

**FINAL REPORT //**

# **Updating and Integrating CLIMATE Datasets and Maps**

Final Report

ESPON 2020 data and maps updates // September 2022

This Final Report is conducted within the framework of the ESPON 2020 Cooperation Programme, partly financed by the European Regional Development Fund.

The ESPON EGTC is the Single Beneficiary of the ESPON 2020 Cooperation Programme. The Single Operation within the programme is implemented by the ESPON EGTC and co-financed by the European Regional Development Fund, the EU Member States, the United Kingdom and the Partner States, Iceland, Liechtenstein, Norway and Switzerland.

This delivery does not necessarily reflect the opinions of members of the ESPON 2020 Monitoring Committee.

**Coordination:**

Daniel Navarro & Efrén Feliu (Fundación TECNALIA Research & Innovation)

**Authors**

Daniel Navarro, Joshua Lizundia-Loiola, Jorge Paz, Beñat Abajo, Carolina Cantergiani, Gemma García & Efrén Feliu (Fundación TECNALIA Research & Innovation)

**Advisory group**

European Environment Agency (EEA): Hans-Martin Füssel

Joint Research Centre (JRC): Luc Feyen, Tiberiu Eugen Antofie, Juan Carlos Ciscar & Francesco Dottori

**ESPON EGTC:** Zintis Hermansons (Project Expert) & Caroline Clause (Financial Expert)

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ISBN: 978-2-919816-65-1

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2022



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## Abbreviations

AR4	IPCC fourth Assessment Report
AR5	IPCC fifth Assessment Report
AR6	IPCC sixth Assessment Report
C3S	Copernicus Climate Change Service
CDS	Copernicus Climate Data Store
CMIP5	Coupled Model Intercomparison Project 5
CMIP6	Coupled Model Intercomparison Project 6
DRMKC	Disaster Risk Management Knowledge Centre
EC	European Commission
EEA	European Environment Agency
ESPON	European Territory Observation Network
ETC	European Topic Centre
EU	European Union
EURO-CORDEX	European contribution to the Coordinated Regional Climate Downscaling Experiment
GCM	Global Climate Models
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
PESETA	Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
SRES	Special Report on Emissions Scenarios published in 2000 by IPCC



# 1 Approach to the ESPON-CLIMATE Update 2022

According to the last IPCC report<sup>1</sup> from the working group I, the emissions of greenhouse gases from human activities are responsible for approximately 1.1°C of warming since the period 1850-1900, and it estimates that global temperatures are expected to reach or exceed 1.5°C of warming on average over the next 20 years. This anthropogenic contribution runs parallel to natural climate variability. The resulting climate changes differ between regions, i.e. each region is affected by different hazards and their intensity. In addition, each region has distinct physical, environmental, social, cultural and economic characteristics that result in different exposure and vulnerability to climate change. However, in the long run, a region might be able to adjust to it, e.g. by increasing its dikes. This adaptive capacity enhances or counteracts the climate change impacts and thus leads to the reduction of a region's overall vulnerability to climate change. The combination of hazard, exposure and vulnerability constitutes a region's risk to the potential effects of climate change.

The initial ESPON-CLIMATE project<sup>2</sup> was conducted in 2011 and there was a subsequent update<sup>3</sup> of data and maps in 2014. This report presents the approach, methodology, indicators, and main results of the second data and maps update conducted in 2022.

Several key factors, which address the technical aspects described further, should be considered when analysing this report. The most relevant is that the new **ESPON-CLIMATE Update 2022** required not only updating the input data, but also entailed revising and adapting the framework methodology and related concepts in order to align it with IPCC 5<sup>th</sup> Assessment Report (AR5)<sup>4</sup>, and the recently published 6<sup>th</sup> Assessment Report (AR6)<sup>5</sup>, given that the former ESPON-CLIMATE from 2011 (and its update) had followed the conceptual framework of the IPCC 4<sup>th</sup> Assessment Report (AR4)<sup>6</sup>. Figure 1 illustrates the differences between the two frameworks, where the **ESPON-CLIMATE Update 2022** approach is the current standard in which the risk components are hazard, exposure and vulnerability. This last component, in turn, is subdivided into sensitivity and adaptive capacity<sup>7</sup>. Colours represent correlation between variables used in the former ESPON-CLIMATE and the 2022 update. For example, the concept of exposure in AR4 (yellow in Figure 1 left), and therefore the indicators used to characterise it, is equivalent to the current concept of hazard in AR5 and AR6 (yellow in Figure 1 right); in the same way, the concept of sensitivity in AR4 (orange in Figure 1 left) is equivalent to the current concept of exposure in AR5 and AR6 (orange in Figure 1 right).

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<sup>1</sup> <https://www.ipcc.ch/2021/08/09/ar6-wg1-20210809-pr/>

<sup>2</sup> (ESPON, 2011)

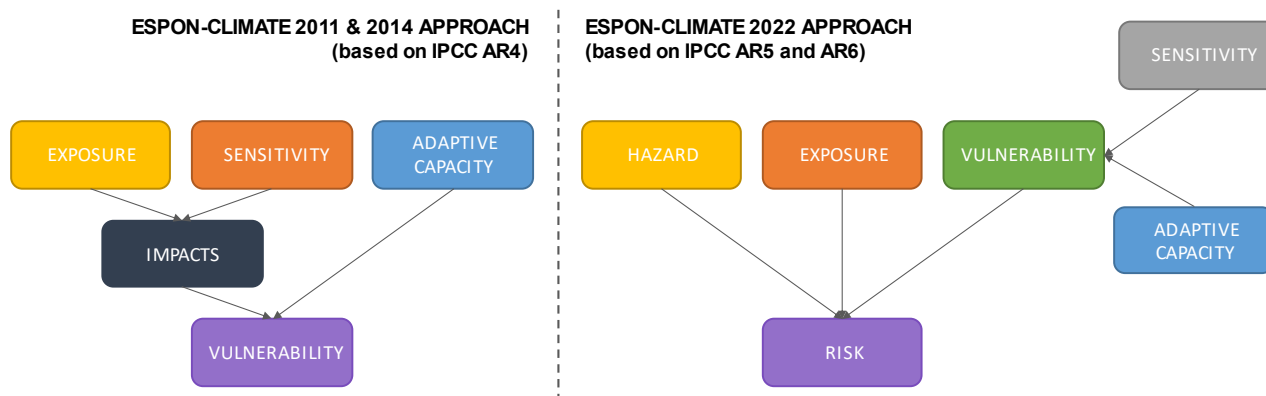
<sup>3</sup> (ESPON, 2014)

<sup>4</sup> (IPCC, 2014)

<sup>5</sup> (IPCC, 2022) The 6th Assessment Report, like the AR5, maintains risk as a central concept and divides it into hazard, exposure and vulnerability, and it subdivides vulnerability into sensitivity and adaptive capacity.

<sup>6</sup> (IPCC, 2007)

<sup>7</sup> The concepts of sensitivity and adaptive capacity used in the climate change community, especially since the publication of IPCC (2012) and IPCC (2014), can nowadays be considered almost equivalent to the concepts of susceptibility and coping capacity in the disaster risk management community.



**Figure 1 Comparison between ESPON-CLIMATE 2011 & 2014 approach and ESPON-CLIMATE Update 2022 approach.**

The change in the methodological framework for the assessment of climate related vulnerabilities and risks implied: (i) a change in the vulnerability and risk assessment components; (ii) an assignment of variables of the previous analysis to the new vulnerability and risk assessment components; and (iii) a modification of the aggregation methodology for integrating vulnerability and risk components.

The new aggregation methodology was based on the impact matrices used in the former ESPON-CLIMATE Update<sup>8</sup>, although converting them into new impact chains<sup>9</sup>, combining analysed hazards with exposed systems (physical, social, environmental, cultural and economic).

The beforementioned changes also implied that the existing weighting factors, derived from an original Delphi Exercise, had to be dismissed, and repeating that process is not in the scope of this update. For this reason, hazard, exposure and sensitivity indicators have been scaled and aggregated with each other using equal-weighted approach. Thus, for adaptive capacity, the indicators have been scaled, and the principal components have been obtained using a Principal Component Analysis (PCA). Finally, the components have been aggregated by applying equal weights. This approach and methodologies had already been applied in many studies related to vulnerability assessment<sup>10</sup>, also used in ESPON-TITAN project<sup>11</sup>.

The proposed methodology attempts to be consistent with IPCC AR5 and, at the same time, ensures traceability with the former ESPON-CLIMATE, i.e. it maintains the original variables and considers the same impact matrices, which relate previous exposure to sensitivity indicators, as the basis for the updated impact chains. Additionally, this update provides a revision of data sources and incorporation of new variables, which is better aligned with recent updates in the climate adaptation policies and resources in Europe.

The revision of the EU Adaptation Strategy, adopted on the 24<sup>th</sup> of February of 2021, is anchored in 4 pillars: smarter, faster and systemic adaptation along international climate action. The Strategy sets the Climate Adapt Platform as the main climate adaptation information portal, including a new access point to Copernicus Climate Change Service (C3S) and the European Climate Data Explorer. The climate data to be offered corresponds to the climate-related hazard indices for Europe, developed by the European Topic Centre (ETC) on Climate Change Adaptation<sup>12</sup>. The revised EU Adaptation Strategy also gave relevance to the EC

<sup>8</sup> Table 2: Relating exposure to sensitivity indicators in (ESPON, 2014).

<sup>9</sup> Risk Supplement to the Vulnerability Sourcebook. Guidance on how to apply the Vulnerability Sourcebook's approach with the new IPCC AR5 concept of climate risk. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ).

<sup>10</sup> (Cutter et al., 2003; Fekete, 2009; Tapia et al., 2017)

<sup>11</sup> (ESPON, 2021b)

<sup>12</sup> Crespi, A., Terzi, S., Cocuccioni, S., Zebisch, M., Berckmans, J., & Füssel, H.-M. (2020). Climate-related hazard indices for Europe. European Topic Centre on Climate Change impacts, Vulnerability and Adaptation. [https://doi.org/10.25424/cmcc/climate\\_related\\_hazard\\_indices\\_europe\\_2020](https://doi.org/10.25424/cmcc/climate_related_hazard_indices_europe_2020)

Joint Research Centre (JRC), and the different initiatives they were managing, such as the JRC PESETA IV report<sup>13</sup>, the Disaster Risk Management Knowledge Centre (DRMKC) and the Risk Data Hub<sup>14</sup>, as key resources for developing adaptation capacities across European member states and regions. Therefore, an effort was done to align the new **ESPON-CLIMATE Update 2022** with this framework, using variables included in the beforementioned report and the vulnerability and risk analysis developed by the JRC. An additional important element is the alignment with the ESPON-TITAN project, which also included an assessment of territorial vulnerability to natural hazards.

Regarding the climate input data sources, and considering the alignment with the IPCC AR5, the input datasets used were derived from the Coupled Model Intercomparison Project 5 (CMIP5) Global Climate Models (GCM), or their downscaled regional versions, known as Regional Climate Models (RCM), which comes from the European contribution to the Coordinated Regional Climate Downscaling Experiment (EURO-CORDEX). A key aspect in relation to climate-related hazards information is the inclusion of three Representative Concentration Pathways (RCP) future climate scenarios. While the former ESPON-CLIMATE Update had only included one climate scenario (the IPCC SRES-A1B, aligned with the IPCC AR4), the update, in addition to the historical one (i.e. present climate), consider:

- RCP2.6 - which is considered a low emissions scenario where emissions start declining beyond 2020.
- RCP4.5 - which is a scenario where emissions start declining beyond 2040 and it is an intermediate emissions scenario.
- RCP8.5 - which represents a very high emissions scenario where emissions continue to rise throughout the century.

Still in terms of climate input data, time horizon was set to 2070-2100, following the same approach of the former ESPON-CLIMATE Update, which is a long-term projection period for which the selected hazard indicators were available.

As mentioned before, the scope of this project does not cover the development of a new Delphi exercise with the updated data model. Anyhow, continuous interaction with key EU institutions (i.e. EEA and JRC) has allowed validating the updated set of variables and risk scenarios, ensuring the alignment with the current EU initiatives and existing resources.

In terms of geographical coverage, the data collection encompasses all the countries participating in the ESPON 2020 Cooperation Programme, i.e. EU-27 plus Switzerland, Iceland, Liechtenstein, Norway and United Kingdom.

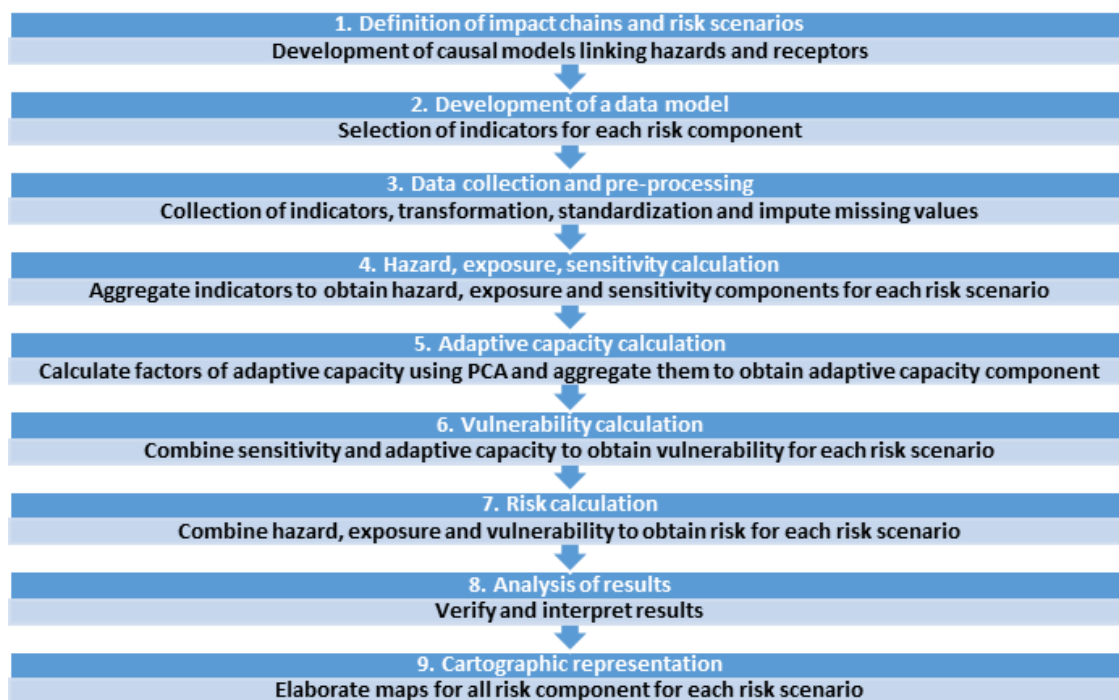
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<sup>13</sup> JRC PESETA IV final report. Climate change impacts and adaptation in Europe. Feyen L., Ciscar J.C., Gosling S., Ibarreta D., Soria A. (edd). EUR 30180EN, Publications Office of the European Union, Luxembourg.

<sup>14</sup> JRC's Risk Data Hub. Available at: <https://drmkc.jrc.ec.europa.eu/risk-data-hub/> (last accessed, February 2022)

## 2 Methodology

The following steps have been followed to obtain the risk scenarios in the **ESPON-CLIMATE Update 2022** (Figure 2): definition of impact chains and risk scenarios; development of a data model; data collection and pre-processing; hazard, exposure and sensitivity calculation; adaptive capacity calculation; vulnerability calculation; risk calculation; analysis of results; cartographic representation.



**Figure 2** Sequence of steps followed in ESPON-CLIMATE Update 2022

In the *first step*, the definition of impact chains and risk scenarios (section 3), the development of causal models linking hazards and receptors have been done based on original ESPON-CLIMATE project and its subsequent update, obtaining 7 impact chains: (i) heat stress on population; (ii) coastal flood on infrastructure, industry and service sectors; (iii) river flood on population; (iv) river flood on infrastructure, industry and service sectors; (v) flash floods on cultural sector; (vi) wildfire on environment; (vii) droughts on primary sector. Moreover, 62 risk scenarios have been selected considering both the baseline climate and the three different climate scenarios in 2070-2100 (low emissions RCP2.6, intermediate emissions RCP4.5 and very high emissions RCP8.5).

The development of the data model (*step 2*), as mentioned above, has not changed significantly, although the indicators were slightly adapted to align with those from the Climate-related hazard indices for Europe<sup>15</sup>, PESETA IV<sup>16</sup> and the Risk Data Hub<sup>17</sup>. Particular indicators were selected to characterise each component (see sections 4.1, 4.2 and 4.3) and impact chain.

Subsequently, the data were collected and pre-processed (*step 3*). The pre-processing of the indicators depends on the source of the data from which they have been obtained, as well as on the nature of the indicators. For example, hazard indicators derived from climate data in NetCDF format required specific and different treatment from those of a socio-economic nature. A detailed description of the pre-processing of each indicator is presented in the following sections. In cases where there is no hazard or exposure, for

<sup>15</sup> (Crespi et al., 2020)

<sup>16</sup> (European Commission et al., 2020)

<sup>17</sup> JRC's Risk Data Hub. Available at: <https://drmkc.jrc.ec.europa.eu/risk-data-hub/> (last accessed, February 2022)

example coastal flood hazard away from the coast, such regions have been excluded from the analysis. The source data from which the indicators were obtained have varied units and scales, which can significantly modify the results when directly combining. Therefore, to solve this problem, and as a step prior to aggregation, all indicators were rescaled to the range between 1 and 2.

Scaling data from 1-2, instead of from 0-1, avoids the risk component to be cancelled due to having the minimum value prior to scaling the data. Two different possible situations are possible: the first one, when there is no exposure or hazard; and the second one, when it coincides with the minimum value of the hazard, exposure or vulnerability distribution. In the first case, the NUTS3 without exposure or hazard is not considered in the risk calculation. In the second, the minimum exposure of the entire sample is assigned 1. If it was scaled between 0 and 1, different situation (when multiplying the components of hazard, exposure and vulnerability; when any of them were the minimum of the distribution; and when scaled) would return value 0, and therefore the risk would also be 0. Therefore, wherever there is no hazard or exposure, the area is excluded from the analysis.

