAT	NUTS-2
Touristic arrivals	Number	Economic	Own calculation based on EUROSTAT data	NUTS-3
Land area	Km^2	Economic	EUROSTAT	NUTS-3
Agriculture share	%	Economic	ESPON Database	NUTS-3
Agriculture area	Km^2	Economic	Own calculation based on EUROSTAT and ESPON Database data	NUTS-3
Roads	Km per thousand km^2	Physical	EUROSTAT	NUTS-2
Railways	Km per thousand km^2	Physical	EUROSTAT	NUTS-2
Settlements	M^2 per capita	Physical	EUROSTAT	NUTS-0

To convert the 'touristic arrivals' from NUTS-2 to NUTS-3 level, a proxy dataset on 'nights spent at tourist accommodation establishments' ('Nights') is used, which is then disregarded in the calculation of the CRI. Firstly, the share of nights at NUTS-3 level is computed as following:

$$Share\ of\ nights\ (NUTS-3) = \frac{Nights\ (NUTS-3)}{Nights\ (NUTS-2)}$$

Secondly, the touristic arrivals at NUTS-3 level are calculated as following:

$$Touristic\ arrivals\ (NUTS-3) = Share\ of\ nights(NUTS-3) * Touristic\ arrivals(NUTS-2)$$

'Touristic arrivals' indicator at NUTS-2 level is disregarded from the future calculations of the CRI.

'Land area' and 'agriculture share' indicators are also disregarded in the calculations as they serve to calculate a proxy for the 'Agriculture area' indicator. All three indicators are at NUTS-3 level. Agriculture area indicator is calculated as follows:

$$Agriculture\ area = Agriculture\ share * Land\ area$$

4.2. Vulnerability

The IPCC definition of vulnerability is adopted which states that it is "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" (IPCC, 2019). We follow the IPCC approach and consider vulnerability as *a function of the sensitivity and adaptive capacity* of the regions to be adversely affected by the climate risk, with the latter having a negative functional relationship with vulnerability. We consider indicators from ESPON (2022) and EEA (2024), while also adding additional indicators, related to social, political, economic, environmental , technological, and infrastructure areas, as shown in Table 4 and Table 5 below.

4.2.1. Adaptive capacity

In our analysis, we define adaptive capacity as "the ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities or to respond to consequences” (IPCC, 2019). The specific indicators used for adaptive capacity are presented in the following table.

Table 4: Vulnerability – adaptive capacity

Indicators	Unit	Category	Data Source	Resolution
Persons with tertiary education	% of population 15-64 years	Social	EUROSTAT	NUTS-2
Long-term health expenditure	% of GDP	Social	EUROSTAT	NUTS-0
Environmental protection expenditure	% of GDP	Environmental	EUROSTAT	NUTS-0
Unemployment rate	% of population 15-74 years	Economic	EUROSTAT	NUTS-2
Risk of poverty	% of population	Economic	EUROSTAT	NUTS-2
GDP per capita	EUR per inhabitant	Economic	EUROSTAT	NUTS-3
Debt	% of GDP	Economic	EUROSTAT	NUTS-0

4.2.2. Sensitivity

Sensitivity is defined as “the degree to which livelihoods and particularly local jobs are adversely affected, directly or indirectly, by climate and energy policies in place” (Vrontisi et al., 2024). The specific indicators considered for sensitivity are presented in the table below.

Table 5: Vulnerability – sensitivity Indicators

Indicators	Unit	Category	Data Source	Resolution
Old age dependency	population 0-14 years and 65+ years over population 15-64 years	Social	EUROSTAT	NUTS-3
European Quality of government index (EQI)	Index	Political	QoG Institute	NUTS-2
Sectoral GVA	Mil. EUR	Economic	EUROSTAT	NUTS-3
Labour input to GVA	Mil. EUR per thousand persons	Economic	Own calculation based on EUROSTAT data	NUTS-3

‘Labour input to GVA’ is calculated as following, where all indicators are at NUTS-3 level:

$$Labour\ input\ to\ GVA = \frac{GVA}{Labour}$$

‘The European Quality of Government Index (EQI)’, developed by the QoG Institute, is an index derived from a comprehensive citizen survey. This survey gathers responses on individuals' perceptions and experiences with public sector corruption, as well as their views on whether various public sector services are provided impartially and are of good quality (QoG Institute, 2024).

4.3. Climate component

Hazard is defined as "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" (IPCC, 2019). The specific indicators considered for the climate component (which may include both hazards and impacts depending on the information available) were provided by CMCC and PIK based on D2.4. The climatic variables provided are based on CMIP6 and reflect the latest trends and developments of climate modelling.

4.4. Overview of the indicators relevant for the specific impact chains

The overview of the relevant indicators considered for each impact chain is presented below.

Table 6: Indicators considered for the impact chains

Indicators	Labour productivity	Tourism	Agriculture	Water scarcity
Climate component				
Maximum continuous hot days		•		
Number of hot days (max temperature above 30)		•	•	
Precipitation			•	
Water balance			•	•
Water flow				•
Number of wet days		•		
Maximum flow				
WBGT	•			
Exposure				
Social				
Population	•			•
Economic				
Employment (sector specific)			•	
Employment rate (sector specific)			•	
Touristic arrivals		•		
Agricultural area			•	

Indicators	Labour productivity	Tourism	Agriculture	Water scarcity
Physical				
Roads				
Railways				
Settlements				
Vulnerability				
Social sensitivity				
Old age dependency	•	•	•	•
Political sensitivity				
European Quality of Government Index	•	•	•	•
Economic sensitivity				
Labour input (labour to GVA)	•			
Environmental capacity				
Environmental protection expenditure	•	•	•	
Economic capacity				
Unemployment rate	•	•	•	•
Risk of poverty	•	•	•	•
Regional GDP per capita	•	•	•	•
Debt to GDP	•	•	•	•

5. Estimation of the Climate Risk Index

This chapter describes the steps in estimation of the Climate Risk Index.

5.1. Normalisation

To calculate the Climate Risk Index, we firstly normalise all indicators across the regions r using the Min-Max approach with the following formula:

$$IN_r = \frac{I_r - I_{min}}{I_{max} - I_{min}}$$

where IN is the normalised indicator. The normalisation of indicators ensures that all values fall within the range [0,1], and therefore data on different scales can be standardised and directly compared, while maintaining the proportional distance between the data points. Normalisation of data also ensures that all indicators contribute equally to the Climate Risk Index components, regardless of their original scale.

5.2. Calculation of the Climate Risk Index

The Climate Risk Index (CRI) is defined as a combination of climate component, exposure and vulnerability, in line with the latest IPCC AR6 framework definition. The components are combined with multiplication, similar to Weis et al. (2016), ESPON (2022) and Vrontisi et al. (2024), as follows:

$$CRI_r = CC_r^{wh} * E_r^{we} * V_r^{wv}$$

Where CRI_r stands for risk index in region r, CC_r is the climate inputs for region r, E is the exposure for region r, and V is the vulnerability for region r. While Weis et al. (2016) do not apply any weights to the sub-indicators, ESPON (2022) and Vrontisi et al. (2024) use versions of a geometric mean. In this analysis, we adopt a similar methodology to Vrontisi et al. (2024), where different weighting factors can be applied to each sub-indicator. Weights wh, we and wv are applied to the CRI components. The weights used for the calculation of individual Risk Indexes are provided in the Annex.

The vulnerability component of the CRI is calculated as following:

$$V_r = \frac{S_r^{ws}}{AC_r^{wa}}$$

Where S_r stands for sensitivity in region r, and AC_r stands for adaptive capacity in region r. Ws and wa are the respective weights of the vulnerability components. In the “central” scenario, the weights are equal to 1/2.

Each component (exposure, adaptive capacity, sensitivity and hazard) is composed of one or more of the following categories: social, economic, physical, environmental, political, technological, and infrastructure. The categories are composed of individual normalised indicators. The full diagram of the framework can be seen in Annex 1. A simplified diagram of the framework is shown in Figure 2.

Each category index is computed by combining all relevant indicators with a multiplication:

$$Category = Indicator_1^{w1} * Indicator_2^{w2} * Indicator_n^{wn}$$

Where *n* is the number of indicators within a category, and w1, w2 and wn are the respective weights of the indicators. In the “central” scenario, the weights are equal to 1/n. For the indicators within the exposure, sensitivity and hazard components, where an indicator *increases* the index (for example, larger population in a region results in higher exposure), it is left in its original form. When it *decreases* the index, its complement to one is taken and used in the calculation.