All exposure and vulnerability indicators have been rescaled linearly between this range. However, the hazard indicators have been rescaled using quantiles, due to their statistical distribution, except for the fluvial and coastal flooding indicators, which have also been rescaled linearly.

In the *step 4*, the indicators were aggregated to obtain the risk components of hazard, exposure and sensitivity. In order to obtain these components, the indicators were aggregated using an equal-weighted geometric mean. A geometric aggregation procedure was preferred over arithmetic aggregation methods due to its ability to minimise the known compensability issues of the latter approaches (Nardo et al., 2008; Tapia et al., 2017; Greco et al., 2019). At this point, it is worth mentioning that considering equal weights does not mean no weight is assumed, but that it is implicitly assumed that the weight is the same for all indicators, which was the option adopted in this research, given the lack of proper information.

The following equations show how each component was calculated. The hazard component in many of the impact chains has only one indicator, therefore, no weighting was necessary. For those impact chains where more than one indicator has been used, it has been calculated using an equal-weighted geometric mean (see Equation 1).

$$HA_t = \prod_i^I ha_t^{1/I} \quad (1)$$

where  $HA_t$  is the hazard score for territory  $t$ ,  $ha$  is the value of hazard indicator  $i$  for territory  $t$ , and the weight is 1 divided by the number of indicators considered for the specific impact chain.

In the case of exposure, two approaches were considered. In the first approach, exposure was calculated in absolute terms, i.e. by considering the total values of exposure indicators, such as the total population of the NUTS3, total area of settlements, etc. On the other hand, in the second approach, exposure was calculated relatively, i.e. by dividing the indicator value by the total area of the NUTS3, resulting in density values, additionally, in the case of spatially explicit hazards, i.e. river flooding and coastal flooding, the relative exposure has been calculated by dividing the exposed assets, thus intersecting with the coastal and river flooding maps by the total assets of the NUTS3. As with the hazard component, in some of the impact chains exposure was characterised by a single indicator, with no need for weighing neither aggregation of indicators. In those cases where several indicators have been used, the aggregation was again equal-weighted geometric mean (Equation 2).

$$EX_t = \prod_i^I ex_t^{1/I} \quad (2)$$

where  $EX_t$  is the exposure score for territory  $t$ ,  $ex$  is the value of exposure indicator  $i$  for territory  $t$ , and the weight is 1 divided by the number of indicators considered for the specific impact chain.

For the calculation of the sensitivity component, there is also some impact chains where only indicator is considered so no need for weighting in those cases. Where there were more than one indicator, an equal-weighted geometric mean has been used (Equation 3).

$$SE_t = \prod_i^I se_t^{1/I} \quad (3)$$

where  $SE_t$  is the sensitivity score for territory  $t$ ,  $se$  is the value of sensitivity indicator  $i$  for territory  $t$ , and the weight is 1 divided by the number of indicators considered for the specific impact chain.

In the *step 5*, adaptive capacity has been considered in a multidimensional way, encompassing multiple aspects such as social, technological, infrastructural, economic and institutional capacity. It is a holistic adaptive capacity common to all impact chains. This has entailed the treatment of numerous indicators, so the approach has been to perform a principal component analysis to reduce the dimensionality of the data and extract the factors that best explain this adaptive capacity, which is now standard practice in many vulnerability studies<sup>18</sup>. For the hazard, exposure and sensitivity components, this approach does not apply due to the reduced number of indicators. To verify that the PCA is pertinent for the adaptive capacity indicators, a series of tests have been done, namely that the determinant of the correlation matrix is non-zero, the Kaiser-Meyer-Olkin (KMO) test is greater than 0.6 and that Bartlett's test of sphericity is significant. Once the factors were obtained, they were aggregated using an equal-weighted geometric mean like in the others risk components but using the factors, instead of the indicators (Equation 4).

$$AC_t = \prod_i^I af_t^{1/I} \quad (4)$$

where  $AC_t$  is the adaptive capacity score for territory  $t$ ,  $af$  is the value of adaptive capacity factor  $i$  for territory  $t$ , and the weight is 1 divided by the number of factors obtained for the specific risk scenario.

The vulnerability component calculation, *step 6*, was performed using Equation 5 by dividing sensitivity by adaptive capacity after re-scaling them following the approach of Tapia et al. (2017).

$$V_t = \frac{SE'_t}{AC'_t} \quad (5)$$

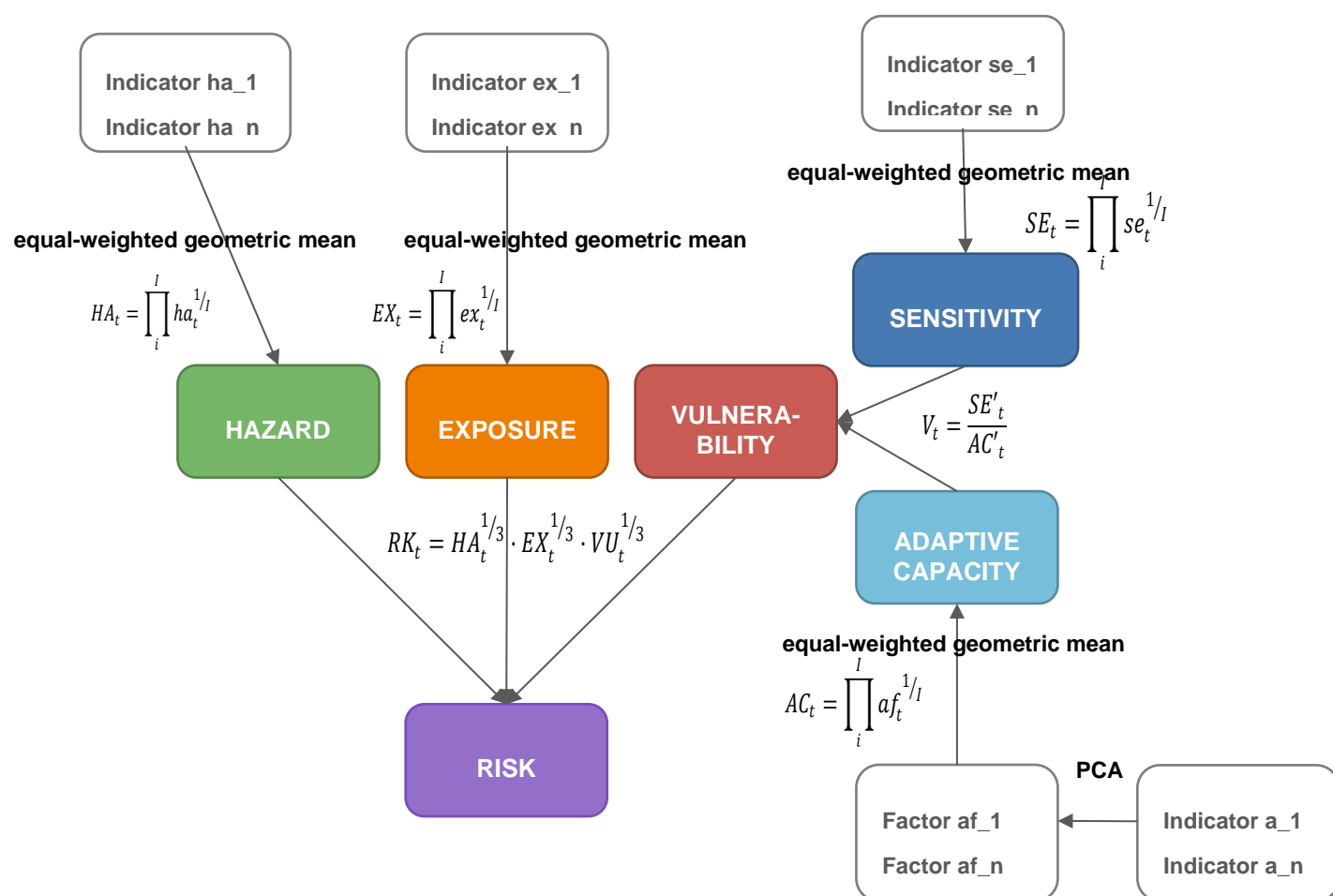
where  $V_t$  is the vulnerability score for territory  $t$ ,  $SE'_t$  the re-scaled sensitivity score for territory  $t$ ,  $AC'_t$  the re-scaled adaptive capacity for territory  $t$ .

Finally, the risk score was calculated (*step 7*) by combining the hazard, the exposure and the vulnerability components using an equal-weighted geometric mean (Equation 6). Due to the large number of risk scenarios and the large number of indicators involved, the results of each calculation have been analysed by visual and statistical inspection to ensure the consistency of the results (*step 8*).

$$RK_t = HA_t^{1/3} \cdot EX_t^{1/3} \cdot VU_t^{1/3} \quad (6)$$

where  $RK_t$  is the risk for territory  $t$ ,  $HA_t$  is the hazard for territory  $t$ ,  $EX_t$  is the exposure for territory  $t$ , and  $VU_t$  the vulnerability for territory  $t$ . Steps 4 to 7 have been iteratively repeated to obtain all risk scenarios. In the case of the aggregated risk scenarios, they have been calculated by combining the risks of each impact chain considering the corresponding scenarios and time periods. Figure 3 shows a diagram summarising steps 4 to 7 for risk calculation.

<sup>18</sup> (Cutter et al., 2003; Fekete, 2009; Bashier Abbas and K. Routray, 2014; Liu and Li, 2016; Tapia et al., 2017; Medina et al., 2020; ESPON, 2021a; Tasnuva et al., 2021; Yu et al., 2021)



**Figure 3** Diagram of risk calculation

Finally, the last step (*step 9*) consisted in linking the results to the NUTS3 geometries for geographical representation and the production of the cartography for the 62 risk scenarios (Table 3) and the related risk components, i.e. hazard, exposure, sensitivity, adaptive capacity, vulnerability and risk.

### 3 Impact chains and risk scenarios

Impact chain refers to the combination of a particular hazard and a particular receptor. An example of an impact chain would be wildfires on the environment, being the hazard the wildfire, and the receptor, the environment, which would have to be characterised through its exposure and vulnerability to that hazard. Impact chains are defined by selecting certain hazard, exposure and vulnerability indicators. The set of impact chains analysed in this study are presented in Table 1, which selection was based on the content of the previous ESPON-CLIMATE project, adapted to the risk-based approach of AR5.

**Table 1 Impact chains analysed in ESPON-CLIMATE Update 2022**

Impact chain	Acronym
Heat stress on population	HE_POP
Coastal flood on infrastructure, industry and service sectors	CF_INF
River flood on population	RF_POP
River flood on infrastructure, industry and service sectors	RF_INF
Flash floods on cultural sector	FF_CUL
Wildfire on environment	WF_ENV
Droughts on primary sector	DR_PRI

The Table 2 shows the specific hazard, exposure and vulnerability indicators used in each impact chain. In order to guarantee that the updated set of indicators, impact chains and risk scenarios are aligned with the European initiatives and latest approaches, a workshop was organized to present, discuss and validate them with the audience, who came from key EU institutions (such as EEA and JRC).

**Table 2 Indicators and impact chains used in ESPON-CLIMATE Update 2022**

Indicator	HE_POP	CF_INF	RF_POP	RF_INF	FF_CUL	WF_ENV	DR_PRI
<b>Hazard</b>							
Annual mean temperature	•						
Annual mean precipitation							•
Consecutive dry days							•
Very heavy rainfall days					•		
Summer days	•						
Tropical nights	•						
River flooding frequency			•	•			
Coastal flooding frequency		•					
Days with fire danger						•	
<b>Exposure</b>							
<b>Physical exposure</b>							
Roads		•		•			
Railways		•		•			
Railway stations		•		•			

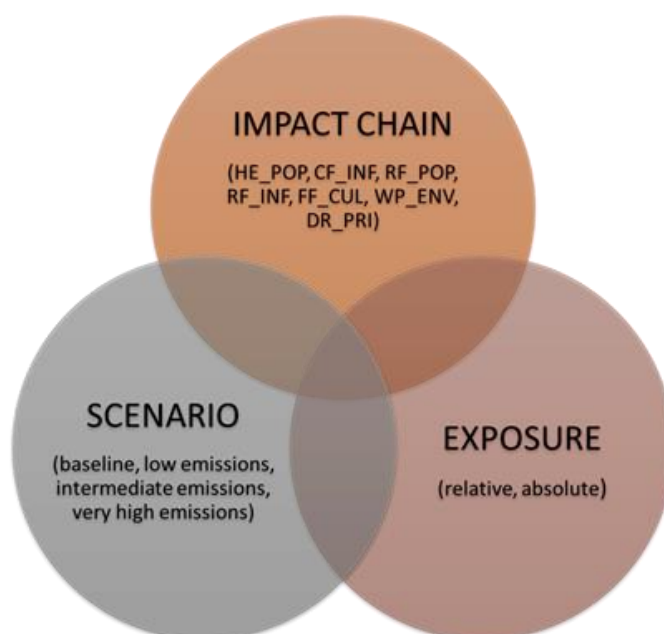


Airports		•			•		
Harbours		•			•		
Settlements		•			•		
Industrial areas		•			•		
Thermal power plants		•			•		
Refineries		•			•		
Social exposure							
Population	•			•			
Educational facilities						•	
Environmental exposure							
Protected areas						•	
Cultural exposure							
Museums						•	
World Heritage Sites						•	
Economic exposure							
Agricultural area							•
Forested area						•	•
Mixed area							•
<b>Vulnerability</b>							
Social sensitivity							
Young-age dependency				•			
Old age dependency	•			•			
Disabled people with need for assistance				•			
Economic sensitivity							
Industrial and service sectors employments		•			•		
Industrial and service sectors GVA		•			•		
Primary sector employments							•
Primary sector GVA							•
Share of irrigable and irrigated areas in utilised agricultural area							•
Touristic arrivals						•	
Social capacity							
Investments in education	•	•	•	•	•	•	•
Persons with tertiary education	•	•	•	•	•	•	•
Risk perception	•	•	•	•	•	•	•
Social capital	•	•	•	•	•	•	•
Gender equality index	•	•	•	•	•	•	•
Technological capacity							
Research staff	•	•	•	•	•	•	•
Patent applications	•	•	•	•	•	•	•

Research and development investments	•	•	•	•	•	•	•
Infrastructure capacity							
Medical doctors	•	•	•	•	•	•	•
Hospital beds	•	•	•	•	•	•	•
Settlement compactness	•	•	•	•	•	•	•
Economic capacity							
Employment rate	•	•	•	•	•	•	•
Risk of poverty	•	•	•	•	•	•	•
Regional GDP	•	•	•	•	•	•	•
National GDP	•	•	•	•	•	•	•
Institutional capacity							
National adaptation strategies	•	•	•	•	•	•	•
Regional quality of government index	•	•	•	•	•	•	•
Municipalities signatories to the Covenant of Majors	•	•	•	•	•	•	•

For each impact chain, different risk scenarios have then been analysed considering the baseline climate (1981-2010), and the low emissions (2070-2100 RCP2.6), intermediate emissions (2070-2100 RCP4.5), and very high emissions (2070-2100 RCP8.5) scenarios at the end of the century. Additionally, each of these risk scenarios was calculated with a relative and an absolute exposure approach. Finally, the aggregate risk has been calculated by combining the risks of the different impact chains for the same period.

The combination of the 7 impact chains, the 4 scenarios and the 2 types of exposure (Figure 4) results in 62 risk scenarios. It should be noted that there is no coastal flooding scenario RCP2.6 and that the 8 aggregate risk scenarios have to be added.



**Figure 4 Risk scenarios as results of impact chains, climate scenarios and exposure characterization**

A comprehensive list of all risk scenarios analysed can be found in Table 3.

**Table 3 Risk scenarios in ESPON-CLIMATE Update 2022.**

<b>Risk scenario</b>	<b>Risk scenario (cont.)</b>
HE_POP baseline climate (1981-2010) with absolute exposure	HE_POP baseline climate (1981-2010) with relative exposure
HE_POP low emissions scenario (2070-2100 RCP2.6) with absolute exposure	HE_POP low emissions scenario (2070-2100 RCP2.6) with relative exposure
HE_POP intermediate emissions scenario (2070-2100 RCP4.5) with absolute exposure	HE_POP intermediate emissions scenario (2070-2100 RCP4.5) with relative exposure
HE_POP very high emissions scenario (2070-2100 RCP 8.5) with absolute exposure	HE_POP very high emissions scenario (2070-2100 RCP 8.5) with relative exposure
CF_INF baseline climate (1981-2010) with absolute exposure	CF_INF baseline climate (1981-2010) with relative exposure
CF_INF intermediate emissions scenario (2070-2100 RCP4.5) with absolute exposure	CF_INF intermediate emissions scenario (2070-2100 RCP4.5) with relative exposure
CF_INF very high emissions scenario (2070-2100 RCP 8.5) with absolute exposure	CF_INF very high emissions scenario (2070-2100 RCP 8.5) with relative exposure
RF_POP baseline climate (1981-2010) with absolute exposure	RF_POP baseline climate (1981-2010) with relative exposure
RF_POP low emissions scenario (2070-2100 RCP2.6) with absolute exposure	RF_POP low emissions scenario (2070-2100 RCP2.6) with relative exposure
RF_POP intermediate emissions scenario (2070-2100 RCP4.5) with absolute exposure	RF_POP intermediate emissions scenario (2070-2100 RCP4.5) with relative exposure
RF_POP very high emissions scenario (2070-2100 RCP 8.5) with absolute exposure	RF_POP very high emissions scenario (2070-2100 RCP 8.5) with relative exposure
RF_INF baseline climate (1981-2010) with absolute exposure	RF_INF baseline climate (1981-2010) with relative exposure
RF_INF low emissions scenario (2070-2100 RCP2.6) with absolute exposure	RF_INF low emissions scenario (2070-2100 RCP2.6) with relative exposure
RF_INF intermediate emissions scenario (2070-2100 RCP4.5) with absolute exposure	RF_INF intermediate emissions scenario (2070-2100 RCP4.5) with relative exposure
RF_INF very high emissions scenario (2070-2100 RCP 8.5) with absolute exposure	RF_INF very high emissions scenario (2070-2100 RCP 8.5) with relative exposure
FF_CUL baseline climate (1981-2010) with absolute exposure	FF_CUL baseline climate (1981-2010) with relative exposure
FF_CUL low emissions scenario (2070-2100 RCP2.6) with absolute exposure	FF_CUL low emissions scenario (2070-2100 RCP2.6) with relative exposure
FF_CUL intermediate emissions scenario (2070-2100 RCP4.5) with absolute exposure	FF_CUL intermediate emissions scenario (2070-2100 RCP4.5) with relative exposure
FF_CUL very high emissions scenario (2070-2100 RCP 8.5) with absolute exposure	FF_CUL very high emissions scenario (2070-2100 RCP 8.5) with relative exposure
WF_ENV baseline climate (1981-2010) with absolute exposure	WF_ENV baseline climate (1981-2010) with relative exposure

WF_ENV low emissions scenario (2070-2100 RCP2.6) with absolute exposure	WF_ENV low emissions scenario (2070-2100 RCP2.6) with relative exposure
WF_ENV intermediate emissions scenario (2070-2100 RCP4.5) with absolute exposure	WF_ENV intermediate emissions scenario (2070-2100 RCP4.5) with relative exposure
WF_ENV very high emissions scenario (2070-2100 RCP 8.5) with absolute exposure	WF_ENV very high emissions scenario (2070-2100 RCP 8.5) with relative exposure
DR_PRI baseline climate (1981-2010) with absolute exposure	DR_PRI baseline climate (1981-2010) with relative exposure
DR_PRI low emissions scenario (2070-2100 RCP2.6) with absolute exposure	DR_PRI low emissions scenario (2070-2100 RCP2.6) with relative exposure
DR_PRI intermediate emissions scenario (2070-2100 RCP4.5) with absolute exposure	DR_PRI intermediate emissions scenario (2070-2100 RCP4.5) with relative exposure
DR_PRI very high emissions scenario (2070-2100 RCP 8.5) with absolute exposure	DR_PRI very high emissions scenario (2070-2100 RCP 8.5) with relative exposure
Aggregated risk baseline climate (1981-2010) with absolute exposure	Aggregated risk baseline climate (1981-2010) with relative exposure
Aggregated risk low emissions scenario (2070-2100 RCP2.6) with absolute exposure	Aggregated risk low emissions scenario (2070-2100 RCP2.6) with relative exposure
Aggregated risk intermediate emissions scenario (2070-2100 RCP4.5) with absolute exposure	Aggregated risk intermediate emissions scenario (2070-2100 RCP4.5) with relative exposure
Aggregated risk very high emissions scenario (2070-2100 RCP 8.5) with absolute exposure	Aggregated risk very high emissions scenario (2070-2100 RCP 8.5) with relative exposure

Each of these risk scenarios is in turn composed of a particular hazard, exposure and vulnerability. It is important to note that, although the risk scenarios considered are the baseline scenario and the different RCP scenarios at the end of the century, only the hazard is projected to the end of the century, but not the exposure neither the vulnerability. In other words, the risk scenarios consider what the effect of the future hazard would be on the present society and environment.

## 4 Data model

### 4.1 Hazard indicators

This first set of indicators had originally been named in the framework of the previous ESPON-CLIMATE Update as climate change “exposure” of Europe’s regions. Nevertheless, from the current state-of-the-art (IPCC AR5), those indicators are not related with the concept of “exposure”, but instead with the concept of “hazard”.

All climate-related indicators used in the previous ESPON-CLIMATE Update were brought up-to-date based on official European datasets. Currently, there are different initiatives that aim to generate coherent and robust sets of climate indicators for Europe and worldwide. In order to avoid the generation of a new parallel set of data, and sharing a confusing message about the climate trends, we reinforced the consistency between the outputs of the new ESPON-CLIMATE Update risk analysis with state-of-the-art datasets that already provide robust estimates of the indicators required by the project. We ensured that all the selected datasets used, ensembles CMIP5 or EURO-CORDEX models or at least provide data for several of them for a posterior combination. The ensembles of models are considered the best way to reduce the uncertainty of climate change projections and analyse its trends in a more robust way<sup>19</sup>. Table 4 shows a summary of all hazard indicators and data sources that have been used in the **ESPON-CLIMATE Update 2022**.

**Table 4. Overview of the hazard indicators used in ESPON-CLIMATE Update 2022 and the corresponding data sources.**

Hazard indicator	Metric	Used in previous ESPON-CLIMATE update	Data source	Date	Spatial resolution
Annual mean temperature	°C	Yes	Copernicus Climate Data Store	2019	0.5 ° x 0.5 ° grid
Annual mean precipitation	mm	Yes	Copernicus Climate Data Store	2019	0.5 ° x 0.5 ° grid
Consecutive dry days	days/year	Yes	Copernicus Climate Data Store	2019	0.5 ° x 0.5 ° grid
Very heavy rainfall days	days/year	Yes	Copernicus Climate Data Store	2019	0.5 ° x 0.5 ° grid
Summer days	days/year	Yes	Copernicus Climate Data Store	2019	0.5 ° x 0.5 ° grid
Tropical nights	days/year	No	Copernicus Climate Data Store	2019	0.5 ° x 0.5 ° grid
River flooding frequency	return period in years	Yes	PESETA IV River floods	2020	5 km x 5 km grid
Coastal flooding frequency	return period in years	Yes	PESETA IV Coastal floods	2016	Feature
Days with fire danger	days/year	No	Copernicus Climate Data Store	2019	0.5 ° x 0.5 ° grid

This set of hazard indicators mainly correspond to the exposure indicators used in the previous ESPON-CLIMATE Update. As described in the following sections, different approaches were followed in the

<sup>19</sup> (Cattiaux et al., 2013)

calculation of each of these indicators depending on the structure in which the original data was available and the characteristics of the indicator. Two new indicators were considered, on the one hand, *tropical nights* were added, considering its strict relationship with thermal comfort, and their impacts on population, on the other hand, *days with fire danger* indicator was added as a proxy to evaluate the impact of the climate change over protected environments, giving that wildfires are one of the main hazards for Mediterranean regions and are expected to increase in the future<sup>20</sup>. Although *heavy winds*, which could suppose a threat for European society due to the potential increase of extratropical storms, etc., were initially considered for inclusion, it was finally discarded due to the inability of current models to adequately project this variable's trends into the future<sup>21</sup>.

Another important difference with the previous ESPON-CLIMATE update was the use of the level of the climate variable as indicator, instead of the projected change of the variable. From the risk framework proposed by the IPCC AR5, it was interpreted that the hazard can be present at any time  $t$  and, hence, the baseline had also its associated risk. The use of the projected change assumes hazard = 0 for the baseline, which is the same as assuming that there is no risk. This assumption was considered unrealistic given that the baseline was defined as a 30-year period that encompassed the end of the 20<sup>th</sup> century, and the very beginning of the 21<sup>st</sup> century, when the climate change was already affecting the human being. Therefore, the level of the variable was considered as indicator of hazard. In that way, the risk for the baseline and for the future scenarios was computed separately and then the change in the risk analysed. The future scenarios considered were the low emissions (RCP2.6), the intermediate emissions (RCP4.5) and the very high emissions (RCP8.5), which respectively assume that emissions start declining beyond 2020, start declining beyond 2040, and continue rising through the century.

The “Selected datasets” section provides a description of each of the data sources used in the **ESPON-CLIMATE Update 2022**, while the “Selected indicators” section explains the importance of the hazard indicators and how they were computed and aggregated at NUTS3 level.

#### 4.1.1 Selected datasets

##### Agroclimatic indicators

The agroclimatic indicators dataset was developed within the C3S Global Agriculture Sectorial Information System contract, whose main contractor is Wageningen University and Research (Netherlands). This contract aimed to develop climate services in support of decision-making in the agriculture sector. Although the agroclimatic indicators were generated to characterise plant-climate interactions, they can be similarly used to assess the impacts of climate change in the physical, social, environmental, cultural and economic aspects. The complete name of the dataset is “Agroclimatic indicators from 1951 to 2099 derived from climate projections” and can be downloaded from the Copernicus Climate Data Store<sup>22</sup>.

To generate the 26 indicators included in the dataset for historical and future time periods, bias-corrected climate datasets provided within the Inter-Sectoral Impact Model Intercomparison (ISIMIP<sup>23</sup>) were used. These climate datasets contain daily-resolution, bias-corrected<sup>24</sup> climate data from 5 CMIP5 GCMs covering the period 1950–2099. The five CMIP5 models (Table 5) represented the full range between warm and wet, and cold and dry climates, and were selected by exploring the relationship between changes in temperature and precipitation. They were all downscaled to a spatial resolution of 0.5°x0.5° degrees and are available globally for RCP2.6, RCP4.5, RCP6.0, and RCP8.5 scenarios. Along with the historical period (1951–2010), three future periods are included in the database (2011–2040, 2041–2070, and 2071–2099).

<sup>20</sup> (Seidl et al., 2017)

<sup>21</sup> (Kumar et al., 2015)

<sup>22</sup> <https://cds.climate.copernicus.eu/cdsapp#!/dataset/sis-agroclimatic-indicators?tab=overview> (last accessed, February 2022)

<sup>23</sup> <https://www.isimip.org/protocol/> (last accessed, February 2022)

<sup>24</sup> (Hempel et al., 2013)

*Version and coverage:* the selected version for this database was the v1.1, which has a global coverage and, hence, provides information for all the pan-European regions.

### PESETA River floods

The series of PESETA (Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis) projects of the Joint Research Centre (JRC) of the European Commission aim to reduce the knowledge gap on the climate change impacts and adaptation. The project performed assessments of impacts for several climate extremes, including river and coastal flooding, among others. The dataset used for ESPON-CLIMATE is called “Flood hazard: high extreme of river runoff” and can be found at the JRC Data Catalogue<sup>25</sup>.

PESETA IV used a comprehensive modelling framework to simulate the response of river flow to present and future climate conditions. The dataset covers all EU countries and the UK, with the exception of Malta, where flooding is caused by pluvial and flash flood events, which were not included in PESETA IV, and water courses are too small to be represented<sup>26</sup>. The dataset uses an ensemble of high-resolution, bias adjusted<sup>27</sup> RCMs from EURO-CORDEX to characterise the change in the mean and extreme climate over Europe under +1.5 °C, +2.0 °C, +3.0 °C, and +4.0 °C (not analysed in PESETA IV report) global warming compared to pre-industrial levels. Several RCMs were used to downscale the results of different CMIP5 models, leading to 11 combinations (Table 5). Since RCM data was originally provided for RCP4.5 and RCP8.5 scenarios and not warming levels, the year when the global temperature reached each of the previously mentioned warming levels was identified for each combination and scenario. Thus, the 30-year period around that central year was used to characterise the world at +1.5°C, +2.0°C, +3.0°C, and +4.0°C warming levels. However, it was found that the differences between RCP4.5 and RCP8.5 for the same warming levels were statistically indistinguishable<sup>28</sup> and, hence, both were combined to characterise each of the warming levels leading to an ensemble of 22 model realisations. These ensembles were used to run at 5 km grid resolution continuous daily streamflow simulations with LISFLOOD, a distributed, physically based hydrological model<sup>29</sup>. The resulting dataset included layers regarding 1) the magnitude of the baseline (i.e. 1981-2010) 100-year return period event; 2) percentage changes in magnitude of the 100-year return period event at a given warming level; and 3) the return period at a given warming level of the event with the same magnitude as the baseline 100-year return period one.

Based on datasets that provide river runoff values for different return periods and Digital Elevation Models (DEM), it is possible to derive flood maps for each of those return periods. In that sense, flood maps for 10-, 20-, 50-, 100-, 200-, and 500-year return periods were generated within the PESETA IV project<sup>30</sup>. However, as will be explained later, one of the main sources for exposure data was the RDH, which had used the flood maps generated by the previous version of PESETA (III). Therefore, to ensure consistency between exposure indicators related to river flood generated within the new ESPON-CLIMATE Update and exposure indicators coming from RDH, the same flood maps were used. It is important to note that the fact of using flood maps and river runoff projections from different PESETA versions did not imply any relevant inconsistency. The flood maps provided by the PESETA projects were static maps that only refer to the reference period and it was confirmed by experts from the JRC that this reference period could be considered common for both versions. Therefore, the flood map of 100-year return period at 100 metres spatial resolution, provided by the RDH team, was used.

<sup>25</sup> (Mentaschi, Alfieri, Dottori, Cammalleri, Bisselink, De Roo, et al., 2020)

<sup>26</sup> Adapting to rising river flood risk in the EU under climate change: JRC PESETA IV project: Task 5. Available at: <https://data.europa.eu/doi/10.2760/14505> (last accessed, February 2022)

<sup>27</sup> (Dosio, 2017)

<sup>28</sup> (Mentaschi, Alfieri, Dottori, Cammalleri, Bisselink, Roo, et al., 2020)

<sup>29</sup> Adapting to rising river flood risk in the EU under climate change: JRC PESETA IV project: Task 5. Available at: <https://data.europa.eu/doi/10.2760/14505> (last accessed, February 2022)

<sup>30</sup> (Dottori et al., 2021)



*Version and coverage:* databases were obtained from PESETA III (2018) and PESETA IV (2020). Regarding the spatial coverage the following NUTS3 regions were not included in the databases:

- PESETA III: full Iceland (IS), full Turkey (TR), El Hierro (ES703), Fuerteventura (ES704), Gran Canaria (ES705), La Gomera (ES706), La Palma (ES707), Lanzarote (ES708), Tenerife (ES709), Guadeloupe (FRY10), Martinique (FRY20), Guyane (FRY30), La Reunión (FRY40), Mayotte (FRY50), Região Autónoma dos Açores (PT200), and Região Autónoma da Madeira (PT300).
- PESETA IV: El Hierro (ES703), Fuerteventura (ES704), Gran Canaria (ES705), La Gomera (ES706), La Palma (ES707), Lanzarote (ES708), Tenerife (ES709), Guadeloupe (FRY10), Martinique (FRY20), Guyane (FRY30), La Reunión (FRY40), Mayotte (FRY50), Malta (MT001), Gozo and Comino/Għawdex u Kemmuna (MT002), Região Autónoma dos Açores (PT200), Região Autónoma da Madeira (PT300), Artvin (TR905), Erzurum (TRA11), Agri (TRA21), Kars (TRA22), Iğdir (TRA23), Hakkari (TRA24), Van (TRB21), Mus (TRB22), Bitlis (TRB23), Hakkari (TRB24), Diyarbakir (TRC22), Mardin (TRC31), Batman (TRC32), Siirt (TRC33), and Siirt (TRC34).

## PESETA Coastal floods

Coastal flooding was analysed within the PESETA IV project as well and, as in the case of river flooding, the dataset is available through the JRC Data Catalogue. It is distributed in three separated files depending on the scenario: historical<sup>31</sup>, RCP4.5<sup>32</sup>, and RCP8.5<sup>33</sup>.

The coastal flooding hazard assessment was driven by nearshore Extreme Sea Levels (ESL)<sup>34</sup>. The ESL is understood as the combined effect of mean sea level, tides, and water level fluctuations due to waves and storm surges. Projections of waves and storm surges were based on hydrodynamic simulations that were driven by atmospheric forcing from six CMIP5 climate models (Table 5). The ensemble was used to account for uncertainty in climate projections. The projections covered the end of the 21<sup>st</sup> century and considered the RCP4.5 and RCP8.5 scenarios. ESL was modelled using segments of variable length (up to 25 km for the straightest coastline stretches) distributed along the European coastline. In the dataset each of these segments is represented by a given location near the coast and ESL values related to 5-, 10-, 20-, 50-, 100-, 200-, 500-, and 1000-year return periods are provided. In the case of future projections, the same information is provided, but with the additional distinction between decades (2070s, 2080s and 2090s).

Regarding the coastal flood maps used by the current ESPON-CLIMATE Update the same issue mentioned in the case of river floods affected to coastal floods. The 100-year return period flood maps at 100 metres of the previous PESETA version were provided by the RDH team to ensure consistency between exposure indicators.

The coastal flooding data used from PESETA provide different results to those obtained in other works<sup>35</sup>, mainly in the Bothnian Bay<sup>36</sup>, where other studies state that sea level relative to land is projected to remain

<sup>31</sup> Voudoukas, Michail; Mentaschi, Lorenzo; Voukouvalas, Evangelos; Verlaan, Martin; Feyen, Luc (2016): Extreme Sea level - Historical. European Commission, Joint Research Centre (JRC) [Dataset] PID: <http://data.europa.eu/89h/9e5ba6f1-8d03-4834-8488-2353e504560f>

<sup>32</sup> Voudoukas, Michail; Mentaschi, Lorenzo; Voukouvalas, Evangelos; Verlaan, Martin; Feyen, Luc (2016): Extreme Sea level - RCP45. European Commission, Joint Research Centre (JRC) [Dataset] PID: <http://data.europa.eu/89h/e9e42344-119d-479e-9bc7-57400d12a8a2>

<sup>33</sup> Voudoukas, Michail; Mentaschi, Lorenzo; Voukouvalas, Evangelos; Verlaan, Martin; Feyen, Luc (2016): Extreme Sea level - RCP85. European Commission, Joint Research Centre (JRC) [Dataset] PID: <http://data.europa.eu/89h/a565eea4-5422-4c7d-a000-2e10ae872da7>

<sup>34</sup> Adapting to rising coastal flood risk in the EU under climate change: JRC PESETA IV project : Task 6. Available at: <https://data.europa.eu/doi/10.2760/456870> (last accessed, February 2022)

<sup>35</sup> (Slangen et al., 2014; Fox-Kemper et al., 2021)

<sup>36</sup> EEA indicator Extreme sea levels and coastal flooding <https://www.eea.europa.eu/ims/extreme-sea-levels-and-coastal-flooding> (last accessed, July 2022)



about constant due to ongoing post-glacial land uplift in this region. These results should therefore be interpreted with caution.