To calculate the main climate risk indicator components (exposure, adaptive capacity, sensitivity, and hazard), all relevant categories within a component are combined with multiplication:

$$Component = Category_1^{w1} * Category_2^{w2} * Category_n^{wn}$$

Where *n* is the number of categories within a component and w1, w2 and wn are the respective weights of each category. In the “central” scenario, the weights are equal to 1/n,

The Climate Risk Index is calculated for each impact chain separately using a weighted average approach. For climatic data we use the percentage change from historical average values:

$$Hazard = w_1 * Climatic\_variable_1 \quad + w_2 * Climatic\_variable_1 \quad + \cdots + w_n * Climatic\_variable_n$$

The list of inputs to calculate the Hazard component for each individual chain are:

1. WBGT on labour productivity [LABOUR]
2. Heat stress and number of wet days on tourist arrivals [TOURIST]
3. Heat stress, precipitation and water balance on agriculture [AGRI]
4. Water balance and water flow on water scarcity [WATER]

For the aggregate Risk Index we use the following formula:

$$ARI_{reg} = RI\_AGR^{a}_{reg} \cdot RI\_TOUR^{a}_{reg} \cdot RI\_WATER^{a}_{reg} \cdot RI\_LAB^{a}_{reg}$$

5.3. Results

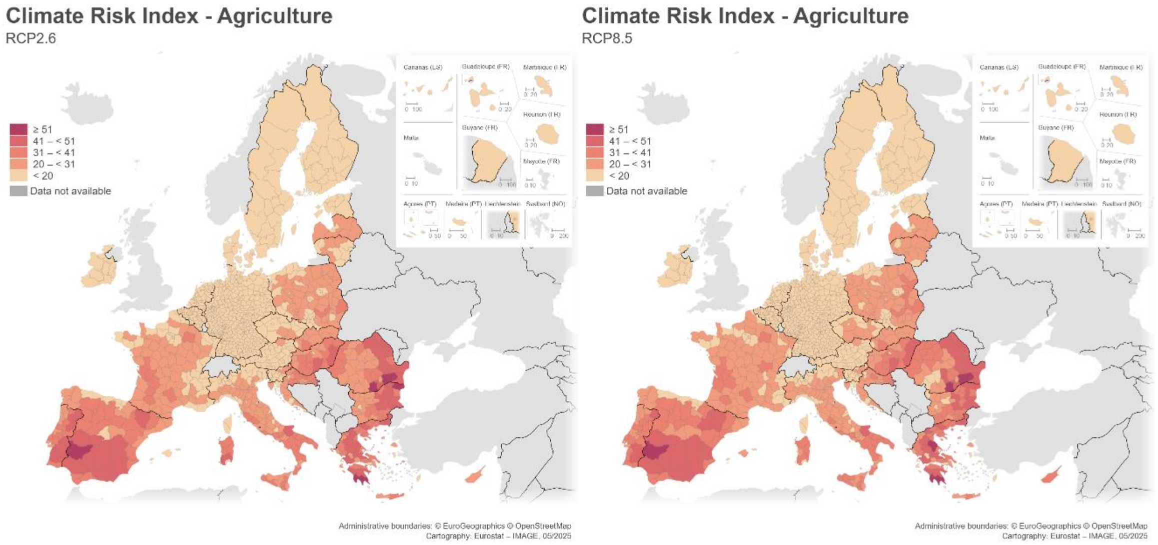
This chapter provides the overview of the Climate Risk Index in the EU NUTS3 regions. The regions are assigned into 5 classes using equal interval classification method. The classes are determined by dividing the range of the CRI values into equal-sized intervals. The results are shown separately for each impact chain and include two variants: one that includes the hazard assuming the RCP 2.6 (low emissions) scenario and the second with hazard assuming the RCP 8.5 (high emissions) scenario. The maps show the spatial pattern of the climate risk, i.e. it shows which regions are most likely to be affected. The individual indicators used for calculation of the risk index for each impact chain can be found in Table 6.

While we use current data for the exposure and vulnerability sub-components, we use the 2050 projections for the hazard sub-component. Therefore, the results can be interpreted what the effect of the future hazard would be on the present society and environment. Besides the key results on the Climate Risk Index, the index subcomponents are also shown for each impact chain to assess the relative importance of each component in relation to the overall index.

5.3.1. Agriculture

The maps of the **risk related to the climate-related stress on agriculture** are shown in Figure 3 for the RCP 2.6 (left column) and RCP 8.5 (right column). The maps show a distinct north-south pattern, where the southern areas are expected to be more affected by the climate-related stress. Very high to high-risk index can be observed in South, in regions of France, Spain, Italy and Greece while also significant risk is projected for Eastern European countries such as Bulgaria and Romania. Comparing the two RCP scenarios, there is no significant change in the spatial pattern. The average risk index average in the RCP 8.5 scenario is about 9% higher compared to the RCP 2.6 scenario.

Figure 3: Climate risk index – Agriculture



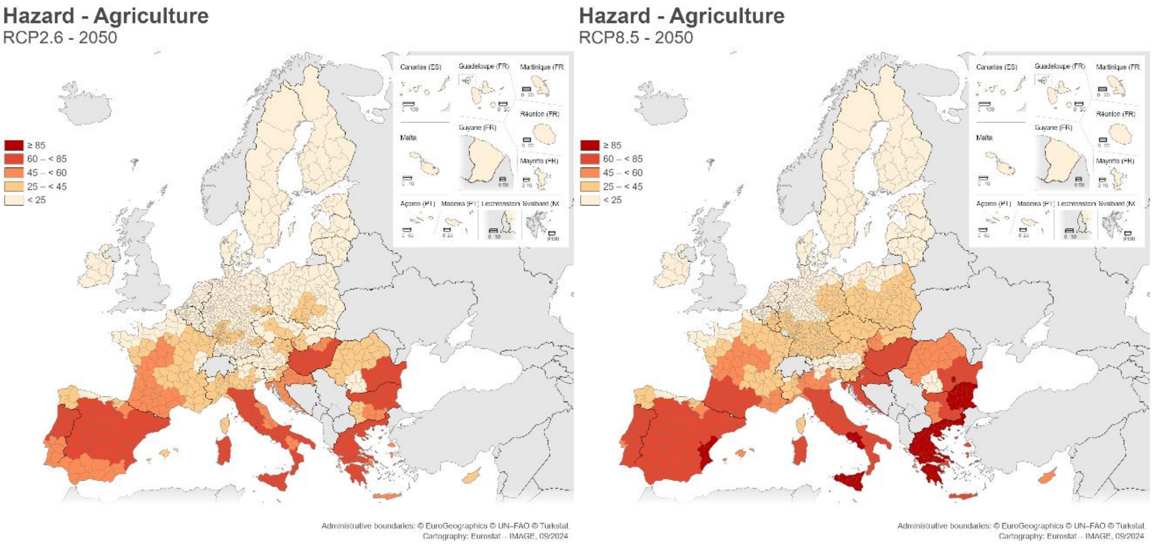
For the Climate Risk Index as well as for the index sub-components, five equal interval classes are defined. The break values for the class distribution of the Climate Risk Index are shown in Table 7.

Table 7: Class breaks for the Climate Risk Indicator

Break values	Legend of labels
≥ 51	Very high
41—51	High
31—41	Medium
20—31	Low
<20	Very low

The maps of **hazard** are shown in Figure 4 for the RCP 2.6 (left column) and RCP 8.5 (right column). In terms of the differences between the RCP scenarios, a similar north-south pattern as in the overall risk index can be observed. It is expected that the southern regions will face higher hazard in terms of the climate-related stress. High to very high risks related to the climate hazard indicators can be observed in Italy, Spain, France, Hungary, Bulgaria, Romania and Greece, across the scenarios. Parts of South Germany, and Poland face relatively higher risk in RCP8.5 compared to RCP2.6 and are classified as medium-risk regions compared to low-risk regions. In other countries, the hazard is classified mostly as low to very low. The average hazard across the regions is about 28% lower in the RCP 8.5 compared to RCP 2.6 scenario.

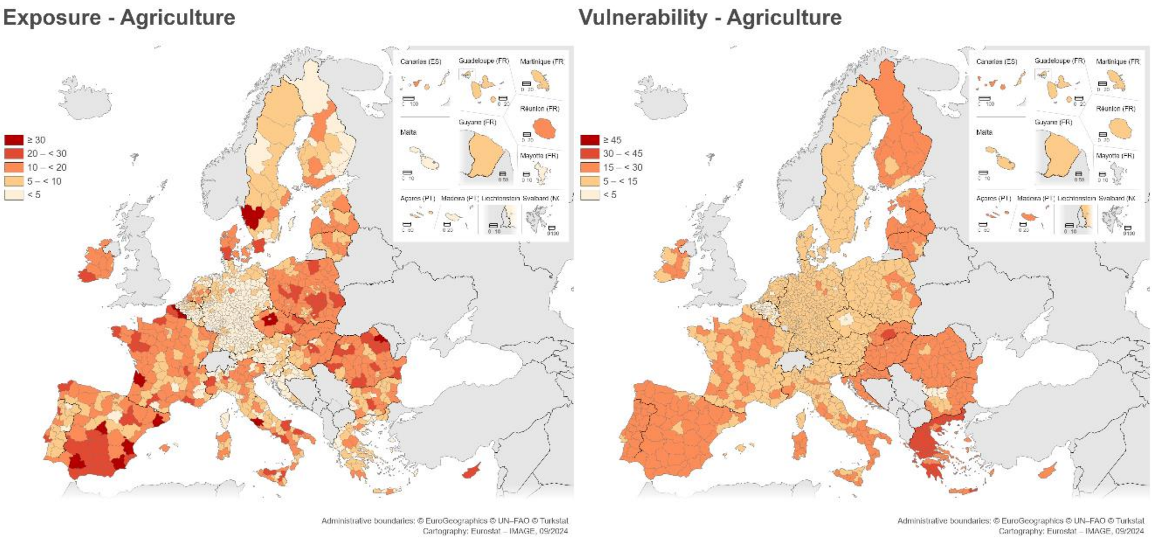
Figure 4: Hazard in RCP2.6 and in RCP8.5 - Agriculture



The **exposure and vulnerability** of the regions are shown in a map in Figure 5. Vulnerability and exposure do not vary between the two climatic variants as they are composed of factors that are not related to climate change. Exposure depends on the primary sector employment and on the agricultural land. In terms of vulnerability, which is composed of sensitivity and adaptive capacity, the highest score is recorded in Spanish and Portuguese in south-western Europe and

Overall, the observed spatial pattern for the Climate Risk Index can be attributed mostly to the spatial pattern of the hazard and exposure components and only in few cases (e.g., in Greece) can be attributed also to the hazard-vulnerability axis.