*Version and coverage:* databases were obtained from PESETA III (2018) and PESETA IV (2020). Regarding the spatial coverage the following coastal NUTS3 regions were not included in the databases:

- PESETA III: Guadeloupe (FRY10), Martinique (FRY20), Guyane (FRY30), La Reunión (FRY40), Mayotte (FRY50), and Região Autónoma dos Açores (PT200).
- PESETA IV: full Albania (AL), full Iceland (IS), full Montenegro (ME), El Hierro (ES703), Fuerteventura (ES704), Gran Canaria (ES705), La Gomera (ES706), La Palma (ES707), Lanzarote (ES708), Tenerife (ES709), Guadeloupe (FRY10), Martinique (FRY20), Guyane (FRY30), La Reunión (FRY40), Mayotte (FRY50), Região Autónoma dos Açores (PT200), and Região Autónoma da Madeira (PT300).

### Fire danger indicators

The fire danger indicators dataset was developed under the umbrella of the C3S European Tourism project. The European tourism demonstrator provides a set of indicators that significantly affect the appeal of tourist destinations. The Canadian Fire Weather Index System (FWI) is one of those indicators. It is a meteorologically based index, used worldwide to assess fire danger in a generalised fuel type (i.e. mature pine stands). The dataset used in ESPON-CLIMATE update is called “Fire danger indicators for Europe from 1970 to 2098 derived from climate projections” and can be downloaded through the Climate Data Store<sup>37</sup>.

FWI combines the responses of soil moisture to atmospheric forcing at different soil depths to derive fire behaviour indices in terms of ease of spread and intensity<sup>38</sup>. It uses as input daily noon values of air temperature, relative humidity, wind speed and daily accumulated precipitation data. This information is obtained from projections of the EURO-CORDEX initiative that provided data in 3-hour time-steps. The dataset provides fire danger indicators for RCP2.6, RCP4.5, and RCP8.5 based on several downscaled GCMs (Table 5). The dataset is available for the historical (1970 – 2005) and future (2006 – 2098) periods and includes five indicators: 1) daily FWI values, 2) averaged seasonal (June – September) FWI values and three threshold specific indices describing the number of days with 3) moderate, 4) high, and 5) very high fire danger conditions. This last classification followed the European Forest Fire Information System (EFFIS) classification. All of them are provided at European scale at 0.1° spatial resolution.

A harmonised wildfire risk assessment across the Pan-European region has recently been published by JRC<sup>39</sup> after the ESPON-Climate update 2022 was concluded, and therefore without the possibility of considering this new data. This study can provide complementary information to identify the areas with highest wildfire risk.

*Version and coverage:* the selected version for this database was the v1.0. The dataset covered the full EURO-CORDEX regions and, therefore, the following NUTS3 regions were excluded:

- El Hierro (ES703), Fuerteventura (ES704), Gran Canaria (ES705), La Gomera (ES706), La Palma (ES707), Lanzarote (ES708), Tenerife (ES709), Guadeloupe (FRY10), Martinique (FRY20), Guyane (FRY30), La Reunión (FRY40), Mayotte (FRY50), Região Autónoma dos Açores (PT200), Região Autónoma da Madeira (PT300), Artvin (TR905), Erzurum (TRA11), Agri (TRA21), Kars (TRA22), Iğdir (TRA23), Hakkari (TRA24), Van (TRB21), Mus (TRB22), Bitlis (TRB23), Hakkari

<sup>37</sup> <https://cds.climate.copernicus.eu/cdsapp#!/dataset/sis-tourism-fire-danger-indicators?tab=overview> (last accessed, February 2022)

<sup>38</sup> Fire Weather Index (FWI) – Dataset description. C3S\_D422\_Lot2\_TEC.2.1.3\_201907\_FWI\_dataset\_description\_v2.pdf. Available at: [https://datastore.copernicus-climate.eu/documents/sis-european-tourism/C3S\\_D422\\_Lot2\\_TEC\\_FWI\\_dataset\\_description\\_v2.pdf](https://datastore.copernicus-climate.eu/documents/sis-european-tourism/C3S_D422_Lot2_TEC_FWI_dataset_description_v2.pdf) (last accessed, February 2022)

<sup>39</sup> Jacome Felix Oom, D., De Rigo, D., Pfeiffer, H., Branco, A., Ferrari, D., Grecchi, R., Artes Vivancos, T., Durrant, T., Boca, R., Maianti, P., Liberta, G. and San-Miguel-Ayanz, J., Pan-European wildfire risk assessment, EUR 31160 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-55138-6, doi:10.2760/437309, JRC130136.

(TRB24), Diyarbakir (TRC22), Mar-din (TRC31), Batman (TRC32), Sirnak (TRC33), and Siirt (TRC34).

**Table 5. Summary of the CMIP5 GCMs used by the different datasets described in Section 4.1.1. Columns represent datasets while the rows are the CMIP5 models. For agroclimatic indicators and PESETA IV coastal floods the GCMs were directly used, while for PESETA IV river floods and fire danger indicators GCMs were downscaled using the RCMs indicated in the cells.**

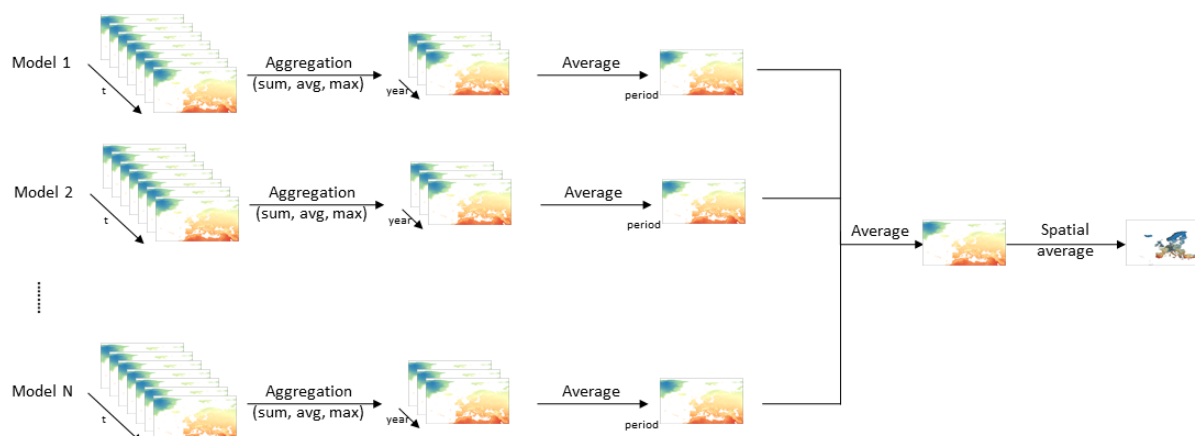
<b>Dataset</b> <b>CMIP5 GCM</b>	<b>Agroclimatic indicators</b>	<b>PESETA IV River floods</b>	<b>PESETA IV Coastal floods</b>	<b>Fire danger indicators</b>
ACCESS1.0				
ACCESS1.3				
CNRM-CM5		CCLM4.8-17 RCA4		RCA4
CSIRO-Mk3.6.0				
EC-EARTH		CCLM4.8-17 HIRHAM5 RACMO22E RCA4		RCA4
GFDL-ESM2G				
GFDL-ESM2M				
HadGEM2-ES		RCA4		RCA4
IPSL-CM5A-LR				
IPSL-CM5A-MR		WRF331F RCA4		RCA4
MIROC-ESM-CHEM				
MPI-ESM-LR		CCLM4.8-17 RCA4		RCA4
NorESM1-M				RCA4

#### 4.1.2 Selected indicators

##### Annual mean temperature

This indicator served to indicate regional variation of changes in temperature, as the main indicator on long-term climate variability and change. It was not intended to use to represent extremes, but to represent the general trend in the temperatures of each region. The temperature extremes are handled by the summer days and tropical nights indicators. Considering that there is high confidence in the fact that temperatures are increasing and that any increase negatively affects societies, the sense of the variable was considered as the higher the temperature, the higher the hazard.

The indicator was obtained based on the agroclimatic indicator “mean of daily mean temperature”, which provides mean value of daily mean temperature over 10 days. The procedure to aggregate this indicator at NUTS3 region level is shown in Figure 5 and was similar for the rest of the indicators derived from the agroclimatic indicators dataset. First, the indicator was aggregated at annual level by averaging all 10-day periods. Second, these annual values were averaged for the baseline and future periods. The baseline period encompassed the years 1981-2010, while the future was defined as 2071-2100. The previous process was repeated for each of the five models provided by the dataset and, thus, in a third step, all the models were combined to get an ensemble indicator. Finally, this last indicator was spatially averaged per NUTS3 region. All this procedure resulted in four annual mean temperature values per NUTS3: baseline (1981-2010), RCP2.6 (2071-2100), RCP4.5 (2071-2100), and RCP8.5 (2071-2100).



**Figure 5. Flux diagram of the obtention of climate indicators from agroclimatic indicators dataset.**

### Annual mean precipitation

In a similar way to annual mean temperature, this indicator represents the general trend in water availability. The extremes are handled by the consecutive dry days (low extreme) and very heavy rainfall days (high extreme) indicators. In this case, it was considered an inverted relationship with hazard, meaning that the higher the precipitation value, the lower the hazard. The higher water availability was considered to generate positive socioeconomic effects, while the lower availability was related to water stress.

The indicator was obtained based on the agroclimatic indicator “precipitation sum”, which provides sum value of daily precipitation sum over 10 days. The procedure to aggregate it was the same of annual mean temperature (Figure 5). First, the 10-day accumulated precipitations were summed annually and then averaged for the baseline and future period, resulting in four annual mean precipitations values per NUTS3 region: baseline (1981-2010), RCP2.6 (2071-2100), RCP4.5 (2071-2100), and RCP8.5 (2071-2100).

### Consecutive dry days

This indicator served to account for drought monitoring and extremes. Thus, the sense of the indicator was considered as the higher the number of consecutive dry days, the higher the hazard.

The indicator was obtained based on the agroclimatic indicator “maximum number of consecutive dry days”, which provides the longest period of consecutive days when daily precipitation sum < 1 mm in each trimester. The procedure to aggregate it is the same of annual mean temperature (Figure 5). First, the maximum number of consecutive dry days among the four trimesters that belong to each specific year was selected. Then, these annual maxima were averaged for the baseline and future period, resulting in four annual maximum consecutive dry days values per NUTS3 region: baseline (1981-2010), RCP2.6 (2071-2100), RCP4.5 (2071-2100), and RCP8.5 (2071-2100).

### Very heavy rainfall days

This indicator indicated changes in regional hazard through the changes in heavy rainfall events and, hence, in hydrologic extremes. It had strong relevance for local heavy rainfall phenomena, especially when occurring over highly sealed surface areas. This indicator also provides information on crop damage and runoff losses. Therefore, it was understood that the higher the number of very heavy rainfall days, the higher the hazard.

The indicator was obtained based on the agroclimatic indicator “very heavy precipitation days”, which provides number of days per 10 days when daily precipitation sum > 20 mm. The procedure to aggregate it was the same of annual mean temperature (Figure 5). First, the annual number of very heavy precipitation days was obtained by summing all 10-day periods. Then, these annual values were averaged for the baseline and future period, resulting in four annual very heavy precipitation days values per NUTS3 region: baseline (1981-2010), RCP2.6 (2071-2100), RCP4.5 (2071-2100), and RCP8.5 (2071-2100).

## Summer days

This indicator serves to indicate changes in regional climate extremes with respect to summer temperatures. This has from a territorial perspective relevance for the tourism sector as well as for human wellbeing. This indicator provides an indication of the occurrence of heat stress. Therefore, it was assumed that the higher the number of summer days, the higher the hazard.

The indicator was obtained based on the agroclimatic indicator “summer days”, which provides number of days per 10 days when the daily maximum temperature  $> X^{\circ}\text{C}$ . X refers to the different thresholds that are provided by the agroclimatic indicators dataset:  $20^{\circ}\text{C}$ ,  $25^{\circ}\text{C}$ ,  $30^{\circ}\text{C}$ , and  $35^{\circ}\text{C}$ . Although in the former ESPON-CLIMATE Update this threshold was set to  $25^{\circ}\text{C}$ , in an internal workshop with experts from JRC and EEA it was decided to update this threshold to  $30^{\circ}\text{C}$  to better account for the current European reality. The procedure to aggregate it was the same of annual mean temperature (Figure 5). First, the annual number of summer days was obtained by summing all 10-day periods. Then, these annual values were averaged for the baseline and future period, resulting in four annual summer days values per NUTS3 region: baseline (1981-2010), RCP2.6 (2071-2100), RCP4.5 (2071-2100), and RCP8.5 (2071-2100).

## Tropical nights

This indicator was used as an indicator for thermal comfort since it is related to different thermal phenomena, such as urban heat island, that directly affect population health. Therefore, it was understood that the higher the number of tropical nights, the higher the hazard.

The indicator was obtained based on the agroclimatic indicator “tropical nights”, which provides number of days per 10 days when daily minimum temperature  $> 20^{\circ}\text{C}$ . The procedure to aggregate it was the same of annual mean temperature (Figure 5). First, the annual number of tropical nights was obtained by summing all 10-day periods. Then, these annual values were averaged for the baseline and future period, resulting in four annual tropical nights values per NUTS3 region: baseline (1981-2010), RCP2.6 (2071-2100), RCP4.5 (2071-2100), and RCP8.5 (2071-2100).

## River flooding frequency

This indicator reflects the expected changes in frequency of the current 100 years river flood event under different climate change scenarios.

The indicator was extracted from the “baseline rp shift XX”, where XX is the warming level, layers of the PESETA IV river floods dataset mentioned earlier. This layer provided the return period at warming levels  $+1.5^{\circ}\text{C}$ ,  $+2.0^{\circ}\text{C}$ ,  $+3.0^{\circ}\text{C}$ , and  $+4.0^{\circ}\text{C}$ , of the event with the same magnitude as the baseline 100-year one. For example, a value of 80 in this layer meant that the same event that currently had a 100-year return period, in the future would have an 80-year return period. It is important to note that the concept “return period” did not mean that those events would necessarily happen once every 100 or, in this example, 80 years. It was just that the event had a probability of 1/100 (or 1/80) to happen. So, strictly speaking this indicator determined the change in the probability of occurrence of a baseline 100-year return period event. Nevertheless, it was considered much more intuitive to talk about increase or decrease in frequency.

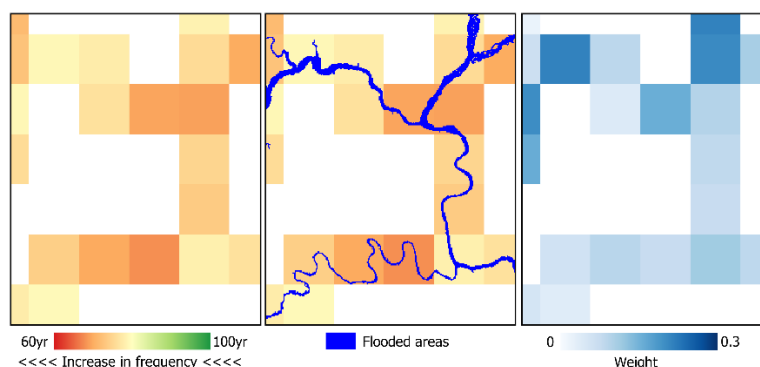
Considering that in the current ESPON-CLIMATE Update the selected future period was 2071 – 2100 for RCP2.6, RCP4.5, and RCP8.5 scenarios, it was necessary to develop an equivalence between the global warming levels and these scenarios. After checking the 30-year periods that were selected to represent each warming level in the initial steps of PESETA IV methodology and consulting the last Summary for Policymakers of the AR6 WGI<sup>40</sup>, it was proposed that:  $+1.5^{\circ}\text{C}$  warming level was equivalent to RCP2.6 at the end of the century,  $+3.0^{\circ}\text{C}$  warming level was equivalent to RCP4.5 at the end of the century, and  $+4.0^{\circ}\text{C}$

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<sup>40</sup> IPCC, 2021: Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press.

warming level was equivalent to RCP8.5 at the end of the century. This equivalence was validated by experts of EEA and JRC.

Once the equivalence between warming levels and RCPs was agreed, the original data, which was provided at 5 km resolution, was aggregated at NUTS3 levels. Although the easiest way to perform the aggregation was to calculate an average of the 5 km grid cells that fell inside the NUTS3 region, this approach did not consider if a given grid cell contained or not flooded areas. Since the hazard that was expected to be characterised with this indicator was the change in frequency of the 100-year return period event of the reference period, it was more reasonable to compute a weighted average, where the weight was set by the proportion of flooded areas inside each grid cell. Figure 6 shows how the weights were computed. For pixels with non-significant changes we keep baseline values for future scenarios.

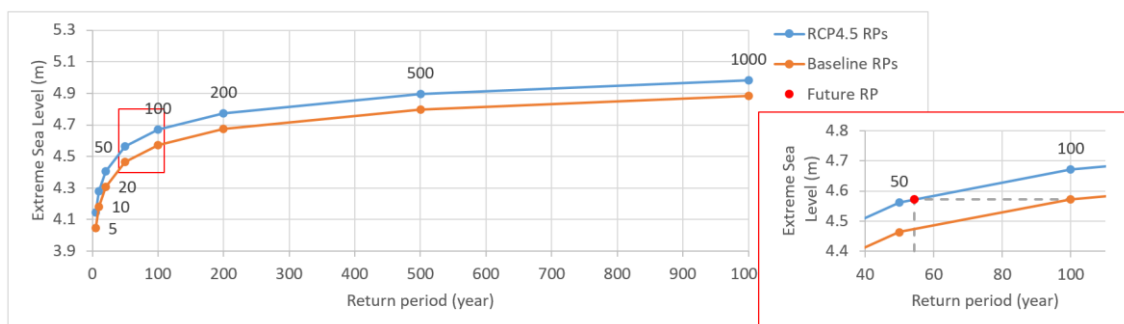


**Figure 6. Weighting procedure used by the aggregation at NUTS3 of river flooding frequency indicator. A value of 0 would mean that the grid cell does not contain any flooded area, while a value of 1 (100%) would mean that the 5 km grid cell is completely flooded.**

### Coastal flooding frequency

Like in the case of river flooding frequency, this indicator was used as a proxy of how frequently a given set of elements (physical, social, etc.) would be exposed to a coastal flooding event of a specific magnitude.

The coastal flooding dataset provided the ESL (in metres) of different locations through the European coastline for several return periods of the baseline, RCP4.5, and RCP8.5 scenarios. However, these values could not be used to directly represent the return period that an event with the same magnitude as the baseline 100-year return period would have in the future. To estimate the future return period of this event, the ESL of the baseline 100-year return period was projected over the line that was constructed based on the future ESL values of 5-, 10-, 20-, 50-, 100-, 200-, 500-, and 1000-year return periods (Figure 7). The final return period was obtained by averaging the return period obtained for each of the future decades (2070s, 2080s, and 2090s).



**Figure 7. Calculation of the return period of the event with the same magnitude as the baseline 100-year return period one. The selected point is located in Nordland at 16.9961 E, 68.3676 N.**

### Days with fire danger

As it was previously pointed out, wildfires are one of the main threats for Mediterranean regions, although it may be a threat for an increasing number of European regions as climate change progresses. This indicator aimed to quantify this hazard by considering the number of days when a given danger level is exceeded. Therefore, it was understood that the higher the number of this type of days, the higher the hazard.

The indicator was obtained based on the fire danger indicator “number of days with high fire danger”. This indicator provides the number of days per year with a FWI greater than 30 based upon the EFFIS classification. The procedure to aggregate it at NUTS3 level was similar to the one used to aggregate the annual mean temperature (Figure 2), although less steps were needed since 1) the dataset already provided annual summary statistics and 2) the dataset already provided the ensemble value of all the models defined in Table 5. Therefore, the annual ensemble values were first averaged for a given period (baseline or future) and then spatially averaged per NUTS3 region, resulting on four fire danger days values per NUTS3 region: baseline (1981-2010), RCP2.6 (2071-2100), RCP4.5 (2071-2100), and RCP8.5 (2071-2100).

## 4.2 Exposure indicators

This second set of indicators had originally been named in the framework of the previous ESPON-CLIMATE Update as “sensitivity”. However, from the current state-of-the-art (IPCC AR5), those indicators are not related with the concept of “sensitivity”, but with the concept of “exposure”.

Apart from the conceptual difference, the dimensions of what here was called exposure were the same five that were included in the previous ESPON-CLIMATE Update: physical, social, environmental, cultural, and economic. The physical exposure indicators measured the infrastructure exposed to different hazards, while the social ones accounted for population exposed to different hazards. The environmental exposure dimension was represented by the natural protected areas exposed. The fourth dimension encompassed the cultural buildings, places, etc. that might be exposed to hazards, while the fifth and last dimension aimed to quantify the economic exposure of the energy sector, agriculture and forestry, and tourism.

Table 6 shows the exposure indicators per dimension that were selected for the current **ESPON-CLIMATE Update 2022** along with the data sources used to obtain the indicators. All the indicators were, as in the case of the hazard ones, aggregated at NUTS3 level.

Moreover, exposure has been calculated both in absolute and relative terms. Absolute exposure means the value of the indicator, which represents the amount of total assets per NUTS3. While relative exposure has been obtained by dividing the indicator value by the total area of the NUTS3, resulting in density values, additionally, in the case of spatially explicit hazards, i.e. river flooding and coastal flooding, the relative exposure has been calculated by dividing the exposed assets, thus intersecting with the coastal and river flooding maps by the total assets of the NUTS3.

**Table 6. Overview of the exposure indicators used in ESPON-CLIMATE Update 2022 and the corresponding data sources.**

Exposure indicator	Metric	Used in previous ESPON-CLIMATE update	Data source	Date	Spatial resolution
Physical exposure indicators					
Roads	k tonnes	Yes	Risk Data Hub	2018	NUTS-3
Railways	k tonnes	Yes	Risk Data Hub	2018	NUTS-3
Railway stations	count	No	Open Street Map	2021	Feature
Airports	count	Yes	EUROSTAT GISCO	2013	Feature
Harbours	count	Yes	EUROSTAT GISCO	2013	Feature
Settlements	km <sup>2</sup>	Yes	Risk Data Hub	2018	NUTS-3
Industrial areas	km <sup>2</sup>	Yes (but within settlements)	Risk Data Hub	2018	NUTS-3
Thermal power plants	count	Yes	EEA E-PRTR	2017	Feature
Refineries	count	Yes	EEA E-PRTR	2017	Feature
Social exposure indicators					
Population	persons	Yes	Risk Data Hub	2018	NUTS-3



Educational facilities	million EUR	No	Risk Data Hub	2018	NUTS-3
Environmental exposure indicators					
Protected areas	km <sup>2</sup>	Yes	Risk Data Hub	2018	NUTS-3
Cultural exposure indicators					
Museums	count	Yes	Cultural gems	2021	NUTS-3
World Heritage Sites	count	Yes	UNESCO	2017	Feature
Economic exposure indicators					
Agricultural area	km <sup>2</sup>	Yes	Risk Data Hub	2018	NUTS-3
Forested area	km <sup>2</sup>	Yes	Risk Data Hub	2018	NUTS-3
Mixed area	km <sup>2</sup>	Yes	Risk Data Hub	2018	NUTS-3

### 4.2.1 Selected datasets

#### Risk Data Hub (RDH)

The DRMKC RDH was created with the aim of offering a common platform to access data and methodologies related to Disaster Risk Management in a more harmonised and facilitated approach for the end-user<sup>41</sup>. It is a GIS Web-platform that addresses three components of risk: hazard, exposure, and vulnerability. The RDH offers a multi-hazard approach that implied an alignment of methodological approaches and data used for disaster risk assessment across different hazards. The RDH encompasses several activities led by the European Commission over the last years, establishing a common framework regarding damage and loss data values and methodologies. It has become the reference database when addressing risk analysis in Europe.

All the data was internally provided by the RDH team. The dataset directly provided the total assets, the assets affected by river flooding, and the assets affected by coastal flooding at NUTS3 level. In the case of river and coastal flooding the exposure was obtained as a geospatial analysis, i.e. overlapping hazard maps and assets.

*Version and coverage:* the database was received on November 2021. The dataset did not cover the following NUTS3 regions:

- full Albania (AL), full Bosnia and Herzegovina (BA), full Kosovo (XK), full Montenegro (ME), full North Macedonia (MK), full Serbia (RS), full Turkey (TR), El Hierro (ES703), Fuerteventura (ES704), Gran Canaria (ES705), La Gomera (ES706), La Palma (ES707), Lanzarote (ES708), Tenerife (ES709), Guadeloupe (FRY10), Martinique (FRY20), Guyane (FRY30), La Reunión (FRY40), Mayotte (FRY50), Região Autónoma dos Açores (PT200), and Região Autónoma da Madeira (PT300).

#### Cultural gems

Cultural gems is a free open source web app, conceived by the European Commission's JRC, to map cultural and creative places in European cities. Its main purpose is to capture diversity in culture and creativity among European cities. Cultural gems include data on museums, cinemas, theatres, art galleries, and other institutional places. The spatial information of all these places is extracted from OpenStreetMap, although information provided by European cities, universities, and other public and private organisations is included as well. More information can be found in their web app<sup>42</sup>.

<sup>41</sup> (Antofie et al., 2019)

<sup>42</sup> <https://culturalgems.jrc.ec.europa.eu/> (last accessed, February 2022)

The data for cultural gems was internally provided by the JRC team involved in the development of the cultural gems dataset.

*Version and coverage:* the database was received on November 2021. The dataset did not cover the following NUTS3 regions:

- El Hierro (ES703), Fuerteventura (ES704), Gran Canaria (ES705), La Gomera (ES706), La Palma (ES707), Lanzarote (ES708), Tenerife (ES709), Guadeloupe (FRY10), Martinique (FRY20), Guayana (FRY30), La Reunión (FRY40), and Mayotte (FRY50).

## UNESCO

The United Nations Educational, Scientific and Cultural Organization's (UNESCO) objective is to encourage the identification, protection and preservation of cultural and natural heritage around the world considered to be of outstanding value to humanity. Thus, based on the definition provided by the 1972 World Heritage Convention, are considered cultural heritage:

- monuments: architectural works, works of monumental sculpture and painting, elements or structures of an archaeological nature, inscriptions, cave dwellings and combinations of features, which are of outstanding universal value from the point of view of history, art or science;
- groups of buildings: groups of separate or connected buildings which, because of their architecture, their homogeneity or their place in the landscape, are of outstanding universal value from the point of view of history, art or science;
- sites: works of man or the combined works of nature and man, and areas including archaeological sites which are of outstanding universal value from the historical, aesthetic, ethnological or anthropological point of view.

*Version and coverage:* The World Heritage Sites (WHS) list that provides the spatial location of all these places was downloaded from the official website<sup>43</sup> on September 2021. The dataset provided a global coverage.

## EUROSTAT

The European Statistical Office, better known as Eurostat, is the statistical office of the European Commission, which produces data on the European Union and promotes the harmonisation of statistical methods in its member states<sup>44</sup>. It provides a wide range of information on general and regional statistics, the economy, population, industry, agriculture, the environment and many other topics. It is a valuable source of information with pan-European coverage and reaching NUTS3 level, which makes it highly relevant for this research as it allows the production of comparable indicators across very diverse regions.

Additionally, and within EUROSTAT, data provided by the Geographic Information System of the Commission (GISCO) was used. GISCO manages databases of geographical information and creates statistical and other thematic maps to cover the needs of the European Commission at European Union, country, and regional level. GISCO chairs the working group that aims to integrate statistical and geospatial information, which includes representatives of National Statistical Institutes and national Mapping and Cadastral Authorities.

*Version and coverage:* since each of the data downloaded from EUROSTAT had different version and coverage, this information was provided in the corresponding exposure indicator in Section 4.2.2.

<sup>43</sup> <https://whc.unesco.org/en/syndication/> (last accessed, February 2022)

<sup>44</sup> <https://ec.europa.eu/eurostat> (last accessed, February 2022)



## OpenStreetMap (OSM)

OpenStreetMap is a collaborative project to create and maintain a free editable geographic database of the world<sup>45</sup>. It has more than two million registered users. Map data is collected from scratch by volunteers performing systematic ground surveys using tools such as a handheld GPS unit, a notebook, digital camera, etc. The availability of aerial photography and other data from commercial and government sources has added important sources of data for manual editing and automated imports. The OSM data had a much finer geographical resolution, which was especially important when combining this data with river and coastal flood maps at 100x100 metres resolution.

*Version and coverage:* Data was downloaded in September 2021, so it includes all the features included until that date. The dataset provided global coverage, so there was data for the full pan-European region.

## EEA E-PRTR

This database is provided by the European Environmental Agency (EEA) and reports the industrial activity in the framework of the Industrial Emission Directive 2010/75/EU and European Pollutant Release and Transfer Register (E-PRTR) Regulation No 166/2006<sup>46</sup>. The dataset contains the location and administrative data for the largest industrial complexes in Europe for 2007-2019 as well as detailed data about energy input and emissions for large combustion plants for 2016-2019.

*Version and coverage:* The downloaded version of the EEA E-PRTR database was the v4.0, which represent the status of the EEA Industrial Reporting database as of March 2021. The dataset's spatial information did not cover the following NUTS3 regions:

- full Albania (AL), full Bosnia and Herzegovina (BA), full Iceland (IS), full Kosovo (XK), full Montenegro (ME), full North Macedonia (MK), full Norway (NO), full Slovakia (SK), and full Turkey (TR).

## 4.2.2 Selected indicators

### Physical exposure indicators

Physical exposure refers to all human artefacts that are important for territorial development and could be affected by climate change. This includes settlements (homes, public buildings, industrial facilities) and infrastructure (e.g. transport and energy infrastructure). The physical dimension of a region is usually adapted to normal regional weather conditions and can thus withstand slight climatic changes. However, buildings and infrastructure may be exposed to more extreme weather events like flash floods, large-scale river floods and coastal storm surges.

The selected indicators to describe the physical dimension of each NUTS3 region were:

*Roads:* data was directly obtained from the RDH in annual freight transported units (k tonnes). Apart from providing total exposure indicators at NUTS3 level, the database already provide exposure crossed with river flood maps and coastal flood maps. Therefore, the only processing that was applied affected those NUTS3 regions whose administrative limits changed from version 2013 (used by RDH) to version 2016 (used by the current ESPON Climate Update). In these few cases, total exposure values were redistributed using a linear relationship with the total area of the equivalent NUTS3 regions, and hazard-specific exposure values using a linear relationship with the total river or coastal flooded area of the equivalent NUTS3 regions. In that way, the aggregated exposure was kept. The procedure was applied to all exposure indicators that were extracted from RDH. In the case of hazard specific exposures, data for 10-, 50-, 100-, 200-, and 500-year return periods was available, but only 100-year data was used (i.e. the reference return period selected in the current ESPON-CLIMATE Update). RDH originally extracted roads from the LUISA modelling platform<sup>47</sup>.

<sup>45</sup> <https://www.openstreetmap.org/> (last accessed, February 2022)

<sup>46</sup> <https://www.eea.europa.eu/data-and-maps/data/industrial-reporting-under-the-industrial-3> (last accessed, February 2022)

<sup>47</sup> (Marin Herrera et al., 2015)

*Railways:* data was directly obtained from the RDH in annual freight transported units (k tonnes). The same methodological context of roads applied in this case.

*Railway stations:* the locations of all railway stations for the whole pan-European region were extracted from OSM searching for “railway”=“station” tag. This included places with at least one switch, where trains begin, end, cross, turn, end etc. This tag is used for all stations with access for passengers. While the previous indicator (railways) accounted for freight traffic, railway stations were used as a proxy to account for the service provided to the passengers<sup>48</sup>. These locations were aggregated at NUTS3 level by counting the number of stations in each specific region. Additionally, a geospatial analysis was performed to get those railways stations affected by river and/or coastal floods by overlapping the locations with the corresponding flood map. All the 100 m grid cells with a water depth greater than 0 m were considered flooded. Thus, two additional indicators were generated: the number of railway stations affected by river floods and by coastal floods.

*Airports:* data was downloaded from EUROSTAT GISCO Airports 2013 dataset. Information was available for the whole pan-European region. The same methodology of railway stations was applied to derive, on the one hand, the total number of airports per NUTS3 and, on the other hand, the number of airports affected by river and/or coastal floods, spatially overlapping the assets with the flood maps..

*Harbours:* data was downloaded from EUROSTAT GISCO Ports 2013 dataset. Information was available for the whole pan-European region. The same methodology of railway stations and airports was applied to derive, on the one hand, the total number of harbours per NUTS3 and, on the other hand, the number of harbours affected by river and/or coastal floods, spatially overlapping the assets with the flood maps.

*Settlements:* data was directly obtained from the RDH in terms of residential built-up area (km<sup>2</sup>). The same methodological context of roads and railways applied in this case. The differences came only from the data sources used by RDH to identify built-up areas. On the one hand, European Settlements Map version 2016 was used to get quantitative values of built-up space. On the other hand, CORINE Land Cover's (g100\_clc12\_V18\_5a) “continuous urban fabric” and “discontinuous urban fabric” classes were used to assign the type.

*Industrial area:* data was directly obtained from the RDH in terms of industrial or commercial built-up area (km<sup>2</sup>). The same methodological context of roads, railways, and settlements applied in this case. The data sources were the same as for settlements but selecting “industrial or commercial units” class from CORINE (g100\_clc12\_V18\_5a).

*Thermal power plants:* the E-PRTR was used for identifying the locations of thermal power plants. Based on the attributes, those features that met the following conditions were considered: mainActivityCode=‘1(c)’ (i.e. thermal power stations and other combustion installation) and facilityTypes=‘EPRTTR’. The same methodology of railway stations, airports, and harbours was applied to derive, on the one hand, the total number of power plants per NUTS3 and, on the other hand, the number of power plants affected by river and coastal floods, spatially overlapping the assets with the flood maps.

*Refineries:* as in the case of the thermal power plants, the E-PRTR was used for identifying the locations of refineries. Based on the attributes, those features that met the following conditions were considered: mainActivityCode=‘1(a)’ (i.e. Mineral oil and gas refineries) and facilityTypes=‘EPRTTR’. The same methodology of railway stations, airports, harbours, and thermal power plants was applied to derive, on the one hand, the total number of refineries per NUTS3 and, on the other hand, the number of refineries affected by river and coastal floods, spatially overlapping the assets with the flood maps.

## Social exposure indicators

Although the term ‘social’ may refer to a wide spectrum of concepts, such as socio-economic differences within a population or qualities of a human collective, in the new **ESPON-CLIMATE Update 2022** those more detailed aspects are handled through the concept of vulnerability, which included sensitivity and adaptive capacity indicators. The exposure was focused on quantifying, in terms of number of human beings and educational facilities, the exposure that a given region had when facing a given hazard.

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<sup>48</sup> (Poelman et al., 2020)

*Population:* data was directly obtained from the RDH in terms of population exposed. As happened with the rest of the indicators available through the RDH, no further processing was needed. Total population, population affected by river floods and population affected by coastal floods per region was directly obtained, for the 100-year return period in the last two cases. RDH originally extracted population data from the Global Human Settlements Layer.

*Educational facilities:* data was directly obtained from the RDH in terms of annual expenditure (Million EUR). The same methodological context explained for population was applicable in this case. However, exposure to coastal flooding was not available through the RDH. As in the case of roads and railways, originally, educational facilities data was extracted from the LUISA modelling platform.

### Environmental exposure indicators

Climate change directly affects different aspects of the environment, which includes not only natural physical entities but also biological life within the earth's biosphere. The positive impact of a wealthy environment and, hence, ecosystem in a region, have been largely studied in terms of water cycle, energy balance, carbon cycle, biodiversity and soil, among others. One of the most successful mechanisms to keep environmentally rich zones safe are the protected areas and, therefore, they were considered the best indicator to characterise the environmental dimension of the exposure.