Figure 5: Exposure and Vulnerability - Agriculture



The **top 20 regions with the highest Climate Risk Index** are presented in Table 8 (for RCP 2.6) and Table 9 (for RCP 8.5). The risk score is presented along with their ranking in terms of hazard, exposure and vulnerability. In general, the Climate Risk Index of the top 15 regions is driven by the high hazard, followed by exposure and to lower extent from vulnerability. While hazard and exposure are typically significantly higher for these regions compared to the EU average, the difference in vulnerability is typically slightly negative or positive. Most of the top-risk regions are found in Romania and Greece (6/20) both in the RCP2.6 and in RCP8.5. In the list of regions with the highest risk we find regions that are agricultural intensive, in the sense that a high share of employment is engaged in primary sector activities. For example, Teleorman (RO317) and Călăraşi (ES613) in Romania more than 35% of the employment is on the primary sector while in Lakonia (EL653) approximately 33% of total employment is in agriculture..

Table 8: Top 20 EU regions according to their Climate Risk Index, RCP 2.6

		Risk Score	Median Risk score	Hazard (Ranking)	Exposure (ranking)	Vulnerability (ranking)
RO317	Teleorman	53.4	13	113	10	73
EL653	Λακωνία, Μεσσηνία	53.1	13	107	39	15
RO312	Călăraşi	53.0	13	113	9	84
ES431	Badajoz	51.9	13	126	4	135
RO315	Ialomiţa	51.9	13	113	11	100
BG332	Добрич	51.6	13	36	21	68
EL633	Ηλεία	50.8	13	3	138	1
EL612	Λάρισα	50.6	13	57	93	7
EL611	Καρδίτσα, Τρίκαλα	50.6	13	57	87	11
PT1C2	Baixo Alentejo	48.6	13	206	28	48
EL526	Σέρρες	48.4	13	63	127	8
ES422	Ciudad Real	48.2	13	145	17	98
RO221	Brăila	48.1	13	139	19	85
EL631	Αιτωλοακαρνανία	47.3	13	3	160	18
RO222	Buzău	46.9	13	139	23	110
ES613	Córdoba	46.8	13	193	16	136
EL524	Πέλλα	46.6	13	63	191	2
ES423	Cuenca	46.5	13	145	40	69
RO216	Vaslui	46.4	13	303	1	145
BG325	Силистра	46.2	13	31	107	42

Table 9 Top 20 EU regions according to their Climate Risk Index, RCP 8.5

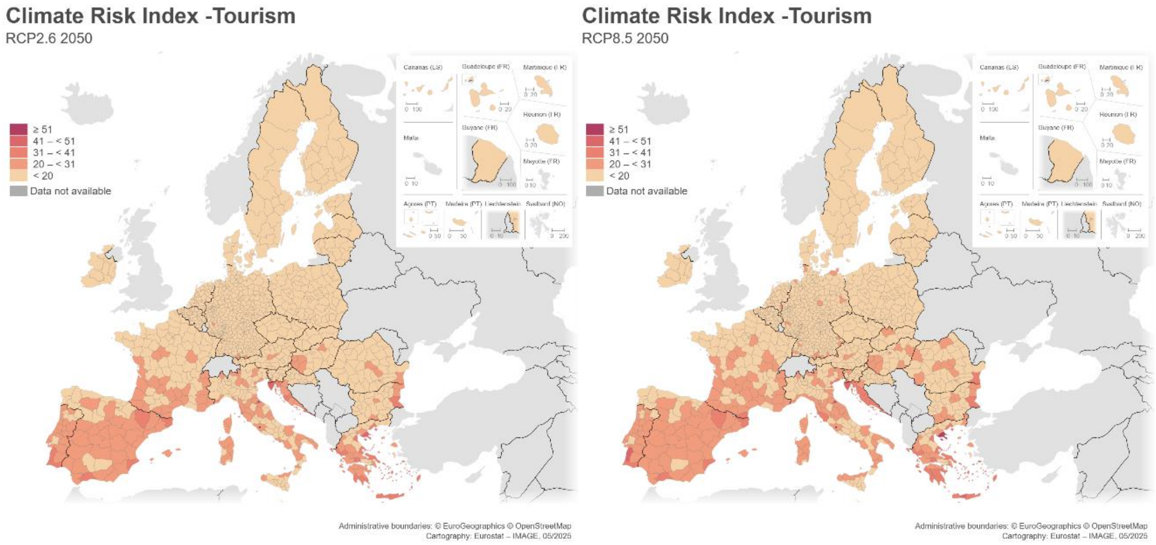
		Risk Score	Median Risk score	Hazard (Ranking)	Exposure (ranking)	Vulnerability (ranking)
RO317	Teleorman	53.6	13	113	10	73
EL653	Λακωνία, Μεσσηνία	54.5	13	107	39	15
RO312	Călăraşi	53.0	13	113	9	84

		Risk Score	Median Risk score	Hazard (Ranking)	Exposure (ranking)	Vulnerability (ranking)
ES431	Badajoz	54.4	13	126	4	135
RO315	Ialomiţa	52.2	13	113	11	100
BG332	Добрич	50.3	13	36	21	68
EL633	Ηλεία	49.0	13	3	138	1
EL612	Λάρισα	51.1	13	57	93	7
EL611	Καρδίτσα, Τρίκαλα	49.9	13	57	87	11
PT1C2	Baixo Alentejo	45.2	13	206	28	48
EL526	Σέρρες	45.5	13	63	127	8
ES422	Ciudad Real	50.6	13	145	17	98
RO221	Brăila	49.3	13	139	19	85
EL631	Αιτωλοακαρνανία	46.1	13	3	160	18
RO222	Buzău	48.7	13	139	23	110
ES613	Córdoba	51.0	13	193	16	136
EL524	Πέλλα	44.5	13	63	191	2
ES423	Cuenca	45.4	13	145	40	69
RO216	Vaslui	50.8	13	303	1	145
BG325	Силистра	43.0	13	31	107	42

5.3.2. Tourism

The maps of the **risk related to the climate-related stress on tourism** (measured by touristic arrivals) are shown in Figure 6 for the RCP 2.6 (left column) and RCP 8.5 (right column). The spatial distribution follows a north-south pattern. The regions with the high to very high risk of the tourism being affected by the climate-related stress are located especially in Spain, France, Italy and Croatia. There is no significant change in the spatial pattern observed between RCP 2.6 and RCP 8.5 scenarios, but an increase in the risk in Italian, southern France and some eastern European regions (mainly in Romania and Bulgaria). In overall, we find a 13% increase in the overall risk index in the RCP 8.5 compared to the RCP 2.6 scenario.

Figure 6: Climate risk index - Tourism



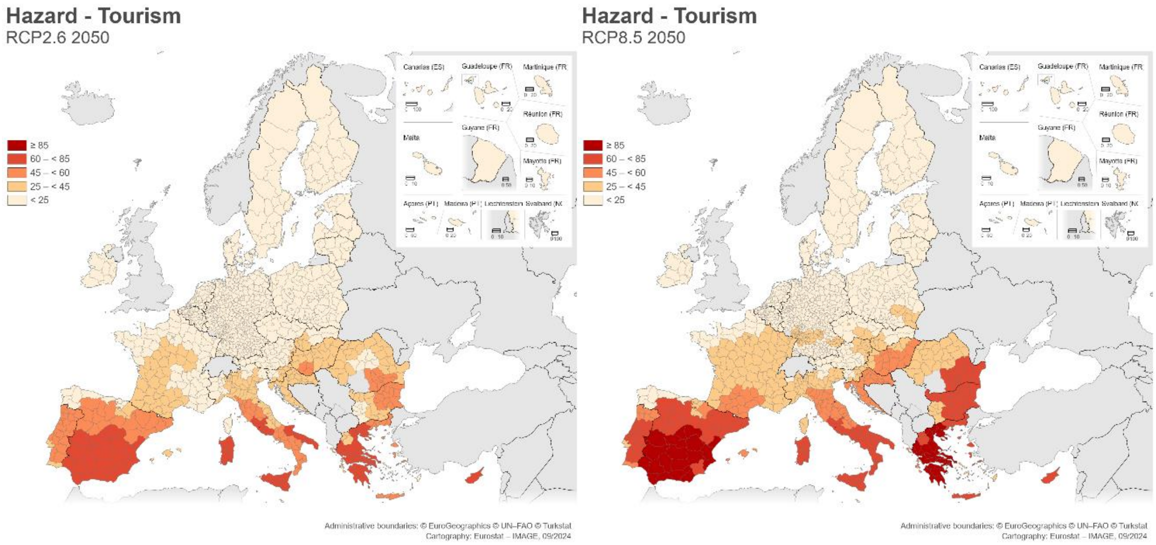
The break values for the Climate Risk Index class distribution are shown in Table 10.

Table 10: Class breaks for the Climate Risk Indicator

Break values	Legend of labels
≥ 51	Very high
41—51	High
31—41	Medium
20—31	Low
<20	Very low

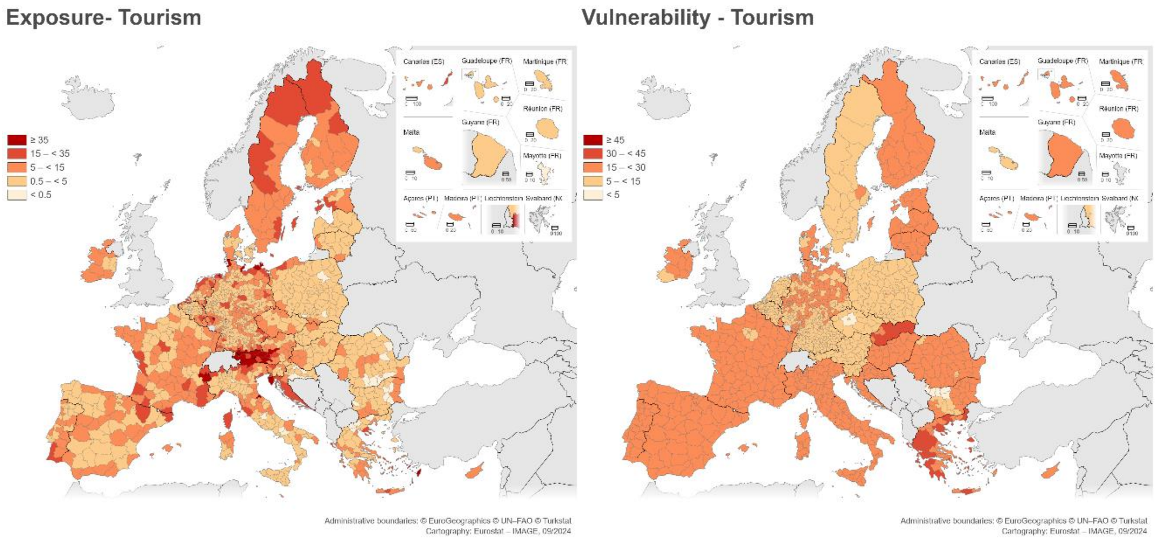
The maps of **hazard** related to the tourism is shown in Figure 7 for the RCP 2.6 (left column) and RCP 8.5 (right column). The maps also show a clear north-south pattern, where the southern regions, in particular Spain, Italy and Greece are more susceptible to the climate-related hazard. The hazard associated with tourism is found to be higher in RCP8.5 compared to RCP2.6 by 36%.

Figure 7: Hazard in RCP2.6 and in RCP8.5 - Tourism



The maps of **exposure and vulnerability** are shown in Figure 8. Neither exposure nor vulnerability show a clear spatial pattern. Most of the regions are ranked as medium to low regarding exposure, with very few exceptions in Spain, France, Austria, Italy and Sweden. Regional exposure is a function of employment in services related to tourism (e.g., retail trade, accommodation and food services) and on the share of tourists with respect to local population as a measure of tourism intensity. On the other hand, most regions are ranked as medium to high in relation to the vulnerability sub-component of the climate risk index.

Figure 8: Exposure and Vulnerability - Tourism



Overall, the observed north-south pattern for the Climate Risk Index can be attributed mostly to the spatial pattern of the hazard sub-component. The top *20* regions with the highest Climate Risk Index are presented in Table 11 (for RCP 2.6) and Table 12 (for RCP 8.5). In general, the Climate Risk Index of the top 20 regions for tourism is not driven solely by one of component but is rather a combination of all three elements. The regions which are identified being at higher risk scores above the average in all three categories. Greece has the highest number of regions in the top 20 with thirteen out of 20 in the top positions in the RCP2.6 and fifteen out of 20 in the RCP8.5. Many of the regions are islands or part of them (e.g., EL621, EL443, EL421 etc.) or highly touristic areas (e.g., EL527 in Greece, PT150 in Portugal).

Table 11: Top 20 EU regions according to their Climate Risk Index, RCP 2.6

		Risk Score	Median Risk score	Hazard (Ranking)	Exposure (ranking)	Vulnerability (ranking)
EL527	Χαλκιδική	48.3	13	53	25	7
HR036	Istarska županija	41.8	13	236	6	87
PT1C1	Alentejo Litoral	38.6	13	109	39	53
EL621	Ζάκυνθος	38.4	13	277	24	3
EL433	Ρέθυμνο	36.8	13	138	83	13
EL421	Κάλυμνος, Κάρπαθος – Ηρωική Νήσος Κάσος, Κως, Ρόδος	36.8	13	361	13	9
EL613	Μαγνησία, Σποράδες	36.8	13	23	170	11
PT150	Algarve	36.3	13	244	30	58
EL434	Χανιά	35.6	13	138	104	12
EL525	Πιερία	35.1	13	109	558	109
EL422	Άνδρος, Θήρα, Κέα, Μήλος, Μύκονος, Νάξος, Πάρος, Σύρος, Τήνος	35.1	13	361	22	6
EL622	Κέρκυρα	35.1	13	277	51	4
EL431	Ηράκλειο	34.7	13	138	119	15
ES617	Málaga	34.1	13	15	107	166
EL432	Λασίθι	34.0	13	138	133	19
EL541	Άρτα, Πρέβεζα	33.3	13	50	260	20
HR031	Primorsko-goranska županija	33.2	13	236	40	96
ES241	Huesca	33.0	13	85	66	253
HR037	Dubrovačko-neretvanska županija	33.0	13	236	43	90
EL515	Θάσος, Καβάλα	32.9	13	95	228	8

Table 12:Top 20 EU regions according to their Climate Risk Index, RCP 8.5

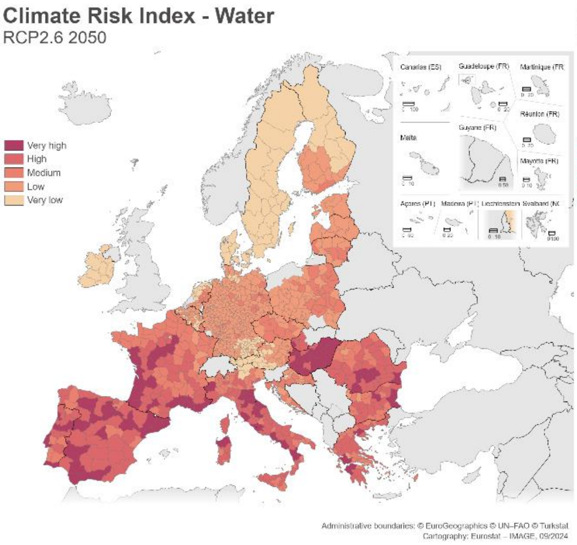
		Risk Score	Median Risk score	Hazard (Ranking)	Exposure (ranking)	Vulnerability (ranking)
EL527	Χαλκιδική	54.1	14	17	25	7
HR036	Istarska županija	45.8	14	210	6	87
EL621	Ζάκυνθος	44.7	14	238	24	3
EL433	Ρέθυμνο	41.3	14	116	83	13