*Protected areas:* data was directly obtained from the RDH in terms of protected area (km<sup>2</sup>). Two data sources were considered originally by the RDH the Natura 2000 network, which included protected areas by Habitats, Birds or both Directives, and World Heritage Natural Sites.

### Cultural exposure indicators

The terms culture and cultural heritage refer to a wide range of tangible artefacts and intangible attributes. The former includes buildings, monuments, works of art, and books, among others, but also special landscapes that have been shaped by human use over centuries and thus acquired certain cultural or historical qualities. The latter, the intangible aspects of culture, encompass things like music, folklore, language, or literature, among others. Although all these cultural aspects may deserve analysis, for conceptual and practical reasons only the tangible dimension of culture could be included in the project, in this case, through the inclusion of museums and World Heritage Sites, as it was done in the previous ESPON-CLIMATE Update.

*Museums:* data was provided by the Cultural Gems database in two formats: a layer containing the specific location of museums (point type) and the footprint of the museums, i.e. the shape of the building projected on the ground (polygon type). Some of the punctual locations referred to museums that were already included in the footprint layer. Therefore, in a first step, all the redundant points were filtered out, by considering a 5 m buffer. Those points that touched a museum footprint were considered redundant. After that, the total number of museums per region was calculated by counting the number of features (point + polygon) that were contained by each NUTS3 region. Thus, the new number of museums, which was around 48,000, more than doubled the number in the previous ESPON-CLIMATE Update (over 20,000).

*World Heritage Sites:* UNESCO's WHS list was used as input database for this indicator. Three types of heritage sites are differentiated within the list based on an attribute called "category": natural, cultural or mixed. Only those locations associated to mixed or cultural sites were considered. Similar to museums, the indicator was defined as the number of WHS contained per NUTS3 region.

### Economic exposure indicators

The economic dimension of exposure aims to characterise how exposed a region could be considering its main economic activities. In that sense, three main aspects were included: agricultural, forestry and mixed areas.

*Agricultural areas:* data was directly obtained from the RDH in terms of agricultural area (km<sup>2</sup>). Similar to previous RDH indicators, total agricultural area per region was considered. The agricultural areas were the sum of three differentiated agricultural classes derived from CORINE (g100\_clc12\_V18\_5a): arable, which include "non-irrigated arable land", "permanently irrigated land" and "rice fields"; pastures, which include the CORINE class of the same name; and permanent crops, which encompassed "vineyards", "fruit trees and berry plantations" and "olive groves".

*Forested areas*: data was directly obtained from the RDH in terms of forested area (km<sup>2</sup>). The same context of agricultural areas applied. The only difference was that the CORINE (g100\_clc12\_V18\_5a) classes included as forested areas were: “broad-leaved forest”, “coniferous forest”, and “mixed forest”.

*Mixed areas*: the sum of agricultural and forested areas. In the previous ESPON-CLIMATE Update the agriculture and forestry sector was represented by the employment and GVA. However, the current **ESPON-CLIMATE Update 2022** prioritised the consistency with the rest of European initiatives. Therefore, it was decided to use agricultural, forested, and mixed areas as a proxy for the economic presence of this sector in a region, assuming a linear correlation.

### 4.3 Vulnerability indicators

The vulnerability in this update has been conceptualised following the AR5<sup>49</sup> approach as the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. Regarding the selected indicators, a trade-off has been made between the indicators of the previous update and other current initiatives such as the RDH and the ESPON-TITAN project.

The indicators included to characterize the sensitivity to climate change are grouped in social sensitivity, economic sensitivity and environmental sensitivity. The Table 7 summarises the selected indicators, whether they were used in the previous update, and the data source from which they were collected.

**Table 7 Overview of the sensitivity indicators used in ESPON-CLIMATE Update 2022 and the corresponding data sources.**

Sensitivity indicator	Metric	Used in previous ESPON-CLIMATE update	Data source	Date	Spatial resolution
Social sensitivity					
Young-age dependency	persons ratio	No	ESPON-TITAN (EUROSTAT)	2018	NUTS-3
Old age dependency	persons ratio	Yes	ESPON-TITAN (EUROSTAT)	2018	NUTS-3
Disabled people with need for assistance	persons ratio	No	Risk Data Hub	2020	NUTS-0
Economic sensitivity					
Industrial and service sectors employments	employment ratio	Yes	EUROSTAT	2018	NUTS-3
Industrial and service sectors GVA	GVA ratio	Yes	EUROSTAT	2018	NUTS-3
Primary sector employments	employment ratio	Yes	EUROSTAT	2018	NUTS-3
Primary sector GVA	GVA ratio	No	EUROSTAT	2018	NUTS-3
Share of irrigable and irrigated areas	area ratio	No	ESPON-TITAN (EUROSTAT)	2016	NUTS-2

<sup>49</sup> (IPCC, 2014)

in utilised agricul-  
tural area

Touristic arrivals	arri- vals/area	Yes	EUROSTAT	2018	NUTS-2
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As with the sensitivity indicators table, the Table 8 summarises the indicators used in the current update for adaptive capacity, whether they were used in the previous update and the data source from where they were obtained. In this case, the adaptive capacity was grouped in social capacity, technological capacity, infrastructure capacity, economic capacity and institutional capacity.

**Table 8 Overview of the adaptive capacity indicators used in ESPON-CLIMATE Update 2022 and the corresponding data sources.**

Adaptive capacity indicator	Metric	Used in previous ESPON-CLIMATE update	Data source	Date	Spatial resolution
Social capacity					
Investments in education	EUR/population	Yes	EUROSTAT	2018	NUTS-0
Persons with tertiary education	persons ratio	Yes	ESPON-TITAN (EUROSTAT)	2018	NUTS-2
Risk perception	dimensionless	Yes	ESPON-TITAN (EUROSTAT)	2020	NUTS-0
Social capital	dimensionless	Yes	ESPON-TITAN (EUROSTAT)	2005	NUTS-0
Gender equality index	dimensionless	No	ESPON-TITAN (EIGE)	2019	NUTS-0
Technological capacity					
Research staff	employment ratio	Yes	ESPON-TITAN (EUROSTAT)	2018	NUTS-2
Patent applications	patents/population	Yes	ESPON-TITAN (EUROSTAT)	2018	NUTS-3
Research and development investments	EUR/population	Yes	ESPON-TITAN (EUROSTAT)	2018	NUTS-2
Infrastructure capacity					
Medical doctors	doctors/population	Yes	ESPON-TITAN (EUROSTAT)	2018	NUTS-2
Hospital beds	beds/population	No	ESPON-TITAN (EUROSTAT)	2018	NUTS-2
Settlement compactness	population/area	Yes	EUROSTAT	2018	NUTS-3
Economic capacity					
Employment rate	employment ratio	Yes	EUROSTAT	2018	NUTS-2
Risk of poverty	persons ratio	No	EUROSTAT	2018	NUTS-2
Regional GDP	EUR/population	Yes	EUROSTAT	2018	NUTS-3

National GDP	EUR/population	Yes	EUROSTAT	2018	NUTS-0
Institutional capacity					
National adaptation strategies	dimensionless	Yes	Risk Data Hub	2020	NUTS-0
Regional quality of government index	dimensionless	Yes	Risk Data Hub	2020	NUTS-2
Municipalities signatories to the Covenant of Majors	municipalities ratio	No	ESPON-TITAN (ESPON)	2013	NUTS-2

### 4.3.1 Selected datasets

#### ESPON-TITAN

The project Territorial Impacts of Natural Disasters, i.e. ESPON-TITAN<sup>50</sup>, had the objective of providing evidence on the direct and indirect economic losses due to natural hazards and an analysis of the best practices of disaster risk management and climate change adaptation at territorial level. In addition to analysing and producing a series of datasets related to hazards and economic impacts, a vulnerability assessment was conducted using a set of indicators that have been used extensively in this research. While the approach followed in that assessment was the same as the approach of the disaster risk reduction community, the approach of the climate change community has increasingly moved towards it, to the extent that susceptibility and sensitivity, as well as coping capacity and adaptive capacity, can be considered as equivalent concepts<sup>51</sup>.

#### Risk Data Hub

See section 4.2.1 for the Risk Data Hub dataset description.

#### EUROSTAT

See section 4.2.1 for the EUROSTAT dataset description.

### 4.3.2 Selected indicators

#### Social sensitivity indicators

*Young-age dependency*: This indicator was taken from the dataset developed in ESPON-TITAN project. In that project, the original source was EUROSTAT, at NUTS3 level and the reference year 2018. Young-age dependency was originally calculated as the ratio between population aged 0-14 years to 15-64. This indicator is new and has been considered for inclusion because the population under 14 years of age is more susceptible to the consequences resulting from climate change.

*Old age dependency*: This indicator was obtained from ESPON-TITAN project. The original data source is EUROSTAT, at NUTS3 level and the reference year is 2018. It was calculated as the ratio between the number of persons aged 65 and over and the number of persons aged between 15 and 64. The old age dependency indicator was also included in the previous update.

<sup>50</sup> ESPON-TITAN – Territorial Impacts of Natural Disasters. Main Report. Available at: <https://www.espon.eu/natural-disasters> (last accessed, February 2022)

<sup>51</sup> (IPCC, 2012, 2014)



*Disabled people with need for assistance:* This indicator was taken from Risk Data Hub. It was not included in the previous update. However, it is a relevant indicator since the disabled people with need for assistance may have more difficulties during and after the occurrence of an extreme event and therefore, they are more sensitive. The original data is at NUTS0 level.

### Economic sensitivity indicators

*Industrial and service sectors employments:* The employment was directly extracted from the table NAMA\_10R\_3EMPERS, “Employment (thousand persons) by NUTS 3 regions”, available through the EUROSTAT portal. The reference period selected was 2018. The service employment indicator was included in previous update but not industrial employment. The following activities were included in the industrial and service employment: industry, wholesale and retail trade, transport, accommodation and food service activities, information and communication, financial and insurance activities, real estate activities, professional, scientific and technical activities, and administrative and support service activities. The indicator was calculated as the percentage of industrial and service employment over the total employment of the region.

*Industrial and service sectors GVA:* the gross value-added (GVA) was directly extracted from the table NAMA\_10R\_3GVA, “Gross value added at basic prices by NUTS 3 regions”, available through the EUROSTAT portal. The reference period selected was 2018. The service GVA indicator was included in previous update but not industrial GVA. The same activities as in the industrial and service sectors employment were selected. The indicator is the result of dividing the GVA of the selected activities by the total GVA of the region.

*Primary sector employment:* The data for this indicator is taken from EUROSTAT. The original table is NAMA\_10R\_3EMPERS, “Employment (thousand persons) by NUTS 3 regions” from 2018. This indicator corresponds to the employment in agriculture, forestry and fisheries indicator in the previous update. It was calculated as the percentage of people employed in agriculture, forestry or fishing.

*Primary sector GVA:* This indicator was obtained from the same table as industrial and service sectors GVA, i.e. NAMA\_10R\_3GVA, “Gross value added at basic prices by NUTS 3 regions” from EUROSTAT but selecting the agriculture, forestry and fishing activities. The reference year is 2018. The indicator was obtained by dividing the primary sector GVA by the total GVA of the region.

*Share of irrigable and irrigated areas in utilised agricultural area:* This new indicator was obtained from ESPON-TITAN project. Data was originally obtained from EUROSTAT, at NUTS2 level and from 2016. The irrigable area corresponds to the surface equipped for irrigation, while the irrigated area measures the actual amount of land irrigated. We understand that where agriculture is irrigated, the dependence on water resources is greater, then crops may be more sensitive to water stress. For example, there is an increase in crops such as avocados due to the economic benefits they bring, but they are highly dependent on water, which means a greater demand for water for crops in a context of scarcity. A more appropriate adaptation could be to use crops that are better adapted to climatic conditions of rising temperatures and water scarcity. Therefore, highly irrigated agricultural areas might be a maladaptation practice.

*Touristic arrivals:* the number of touristic arrivals was obtained from the “arrivals at tourist accommodation establishments by NUTS 2 regions” table, available through the EUROSTAT portal (online code TOUR\_OCC\_ARN2). The unit of measure is number of arrivals and it was selected the total number, so domestic and foreign visitors were included. The reference year, as with previous indicators was 2018 and the spatial scale is NUTS2. The indicator was calculated dividing the number of arrivals by the area, therefore obtaining a density like indicator. The same value at NUTS2 level was assigned to all the NUTS3 which belongs to it.

### Social adaptive capacity indicators

*Investments in education:* This indicator was included in the previous update. It was obtained from EUROSTAT, at NUTS0 level and from 2018. The procedure to assign the NUTS3 level is the same as the one described in previous indicators. This indicator is calculated by dividing the resources devoted to education by the total population.

*Persons with tertiary education:* The persons with tertiary education indicator was also included in the previous update. For this update, the data was collected from ESPON-TITAN. The original data is from EUROSTAT, at NUTS2 scaled and from 2018. The indicator is calculated as the rate of population with tertiary education between 25-64 years old.

*Risk perception:* The risk perception indicator is related to the previously used indicator knowledge and attitudes on climate change. It was taken from ESPON-TITAN and at NUTS0 scale. It was calculated as the aggregated value of perception of droughts and floods importance, perception of climate change importance, and budget prioritization by population for climate change and environmental protection.

*Social capital:* This indicator was also taken from ESPON-TITAN. The original data is from EUROSTAT and at NUTS0 level. It was calculated as a combination of social trust, social support and participation. This indicator is new, but it is very much related to the indicator participation in voluntary organizations from previous update.

*Gender equality index:* The gender equality index is a new indicator which was not included in the previous update. The data was collected from ESPON-TITAN. The original data came from European Institute for Gender Equality (EIGE) at a NUTS0 level, and it considers work, money, knowledge, time, power and health domains.

### Technological adaptive capacity indicators

*Research staff:* This indicator was included in the previous update. The indicator is taken from ESPON-TITAN, which original source is EUROSTAT, at NUTS2 scale and from 2018. The indicator was built as the “research and development personnel” and “researchers” as percentage of total employment.

*Patent applications:* The data for this indicator was collected from ESPON-TITAN. The patent applications indicator was already considered in the previous update. The original data source is EUROSTAT, at NUTS3 level and from 2018. It was calculated as the patent applications to the European Patent Office (EPO) per million inhabitants.

*Research and development investments:* This indicator was taken from ESPON-TITAN. The original data came from EUROSTAT, at NUTS2 level from 2018. The research and development investments indicator was also included in the previous update. To obtain this indicator the research and development expenditure as percentage of GDP was calculated.

### Infrastructure adaptive capacity indicators

*Medical doctors:* This indicator was included in previous update and it is now updated with the more recent data from ESPON-TITAN project. In that project, the data was collected from EUROSTAT at NUTS2 level. It was calculated as the number of physicians or medical doctors per 100 000 inhabitants.

*Hospital beds:* To complete the infrastructure capacity indicators, this new indicator was included. It was collected from ESPON-TITAN. The original data source is EUROSTAT at NUTS2 level. It was calculated as the number of hospital beds per 100 000 inhabitants.

*Settlement compactness:* This indicator was calculated as the ratio between the total population of the NUTS3 region between the settlement area of that region. The data to build this indicator come from Risk Data Hub, see population and settlement area indicators from the exposure section.

### Economic adaptive capacity indicators

*Employment rate:* Employment rate indicator was obtained from EUROSTAT. The downloaded table is LFST\_R\_LFE2EMPRTN which is “Employment rates by sex, age, educational attainment level, citizenship and NUTS 2 regions”. The reference year selected is 2018, the age class selected is 20 to 64 years, and the unit of the indicator is percentage. The data is at NUTS2 level, therefore the values at NUTS2 level are assigned to the NUTS3 level which belong to them.

*Risk of poverty:* This new indicator is taken from EUROSTAT. The downloaded table is ILC\_PEPS11 which is “Persons at risk of poverty or social exclusion by NUTS regions - EU 2020 strategy”. The reference year selected is 2018, and the unit of measure is percentage. The regional level is NUTS2 and the procedure to obtain the values at NUTS3 level is the same as the one described in employment rate indicator. It describes the percentage of people at risk of poverty or social exclusion. To account for the risk of poverty as a capacity indicator, the original values are inverted, i.e. transform through one minus the value. Therefore, a region with an original value of 30 percent of risk of poverty will have a 70 percent of lack of risk of poverty.



*Regional GDP:* The data for this indicator was downloaded from EUROSTAT. The table downloaded is NAMA\_10R\_3GDP and it is the gross domestic product (GDP) at current market prices by NUTS 3 regions calculated as euro per inhabitant. The downloaded data is from 2018.

*National GDP:* As with regional GDP indicator, the data for this indicator was downloaded from EUROSTAT. The downloaded table was the same, NAMA\_10R\_3GDP, but only NUTS0 level data was selected. The data is from 2018 and it is also the gross domestic product (GDP) at current market prices measure as euro per inhabitant.

### **Institutional adaptive capacity indicators**

*National adaptation strategies:* This indicator was taken from Risk Data Hub. National adaptation strategies is a new indicator, not included in the previous update, that reflects the level of institutional commitment related to adaptation policies at the national level including national adaptation strategies (NASS) and plans (NAPs). Additional information can be found in Climate-ADAPT platform<sup>52</sup>.

*Regional quality of government index:* The regional quality of government index is very much related with the previous indicator European quality of Government Index, but in this new update a finer scale indicator is used which is at NUTS2 level. The data for this indicator was taken from Risk Data Hub.

*Municipalities signatories to the Covenant of Majors:* This is a new indicator that was taken from ESPON-TITAN. The original data source was ESPON, and it was calculated as the weighted share of municipalities that have signed the Covenant of Majors and have also submitted an Action Plan.