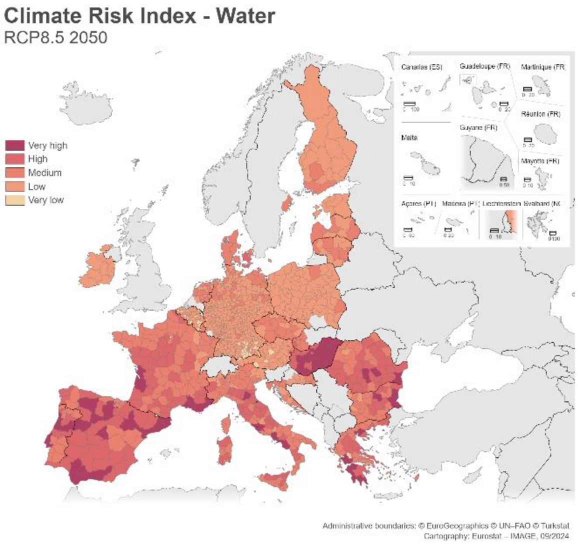
		Risk Score	Median Risk score	Hazard (Ranking)	Exposure (ranking)	Vulnerability (ranking)
PT1C1	Alentejo Litoral	41.3	14	130	39	53
EL622	Κέρκυρα	40.8	14	238	51	4
EL613	Μαγνησία, Σποράδες	40.3	14	14	170	11
EL421	Κάλυμνος, Κάρπαθος – Ηρωική Νήσος Κάσος, Κως, Ρόδος	40.2	14	381	13	9
EL434	Χανιά	39.9	14	116	104	12
EL525	Πιερία	39.3	14	130	558	109
EL431	Ηράκλειο	38.9	14	116	119	15
PT150	Algarve	38.9	14	263	30	58
EL422	Άνδρος, Θήρα, Κέα, Μήλος, Μύκονος, Νάξος, Πάρος, Σύρος, Τήνος	38.3	14	381	22	6
EL432	Λασίθι	38.2	14	116	133	19
EL515	Θάσος, Καβάλα	37.0	14	66	228	8
EL541	Άρτα, Πρέβεζα	36.7	14	36	260	20
EL624	Λευκάδα	36.6	14	238	110	1
BG341	Бургас	36.5	14	54	115	111
EL653	Λακωνία, Μεσσηνία	36.4	14	40	230	34
HR031	Primorsko-goranska županija	36.4	14	210	40	96

5.3.3. Water scarcity

The maps of the **risk related to the climate-related stress (water balance and water flow on water scarcity)** are shown in Figure 9 for the RCP 2.6 (left column) and RCP 8.5 (right column). The maps show that central and northern European regions face relatively lower risk compared to the southern and eastern European areas, which are expected to be more affected by the climate-related stress in terms of the water scarcity. Very high to high-risk index can be observed in regions of Spain, France Italy, Greece and Hungary. There is no significant change in the spatial pattern between the two scenarios. The overall risk index average in the RCP 8.5 scenario is about 4% lower than in the RCP 2.6 scenario.

Figure 9: Climatic Risk Index – Water scarcity





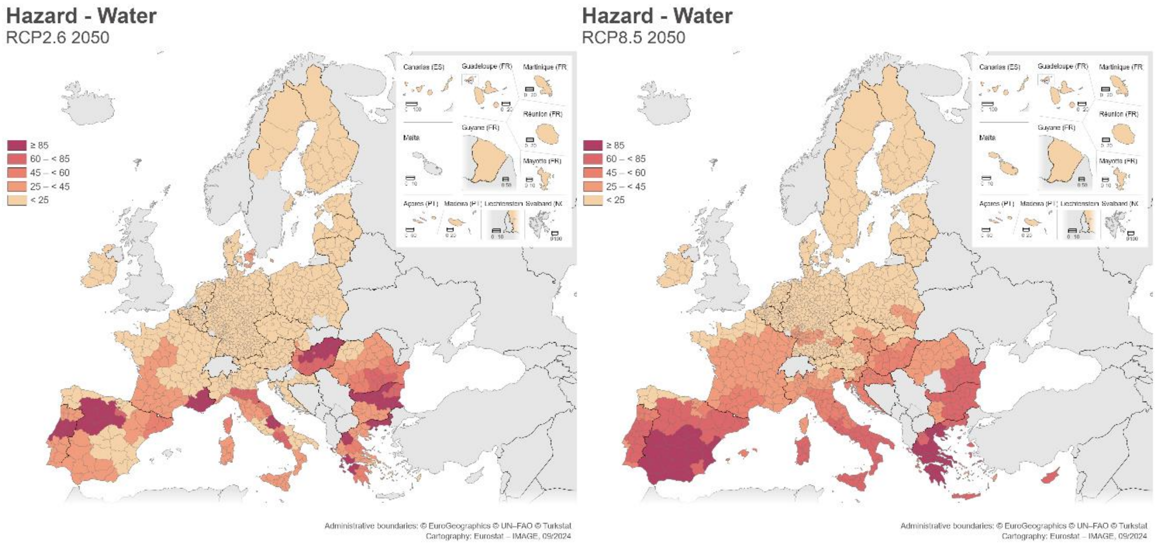
For the Climate Risk Index as well as for the index sub-components, five equal interval classes are defined. The break values for the class distribution of the Climate Risk Index are shown in the following table.

Table 13: Class breaks for the Climate Risk Index Indicator

Break values	Legend of labels
≥ 32	Very high
18—32	High
12—18	Medium
5—12	Low
<5	Very low

The maps of **hazard** related to water scarcity are shown in Figure 10 for the RCP 2.6 (left column) and RCP 8.5 (right column). In terms of the differences between the RCP scenarios, a more pronounced north-south pattern as in the overall risk index can be observed. It is expected that the southern regions will face higher hazard in terms of the climate-related stress. High to very high risks related to the climate hazard indicators can be observed in Italy, Spain, France, Hungary, Bulgaria, Romania and Greece, across the scenarios. In other countries, the hazard is classified mostly as low to very low.

Figure 10: Hazard in RCP2.6 and in RCP8.5 - Tourism



The **exposure and vulnerability** of the regions are shown in a map in Figure 11. Most of the regions are estimated to have a very low to medium exposure. In terms of vulnerability, which is composed of sensitivity and adaptive capacity, most regions are classified to have a medium to high vulnerability, while no clear spatial pattern can be observed. Overall, the observed south-north pattern for the Climate Risk Index can be attributed mostly to the spatial pattern of the hazard sub-component.

The **top 20 regions with the highest Climate Risk Index** are presented in Table 14 (for RCP 2.6) and Table 15 (for RCP 8.5). In overall, the regions at highest risk are in Spain, Italy, France and Hungary. Between the two climatic variants, we find that Spanish regions are most affected in RCP8.5 as seven out of twenty regions are placed in the top 20 tier compared to RCP2.6 where only three Spanish regions are found in the most affected shortlist.

Figure 11: Exposure and Vulnerability – Water scarcity

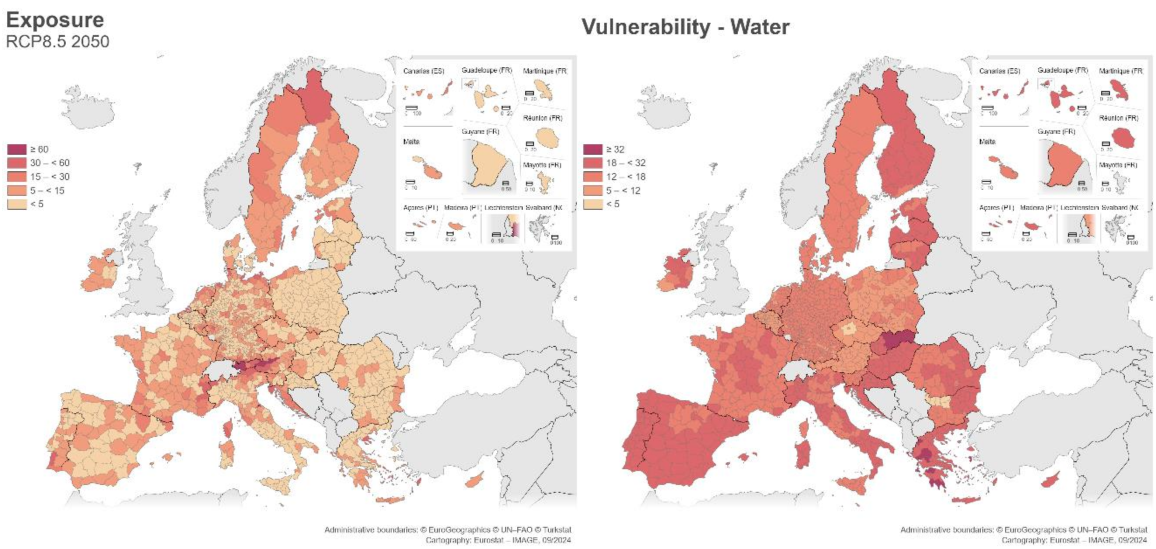


Table 14 Top 20 EU regions according to their Climate Risk Index, RCP 2.6

Region code	Region name	Climate Risk Index	Hazard	Exposure	Vulnerability	Hazard difference
ES511	Barcelona	43	11	129	2	430
FRL04	Bouches-du-Rhône	37	11	50	17	589
ITF33	Napoli	37	11	95	32	360
ITI43	Roma	36	11	285	3	702
FRL05	Var	36	11	51	40	407
ITF35	Salerno	35	11	97	67	222
HU120	Pest	35	10	57	69	260
ES300	Madrid	34	10	303	1	677
HU311	Borsod-Abaúj-Zemplén	33	10	61	155	120
FRI12	Gironde	33	10	191	13	471
HU321	Hajdú-Bihar	33	10	64	175	89
RO223	Constanţa	32	10	114	43	226
BG341	Бургас	32	10	35	163	151
PT170	Área Metropolitana de Lisboa	32	10	243	10	248
FRI32	Charente-Maritime	32	10	214	34	265
ES514	Tarragona	32	10	132	49	339
RO316	Prahova	31	10	91	129	191
ES512	Girona	31	10	130	59	281
HU232	Somogy	31	10	68	266	71
HU331	Bács-Kiskun	30	10	71	234	127

Table 15 Top 15 EU regions according to their Climate Risk Index, RCP 8.5

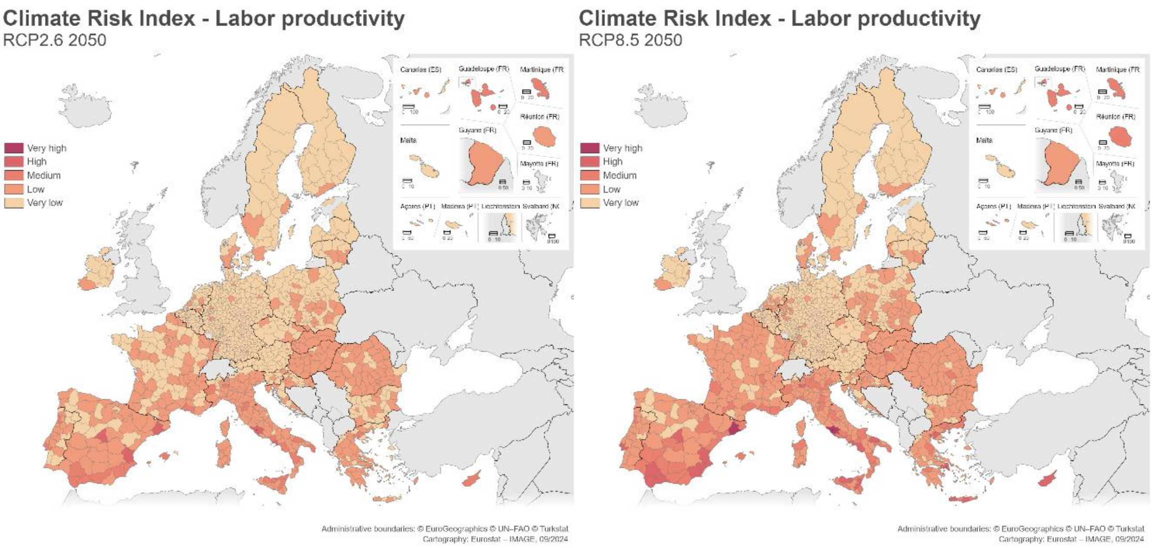
Region code	Region name	Climate Risk Index	Hazard	Exposure	Vulnerability	Hazard difference
ES511	Barcelona	38	11	129	2	430
FRL04	Bouches-du-Rhône	37	11	50	17	589
FRL05	Var	36	11	51	40	407
HU120	Pest	35	11	57	69	260
HU311	Borsod-Abaúj-Zemplén	33	11	61	155	120
ITF33	Napoli	33	11	95	32	360
HU321	Hajdú-Bihar	33	11	64	175	89
BG341	Бургас	32	11	35	163	151
RO223	Constanţa	31	11	114	43	226
ITF35	Salerno	31	11	97	67	222
ES300	Madrid	30	11	303	1	677
ES418	Valladolid	30	11	23	151	331
ES413	León	30	11	18	168	279

Region code	Region name	Climate Risk Index	Hazard	Exposure	Vulnerability	Hazard difference
ES618	Sevilla	30	11	251	5	199
HU323	Szabolcs-Szatmár-Bereg	30	11	66	262	104
ES415	Salamanca	30	11	20	183	263
FRL06	Vaucluse	29	11	52	156	392
PT16B	Oeste	29	11	4	314	87
PT16E	Região de Coimbra	29	11	6	292	106
ES617	Málaga	29	11	250	8	214

5.3.4. Labor productivity

The maps of the **risk related to the climate-related stress (WBGT) on labour productivity** are shown in Figure 12 for the RCP 2.6 (left column) and RCP 8.5 (right column). The maps show a north-south pattern, where the southern areas are estimated to be more affected by the climate-related stress. Very high to high-risk index can be observed especially in the regions of Spain and Italy in the RCP8.5. There is a slight change in the spatial pattern between the two scenarios, where more regions are classified as having a medium instead of a low risk in the RCP 8.5 scenario. The overall risk index average in the RCP 8.5 scenario is about 16% higher than in the RCP 2.6 scenario.

Figure 12: Climatic Risk Index – Labor productivity



The break values for the class distribution of the Climate Risk Index are shown in Table 16.

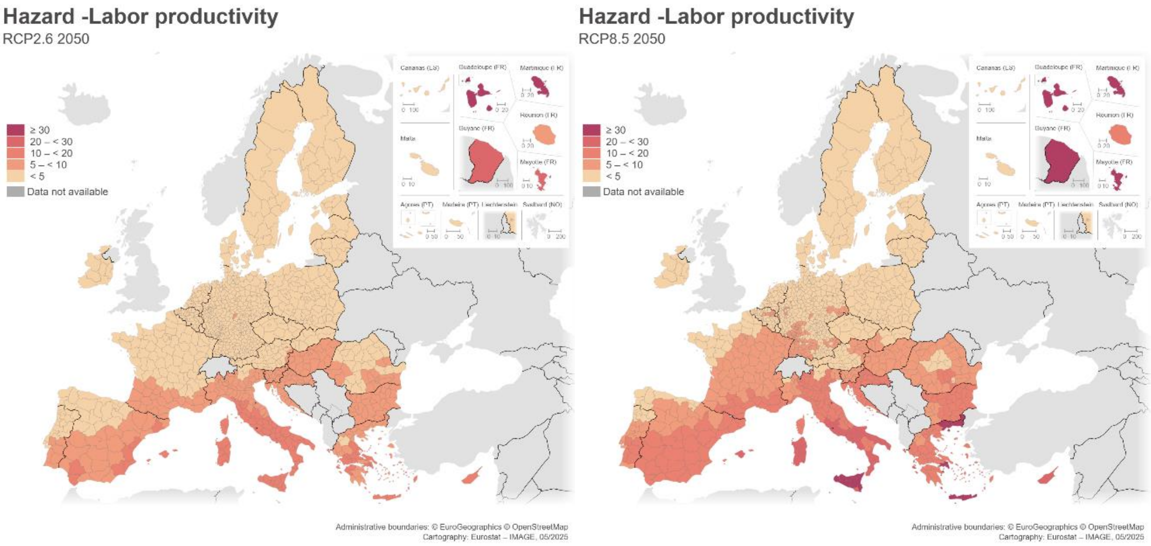
Table 16 Class breaks for the Climate Risk Indicator

Break values	Legend of labels
≥ 30	Very high
20—30	High
15—20	Medium

Break values	Legend of labels
8—15	Low
<8	Very low

The maps of **hazard** are shown in Figure 13 for the RCP 2.6 (left column) and RCP 8.5 (right column). In both climatic variants and in terms of hazard most regions fall are classified as low. In the RCP8.5 there are certain regions which record pretty high hazard scores such as regions in Kriti, Anatoliki Makedonia and Thraki and in Sicily.

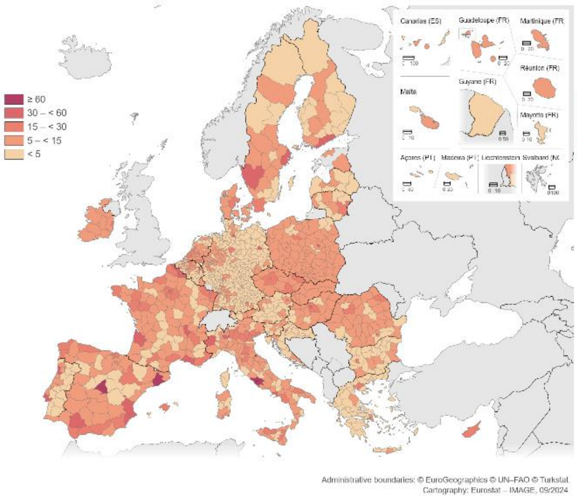
Figure 13: Hazard in RCP2.6 and RCP8.5 – Labor productivity



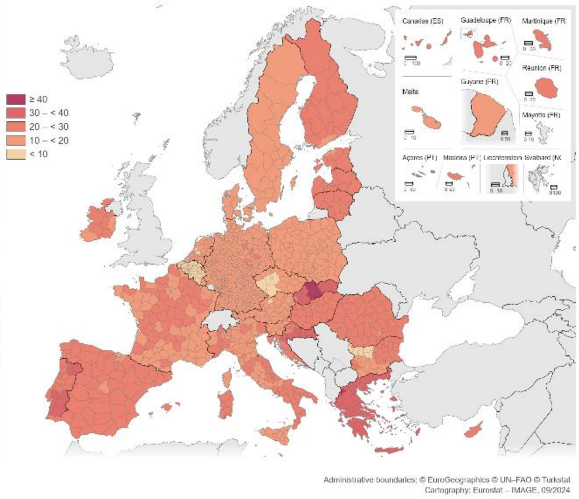
The **exposure and vulnerability** of the regions are shown in a map in Figure 14. Most of the regions are estimated to have a very low to medium exposure in terms of population and employment rate. In terms of vulnerability, most regions are classified to have a medium to high vulnerability. No clear spatial patterns can be observed for exposure and vulnerability.