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<sup>52</sup> Climate-ADAPT Country Profiles <https://climate-adapt.eea.europa.eu/countries-regions/countries>

## 5 Main results

To simplify the presentation of the results, only the baseline climate and the very high emissions scenarios are presented in detail, considering both their absolute and relative exposure. This makes it possible to look at both current risk and future risk in the very high emissions scenario, as well as to identify the areas of change after comparing them.

On the other hand, risk scenarios with absolute exposure show the amount of assets exposed, e.g. total population or agricultural area. However, it should be highlighted that the NUTS3 are of very different sizes and follow different division criteria, depending on the country (e.g. Germany, where the size of the NUTS3 is significantly smaller in the whole country; Paris, which is subdivided into several NUTS3 as opposed to the rest of France, or Madrid and Rome, where the city is part of a larger region). To overcome this situation, it is relevant to perform a combined reading of the risk with absolute and relative exposure.

This section includes the description of the main results. The rest of them, including the 62 risk scenarios (Table 3), as well as the intermediate results for hazard, exposure, sensitivity, adaptive capacity, vulnerability and risk, can be found in the Annex of maps, at high resolution.

### 5.1 Adaptive capacity

Adaptive capacity has been considered holistically and capable of influencing the distribution of risk in any of the impact chains analysed. It is therefore an adaptive capacity common to all risk scenarios. A total of 18 indicators of a social, economic, institutional, infrastructural and technological nature have been selected.

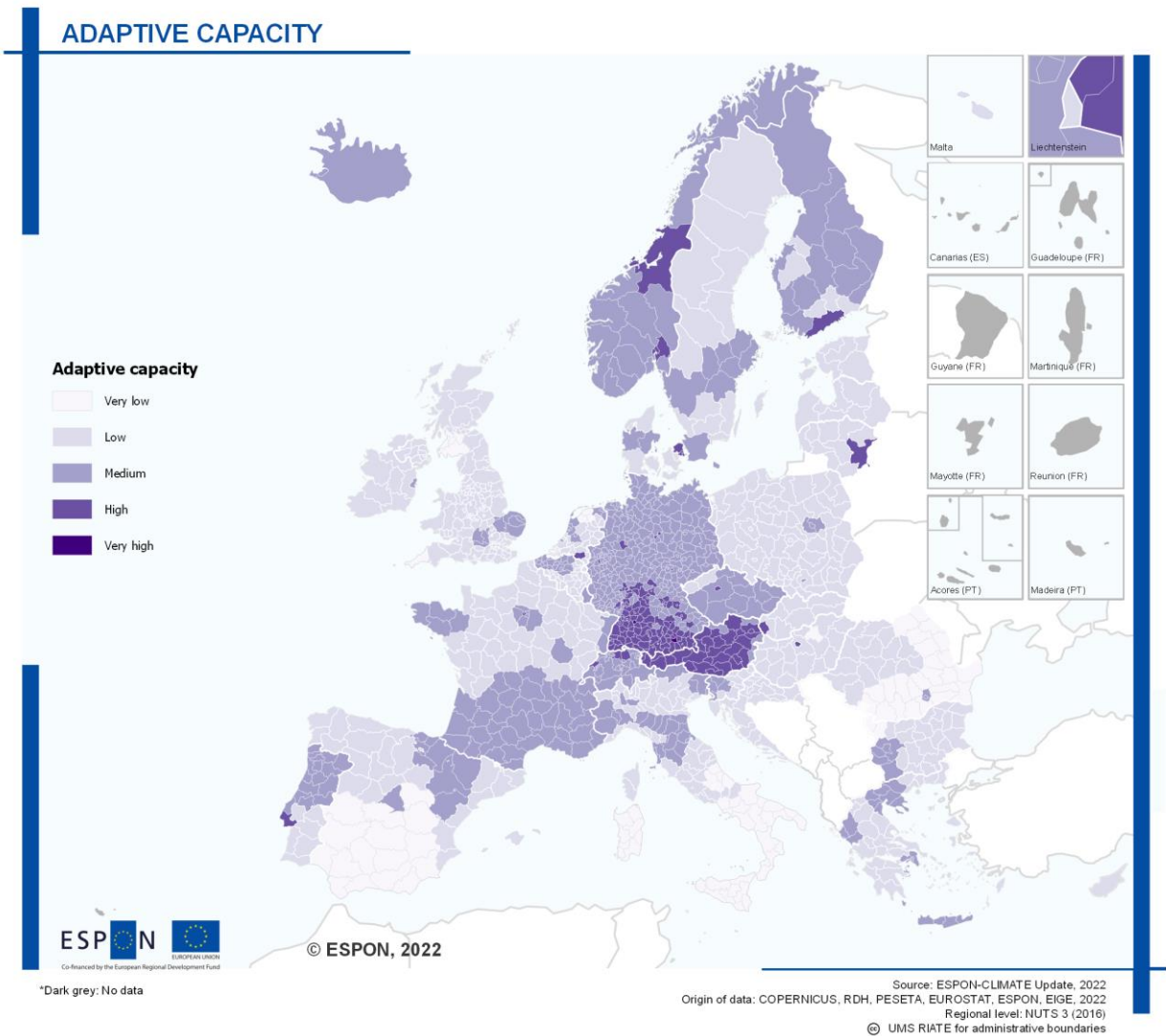
PCA has been performed to extract the factors that are able to explain the most variance in the data. Firstly, a series of tests were performed, specifically the Bartlett's test of sphericity was significant at an alpha level of 0.05 and the overall Kaiser-Meyer-Olkin factor adequacy was 0.838. Both tests indicated that the PCA analysis was pertinent.

The selection of the number of factors was based on the elbow criterion, i.e. the interpretation of the factor vs. percentage of variance graph to determine the smallest number of factors that explain the highest percentage of cumulative variance. This resulted in the selection of 4 factors, that explain 70% of the variance, which are:

- Social and institutional development – This factor is highly correlated with social capacity and institutional capacity indicators like gender equality, social capital, national GDP, investment in education, quality of government, national adaptation strategies and risk perception.
- Hospital resources – This factor mainly explains the indicator hospital beds.
- Innovation – The innovation factor is highly correlated with infrastructure and technological capacity indicators like research staff, investment in research, number of patents, medical doctors and local GDP.
- Economic development – The last factor is highly correlated with economic capacity indicators like employment rate and lack of risk of poverty.

Finally, the factors obtained have been aggregated to calculate adaptive capacity. Map 1 shows the spatial distribution of adaptive capacity, where a spatial pattern can be observed in which Austria and southern Germany stand out for their very high level, while in the territories of Romania, southern Italy and southern Spain adaptive capacity is very low.

Map 1 Adaptive capacity



## 5.2 Risk of heat stress on population

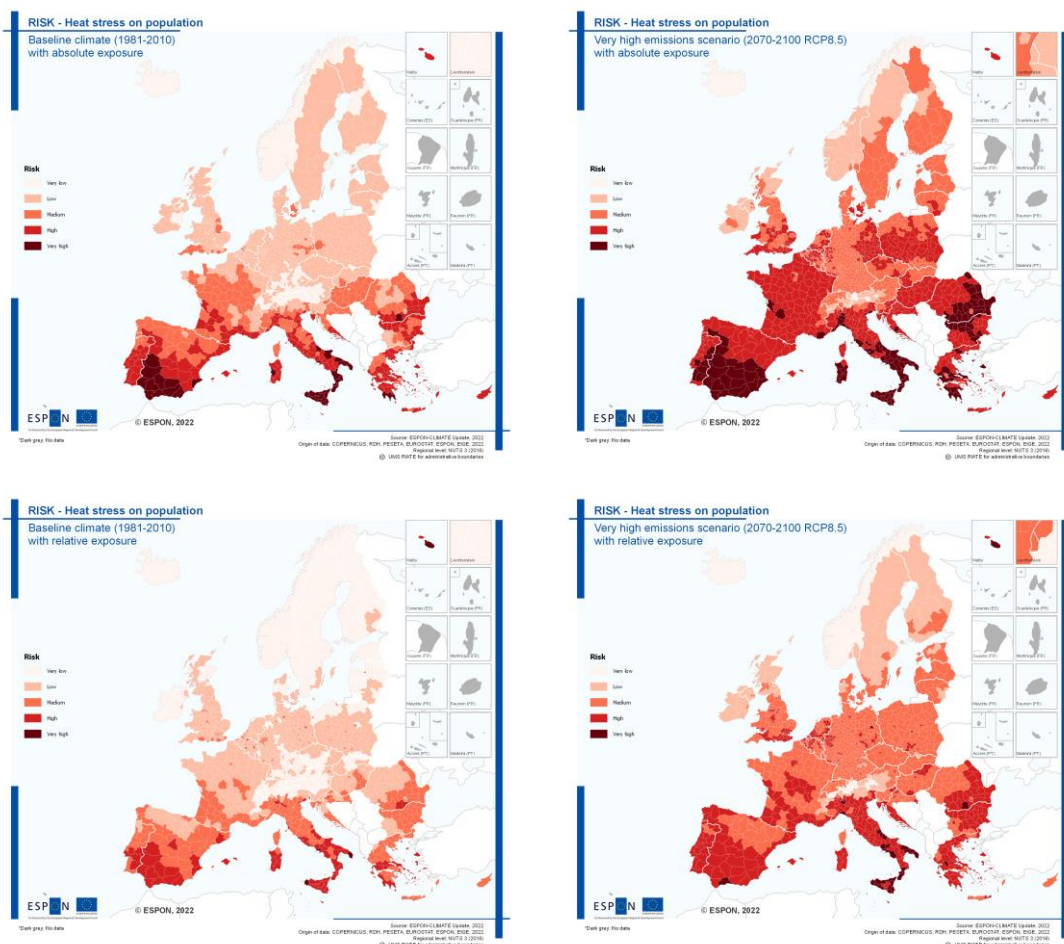
The maps of risk of heat stress on population are shown in Map 2 for the baseline climate (first column) and for the very high emissions scenario (second column) as well as considering the risk calculation with absolute exposure (first row) and with relative exposure (second row). The indicators used in this impact chain for all the risk components can be found in Table 2.

The Map 2 shows that the risk is expected to increase from the baseline climate (1981-2010) to the very high emissions scenario at the end of the century (RCP8.5 in 2070-2100), and it shows a distinct north-south pattern, with southern areas being the most affected for RCP8.5 in the 2070-2100 period.

A result of interest arises from comparing the risk in the very high emissions scenario at the end of the century with absolute exposure and the risk with relative exposure. This is the case for example in Paris, where the total population is divided between the four NUTS3 that form the metropolitan area, resulting in a limited absolute exposure and therefore a lower risk, while the population density is considerably high, making the relative exposure very high and therefore the risk with relative exposure very high.

Maps of all risk components (hazard, exposure, sensitivity, adaptive capacity, vulnerability and risk) as well as the low emissions and intermediate emissions scenarios (RCP2.6 and RCP4.5 respectively) can be found in the high-resolution map annex.

**Map 2 Risk scenarios of heat stress on population. In rows, absolute and relative exposure. In columns, baseline climate and very high emissions scenario.**



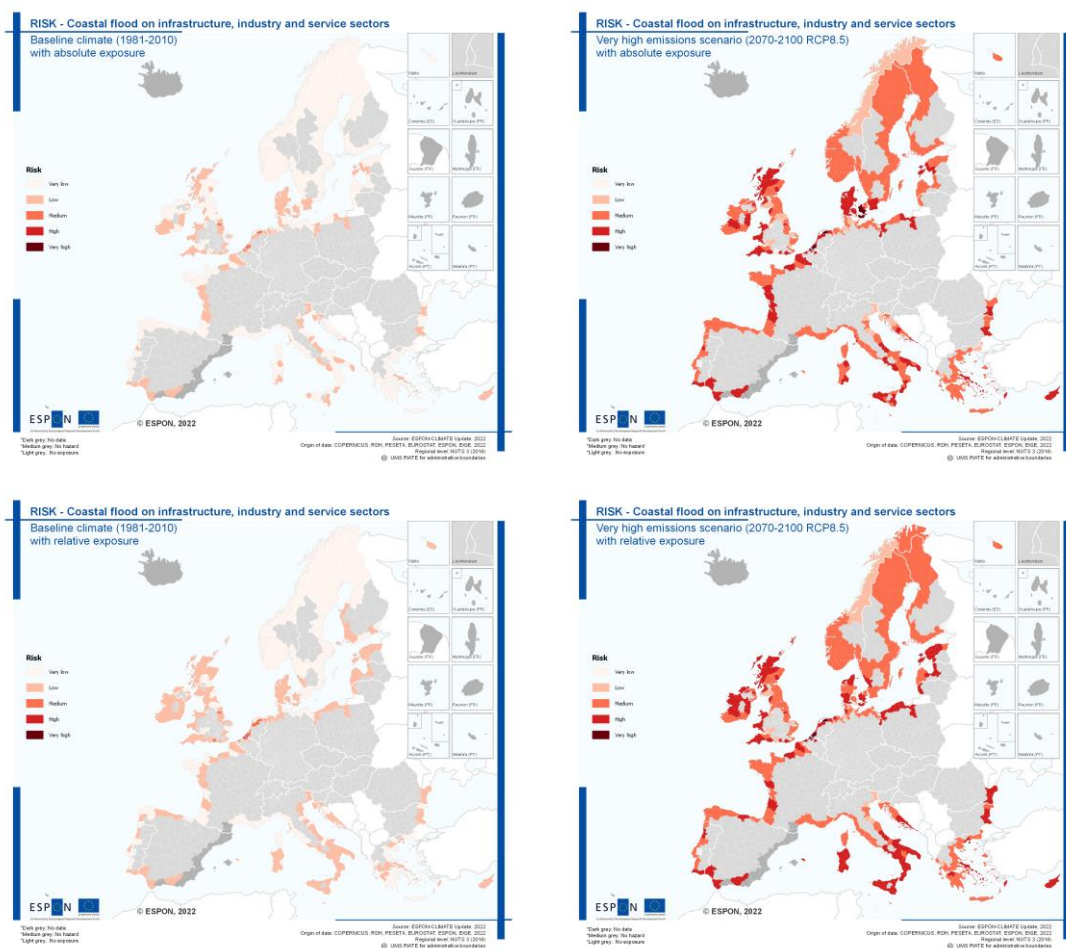
## 5.3 Risk of coastal flood on infrastructure, industry and service sectors

The maps of risk of coastal flood on infrastructure, industry and service sectors are shown in Map 3 for the baseline climate (first column) and for the very high emissions scenario (second column) as well as considering the risk calculation with absolute exposure (first row) and with relative exposure (second row). The indicators used in this impact chain for all the risk components can be found in Table 2.

There is a clear increase in risk from the baseline climate in 1981-2010, to the very high emissions scenario in 2070-2100 (RCP8.5). In fact, the coastal flood risk impact chain is the one of the seven impact chains analysed in which the largest increases in risk are observed between the base period and the future period.

In the baseline climate scenarios, no territory exceeds the medium risk in the risk scenario with absolute exposure, and in the risk scenario with relative exposure only one territory exceeds the medium risk in the Netherlands. Besides, in the very high emissions scenario at the end of the century, practically all countries have territories with at least high risk, with the Netherlands and Denmark standing out.

**Map 3 Risk scenarios of coastal flood on infrastructure, industry and service sectors. In rows, absolute and relative exposure. In columns, baseline climate and very high emissions scenario.**





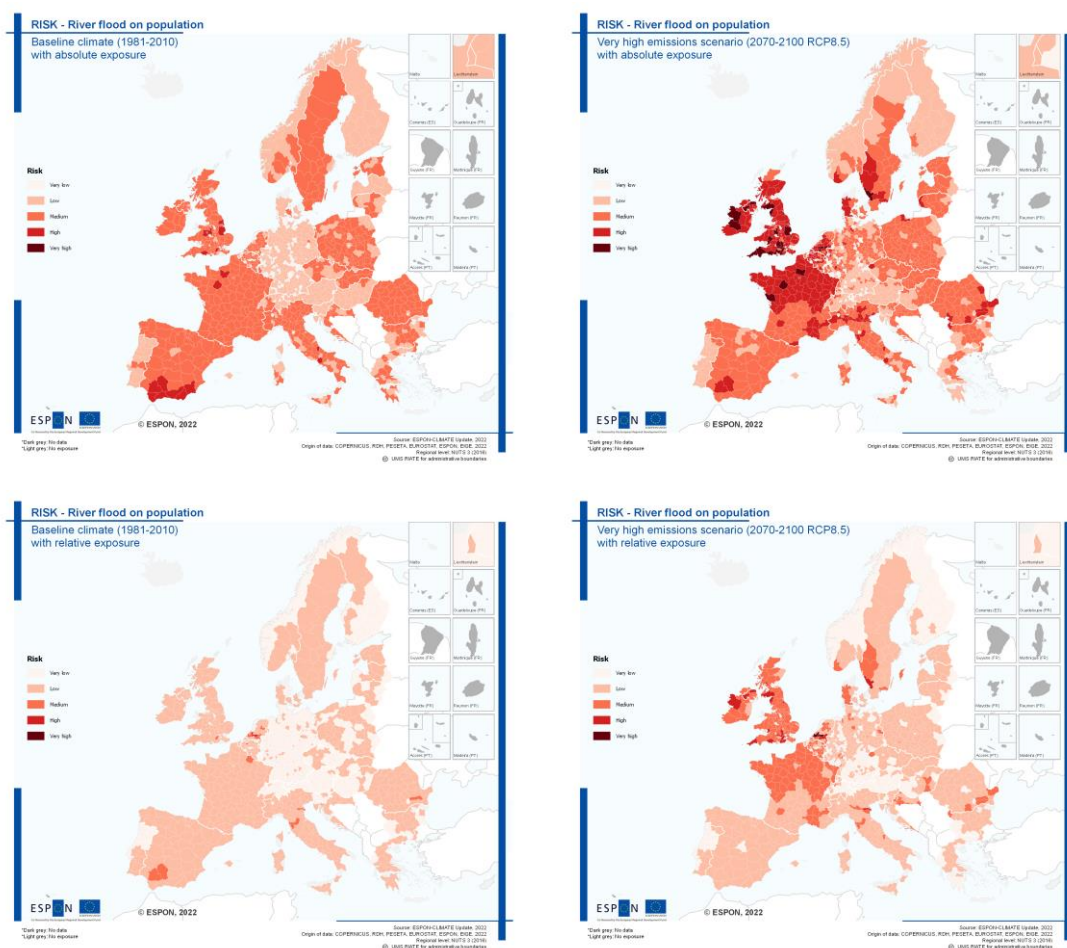
## 5.4 Risk of river flood on population

The maps of risk of river flood on population are shown in Map 4 for the baseline climate (first column) and for the very high emissions scenario (second column) as well as considering the risk calculation with absolute exposure (first row) and with relative exposure (second row). The indicators used in this impact chain for all the risk components can be found in Table 2.