Figure 14: Exposure and vulnerability – Labor productivity

Exposure - Labor productivity



Vulnerability- Labor productivity



The **top 20 regions with the highest Climate Risk Index** are presented in Table 17 (for RCP 2.6) and Table 18 (for RCP 8.5). Rankings are driven mainly by hazard and exposure. Urban areas are more prone to the impacts of climate change in labour productivity due to their higher labour intensity as the regional economies depends mainly on services. The risk shortlist includes capitals and large cities such as Athens, Rome, Madrid, Napoli, Milan, Barcelona etc.

Table 17 Top 20 EU regions according to their Climate Risk Index, RCP 2.6

		Risk Score	Median Risk score	Hazard (Ranking)	Exposure (ranking)	Vulnerability (ranking)
ES511	Barcelona	27	7	96	2	338
ITI43	Roma	25	7	19	3	716
ES300	Madrid	24	7	177	1	488
ITF33	Napoli	23	7	38	7	305
ES523	Valencia/València	22	7	67	8	221
ES618	Sevilla	20	7	95	19	216
ES521	Alicante/Alacant	20	7	69	24	211
ITC4C	Milano	20	7	171	4	700
ES620	Murcia	19	7	75	26	191
ITG12	Palermo	18	7	5	66	496
ES617	Málaga	18	7	101	31	228
CY000	Cyprus	18	7	34	68	136
ITG17	Catania	18	7	8	75	459
EL522	Thessaloniki	18	7	123	58	50
ITF47	Bari	18	7	50	42	273
PT170	Área Metropolitana de Lisboa	18	7	346	6	193
ITF35	Salerno	17	7	43	64	236

		Risk Score	Median Risk score	Hazard (Ranking)	Exposure (ranking)	Vulnerability (ranking)
EL303	Athens, Central zone	17	7	39	89	210
ITC11	Torino	17	7	249	11	387
ES612	Cádiz	16	7	97	59	224

Table 18 Top 20 EU regions according to their Climate Risk Index, RCP 8.5

		Risk Score	Median Risk score	Hazard (Ranking)	Exposure (ranking)	Vulnerability (ranking)
EL303	Athens, Central zone	33	8	1	89	210
ES511	Barcelona	31	8	126	2	338
ITI43	Roma	30	8	42	3	716
EL305	Eastern Attika	30	8	6	257	84
EL301	Atherns, North zone	28	8	2	265	181
ITF33	Napoli	28	8	52	7	305
ES300	Madrid	27	8	223	1	488
ES523	Valencia/València	27	8	76	8	221
EL431	Heraklion	27	8	10	434	47
EL307	Peiraeus and islands	27	8	3	347	146
EL304	Atherns, south zone	26	8	4	374	150
EL302	Atherns, West zone	24	8	5	474	137
ES618	Sevilla	24	8	81	19	216
ES521	Alicante/Alacant	24	8	78	24	211
CY000	Cyprus	24	8	30	68	136
ES620	Murcia	23	8	93	26	191
ES617	Málaga	22	8	91	31	228
ITC4C	Milano	22	8	186	4	700
EL522	Thessaloniki	22	8	115	58	50
ITF47	Bari	22	8	60	42	273

5.3.5. Aggregate Risk Index

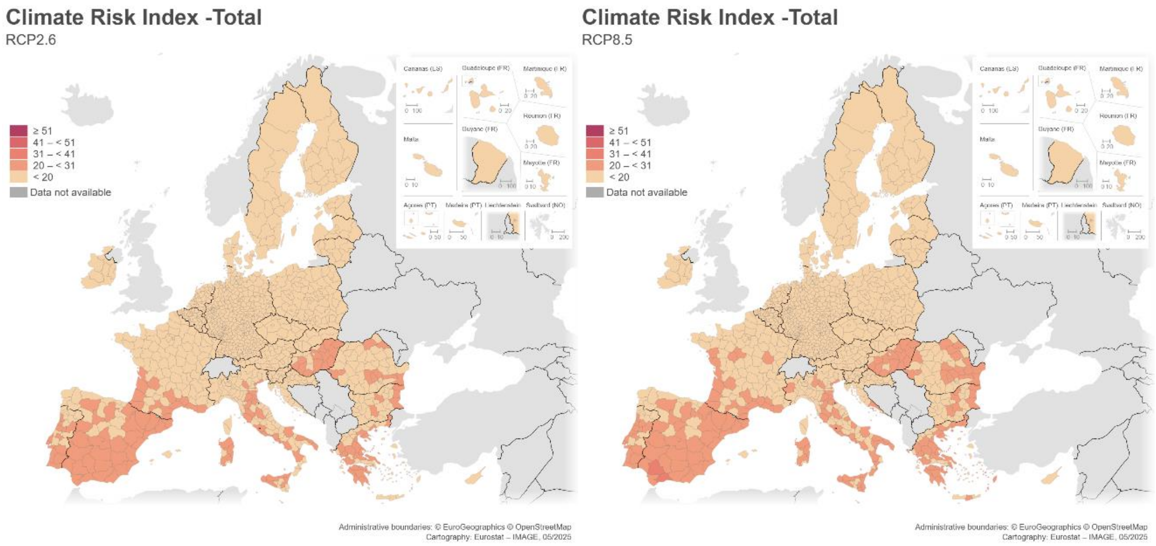
The aggregate risk index includes all individual impact chains and ranks regions according to their relative damage. Based on their overall risk regions are grouped into five risk categories based on the following table:

Table 19: Class breaks for the Climate Risk Index Indicator

Break values	Legend of labels
≥ 51	Very high
41—51	High
31—41	Medium
20—31	Low
<20	Very low

In RCP2.6 regions in southern Europe face the relatively higher risk associated to climate change compared with regions that are in the central and northern Europe (i.e. Germany, Belgium, Austria, Netherlands, Denmark etc.) while the overall value of the aggregate risk index in RCP8.5 is greater for most regions and a higher number of regions in Bulgaria and Romania face greater risk compared to RCP2.6.

Figure 15: Climatic Risk Index – Total



In terms of top-losing regions we find that in RCP2.6 we find most regions are in Italy, Spain and France. For metropolitan areas the results are driven by the high risk associated with changes in labour productivity, and the impacts of water scarcity as the number of people affected by potential shortages greatly increases (e.g., Sevilla). Other regions such as Huesca are mainly affected by changes in tourism while Alicante is affected both by risk imposed on the primary production sectors and on labour productivity. The results differ between RCP2.6 and RCP8.5 as the hazard component substantially increases between the two climatic variants and depending on the dynamics and relative change can lead to changes in the ranking.

Table 20: Top 20 EU regions according to their Aggregate Risk Index

	RCP2.6			RCP8.5	
1	ES618	Sevilla	**1**	ES618	Sevilla
2	ES617	Málaga	**2**	ES617	Málaga

	RCP2.6			RCP8.5	
3	ITI43	Roma	**3**	BG341	Бургас
4	ES511	Barcelona	**4**	ES511	Barcelona
5	RO223	Constanţa	**5**	RO223	Constanţa
6	BG341	Бургас	**6**	EL653	Λακωνία, Μεσσηνία
7	EL653	Λακωνία, Μεσσηνία	**7**	ES521	Alicante/Alacant
8	ES521	Alicante/Alacant	**8**	ES523	Valencia/València
9	ITF35	Salerno	**9**	ES614	Granada
10	ES431	Badajoz	**10**	ITI43	Roma
11	ES614	Granada	**11**	ES611	Almería
12	ITG2D	Sassari	**12**	EL515	Θάσος, Καβάλα
13	ES523	Valencia/València	**13**	ITF35	Salerno
14	ES611	Almería	**14**	EL522	Θεσσαλονίκη
15	ITF33	Napoli	**15**	ES612	Cádiz
16	EL633	Ηλεία	**16**	ES620	Murcia
17	EL522	Θεσσαλονίκη	**17**	ITF33	Napoli
18	ES514	Tarragona	**18**	ES431	Badajoz
19	ES243	Zaragoza	**19**	EL633	Ηλεία
20	ES620	Murcia	**20**	ES300	Madrid

6. Conclusions

In this report we developed an index that aims to assess the relative risk of climate change impacts at the NUTS3 level using the latest available climate inputs. This index combines social, economic and political elements with climate change effects in order to estimate the relative probability of a regio to be adversely affected by climate change impacts. We have assessed four impact individual impact chains and one aggregate risk. The setup of the Risk Index implies that it can be easily updated with further climatic inputs to assess the relative risk of additional impact chains. However, our estimation of the aggregate risk does not include the full spectrum of potential impacts and should be used carefully.

Our results indicate that is a relatively higher (aggregate) risk for Southern and East European regions (S-E) compared to the Central and North Europe (C-N). This pattern is compatible with other risk indexes such as the ND-GAIN index, while in the INFORM Climate Change Risk Index Italy, Greece and Bulgaria are indentified as (realtively) in higher risk but so do Germany and France. The risk is driven both by higher exposure and intensity of climate change impacts especially in Italy, Spain and Southern France, while in Greece, Bulgaria and Romania these effects are further enhanced by higher vulnerability that can be associated to the sociopolitical status. As far as it concerns individual impact chains this S-E versus C-E pattern is present in agriculture, tourism and labour productivity impact chains while with respect to water scarcity risk is more evenly distributed among regions.

The purpose of risk index development is to highlight regions that will most likely require support and specific actions to address the climate change impacts and can be used for policy making. Using heatmaps and data that are widely available such indexes can be easily updated to the latest available data and to can be communicated to larger audiences.

7. Annex 1

Figure 16: The augmented Climate Risk Index

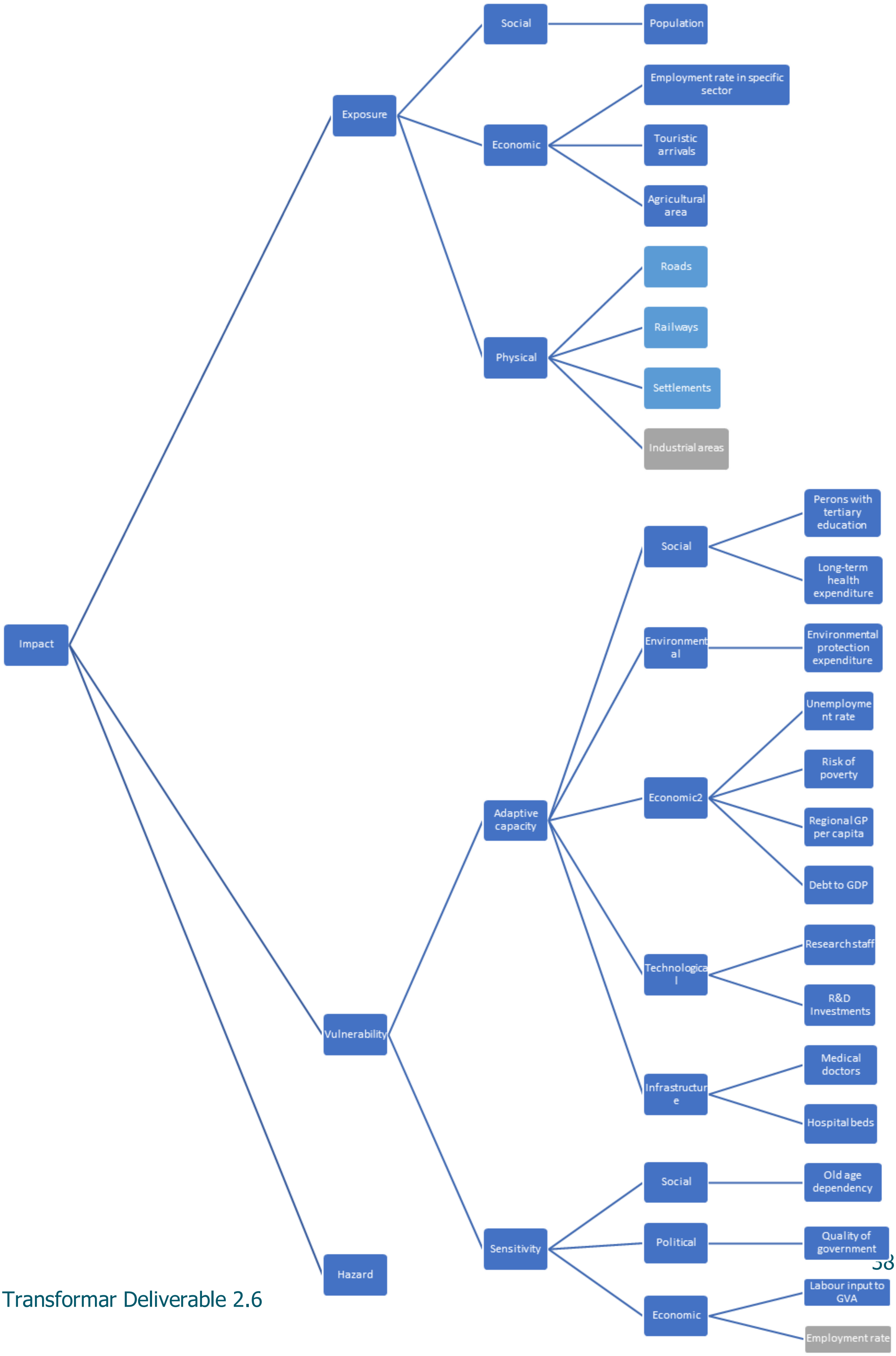

Impact
Exposure
Vulnerability
Hazard
Social
Population
Economic
Employment rate in specific sector
Touristic arrivals
Agricultural area
Physical
Roads
Railways
Settlements
Industrial areas
Adaptive capacity
Social
Perons with tertiary education
Long-term health expenditure
Environmental
Environmental protection expenditure
Economic2
Unemployment rate
Risk of poverty
Regional GP per capita
Debt to GDP
Technological
Research staff
R&D Investments
Infrastructure
Medical doctors
Hospital beds
Sensitivity
Social
Old age dependency
Political
Quality of government
Economic
Labour input to GVA
Employment rate

Table 21: Weights used for the calculation of Risk Index by impact chain

		Exposure	Vulnerability	Hazard
Agriculture	**RISK**	**33%**	**33%**	**33%**
	Economic[6]	**100%**		
	Sectoral employment (abs)	25%		
	Sectoral employment (relative)	25%		
	Agricultural land	50%		
	Adaptive capacity		**50%**	
	Economic indicators		**33%**	
	Unemployment rate		25%	
	Risk of poverty		25%	
	GDP per capita		25%	
	Debt to GDP ratio (national)		25%	
	Social indicators		**33%**	
	Education		50%	
	Health		50%	
	Environmental protection		**33%**	
	Expenditures as % of GDP		100%	
	Sensitivity		**50%**	
	Old age dependency ratio		33%	
	Quality of governance index		33%	
	Sectoral GVA (% of total)		33%	
	Precipitation (change)			**33%**
	Water disposal (change)			**33%**
	Days above 30 (change)			**33%**
Tourism	**RISK**	**33%**	**33%**	**33%**
	Economic	**100%**		
	Sectoral employment (abs)	50%		
	Sectoral employment (relative)	50%		
	Adaptive capacity		**50%**	
	Economic indicators		**33%**	
	Unemployment rate		25%	
	Risk of poverty		25%	
	GDP per capita		25%	
	Debt to GDP ratio (national)		25%	
	Social indicators		**33%**	
	Education		50%	

[6] We assume an equal weighting between economic and social factors. That is the reason we deviate from equal weighting of sub-components.

	Health		50%	
	Environmental protection		**33%**	
	Expenditures as % of GDP		100%	
	Sensitivity		**50%**	
	Old age dependency ratio		33%	
	Quality of governance index		33%	
	Sectoral GVA (% of total)		33%	
	[7]**Continuous hot days (change)**			**45%**
	Days above 30 (change)			**45%**
	Number of wet days (change)			**10%**
Water scarcity	**RISK**	**33%**	**33%**	**33%**
	Economic	**100%**		
	Sectoral employment (tourism-related)	25%		
	Sectoral employment (agriculture-realted)	25%		
	Population	50%		
	Adaptive capacity		**50%**	
	Economic indicators		**33%**	
	Unemployment rate		25%	
	Risk of poverty		25%	
	GDP per capita		25%	
	Debt to GDP ratio (national)		25%	
	Social indicators		**33%**	
	Education		50%	
	Health		50%	
	Environmental protection		**33%**	
	Expenditures as % of GDP		100%	
	Sensitivity		**50%**	
	Old age dependency ratio		33%	
	Quality of governance index		33%	
	Sectoral GVA (% of total)		33%	
	Water disposal (change)			**50%**
	Water withdrawal (change)			**50%**
Labor productivty	**RISK**	**33%**	**33%**	**33%**
	Economic	**100%**		
	Sectoral employment (tourism-related)	25%		
	Sectoral employment (agriculture-realted)	25%		
	Population	50%		
	Adaptive capacity		**50%**	
	Economic indicators		**33%**	

[7] We apply higher weights to indexes that have the potential of increasing thermal discomfort.

Unemployment rate	25%
Risk of poverty	25%
GDP per capita	25%
Debt to GDP ratio (national)	25%
Social indicators	**33%**
Education	50%
Health	50%
Environmental protection	**33%**
Expenditures as % of GDP	100%
Sensitivity	**50%**
Old age dependency ratio	33%
Quality of governance index	33%
Sectoral GVA (% of total)	33%
Changes in skilled labor productivity (linked with WBGT)	**weighted by the share of skilled labor (region specific)**
Changes in unskilled labor productivity (linked to WBGT)	**weighted by the share of unskilled labor (region specific)**

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