A very significant increase in the risk of river flooding on the population is observed mainly in Ireland, the United Kingdom, France, Belgium, the Netherlands, Germany, Sweden and northern Italy. However, in contrast to this increase in risk, in many southern regions, for example in certain territories of Portugal, Spain or Greece, the risk evolves in the opposite direction, decreasing in the future period compared to the baseline.

This result is due to the 100-year return period flood event frequency change projections made by the JRC (see section 4.1 for further information), where this pattern of increasing flood frequency (higher frequency equals higher hazard and therefore higher risk) is observed in central and northern Europe, and decreasing frequency in southern Europe of the 100-year flood event.

**Map 4 Risk scenarios of river flood on population. In rows, absolute and relative exposure. In columns, baseline climate and very high emissions scenario.**



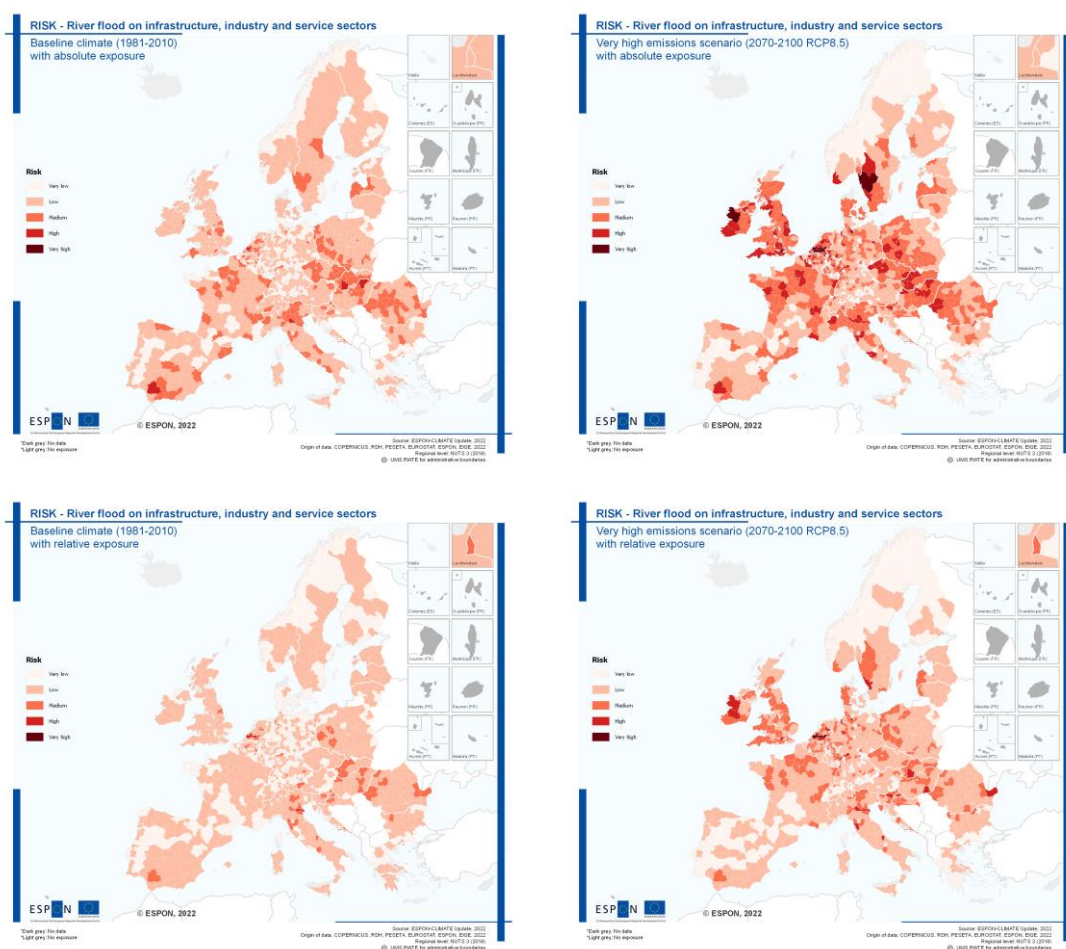
## 5.5 Risk of river flood on infrastructure, industry and service sectors

The maps of risk of river flood on infrastructure, industry and service sectors are shown in Map 5 for the baseline climate (first column) and for the very high emissions scenario (second column) as well as considering the risk calculation with absolute exposure (first row) and with relative exposure (second row). The indicators used in this impact chain for all the risk components can be found in Table 2.

This impact chain also shows an increase in risk from the baseline climate to the very high emissions scenario at the end of the century. As was the case with the impact chain of river flood on population, in some specific regions of southern Europe the risk decreases, although it is not so clearly observed.

In general, there is no clear spatial pattern, many countries have at least one territory with high or very high risk, although Ireland, the Netherlands and Sweden may stand out among them.

**Map 5 Risk scenarios of river flood on infrastructure, industry and service sectors. In rows, absolute and relative exposure. In columns, baseline climate and very high emissions scenario.**

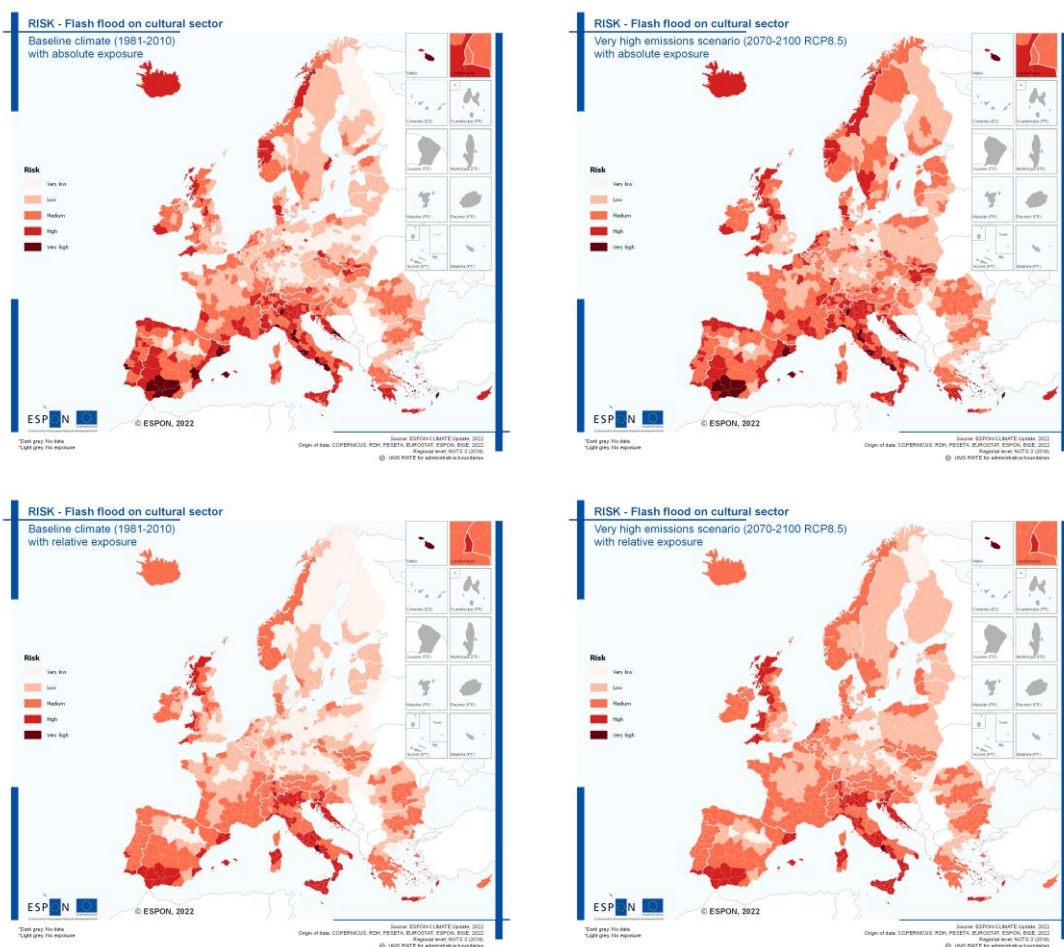


## 5.6 Risk of flash floods on cultural sector

The maps of risk of flash floods on cultural sector are shown in Map 6 for the baseline climate (first column) and for the very high emissions scenario (second column) as well as considering the risk calculation with absolute exposure (first row) and with relative exposure (second row). The indicators used in this impact chain for all the risk components can be found in Table 2.

In the case of the risk of flash floods on cultural sector no significant differences are observed between the baseline climate and the very high emissions scenario in the very high-risk cases. Nevertheless, many of the territories with very low or low risk in the baseline climate reach medium risk in the very high emissions scenario. In the risk scenario with absolute exposure we find territories with high or very high risk in a large number of countries, while in the risk scenario with absolute exposure Malta, Spain, Italy, Croatia, Greece and the United Kingdom are particularly noteworthy for having territories with high or very high risk.

**Map 6 Risk scenarios of flash floods on cultural sector. In rows, absolute and relative exposure. In columns, baseline climate and very high emissions scenario.**





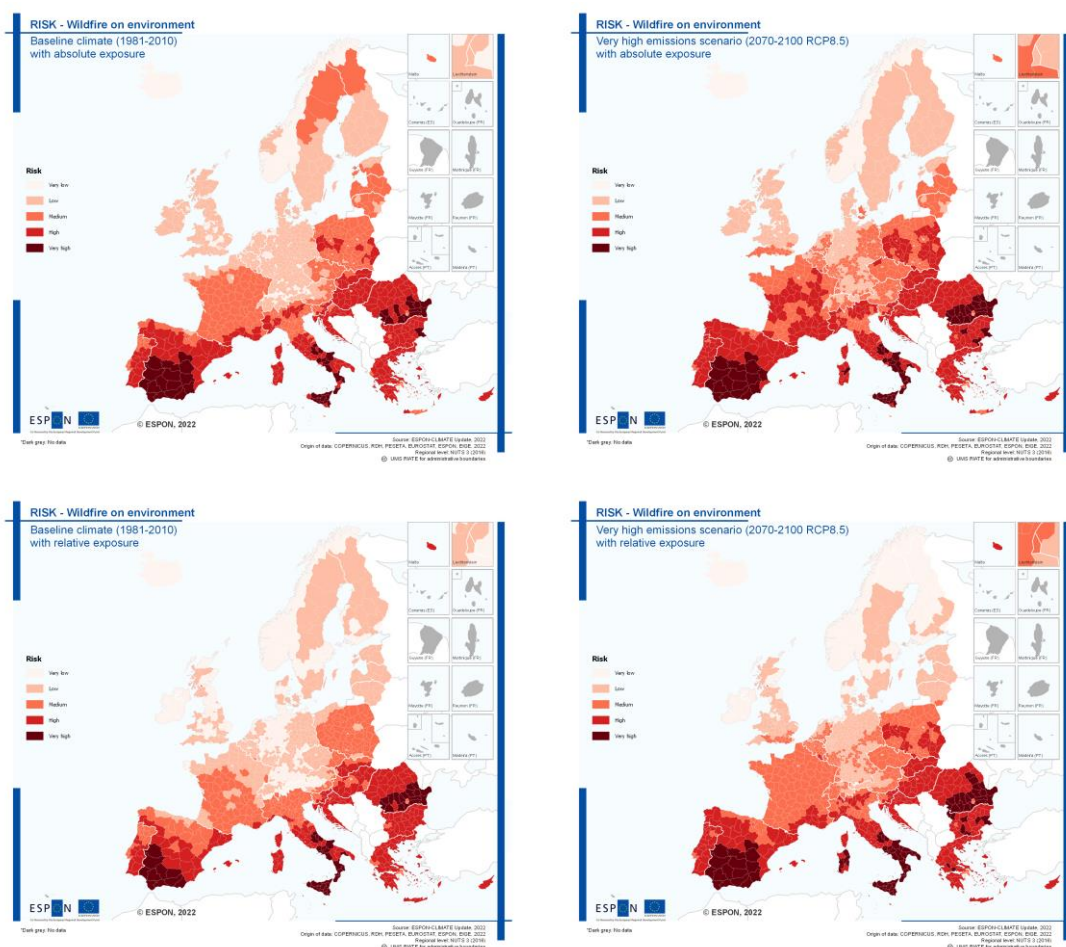
## 5.7 Risk of wildfire on environment

The maps of risk of wildfire on environment are shown in Map 7 for the baseline climate (first column) and for the very high emissions scenario (second column) as well as considering the risk calculation with absolute exposure (first row) and with relative exposure (second row). The indicators used in this impact chain for all the risk components can be found in Table 2. In the absence of a proper indicator, it was assumed equal environmental sensitivity to wildfires across Europe.

Wildfire risk on environment shows a spatial pattern characterised by a more accentuated risk in the southernmost territories. However, in the very high emissions scenario at the end of the century, the risk increases progressively, making the risk also considerable in more northerly latitudes.

Countries with very high-risk territories are Spain, Romania, Italy and Bulgaria, and those with high risk territories are Greece, Cyprus, Croatia, Hungary, Slovenia, Poland, France and Portugal, in addition to those mentioned above.

**Map 7 Risk scenarios of wildfire on environment. In rows, absolute and relative exposure. In columns, baseline climate and very high emissions scenario.**



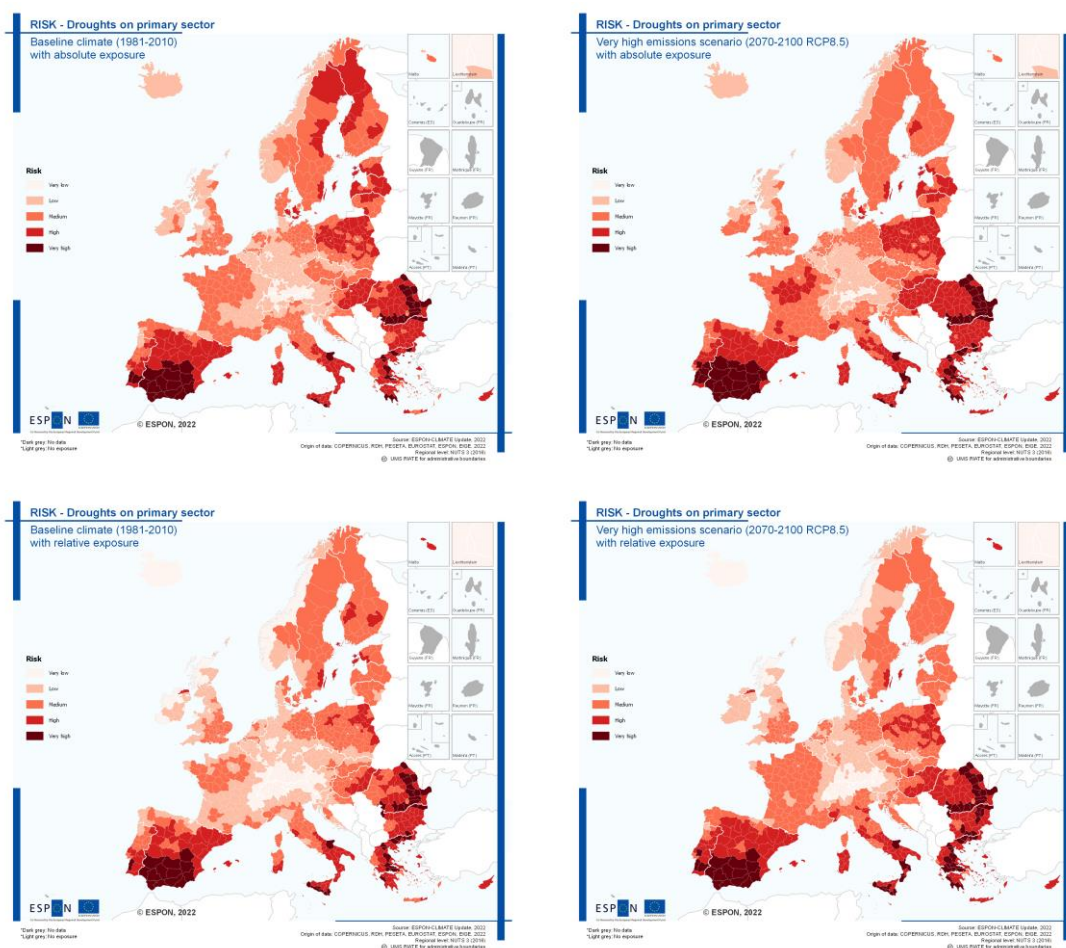
## 5.8 Risk of droughts on primary sector

The maps of risk of droughts on primary sector are shown in Map 8 for the baseline climate (first column) and for the very high emissions scenario (second column) as well as considering the risk calculation with absolute exposure (first row) and with relative exposure (second row). The indicators used in this impact chain for all the risk components can be found in Table 2.

In the case of the risk of droughts on primary sector, the trend is not homogeneous among all the territories when we analyse the evolution between the baseline climate and the very high emissions scenario at the end of the century. Almost everywhere in the study area there is an increase in risk, but in certain regions of Sweden and Finland the risk decreases as water availability in these regions is expected to be even higher than at present.

The countries with the highest risk territories are Romania, Bulgaria, Greece, Italy, Spain and Portugal. However, it should also be noted that the risk of droughts on primary sector is already very high in many regions in the baseline climate.

**Map 8 Risk scenarios of droughts on primary sector. In rows, absolute and relative exposure. In columns, baseline climate and very high emissions scenario.**



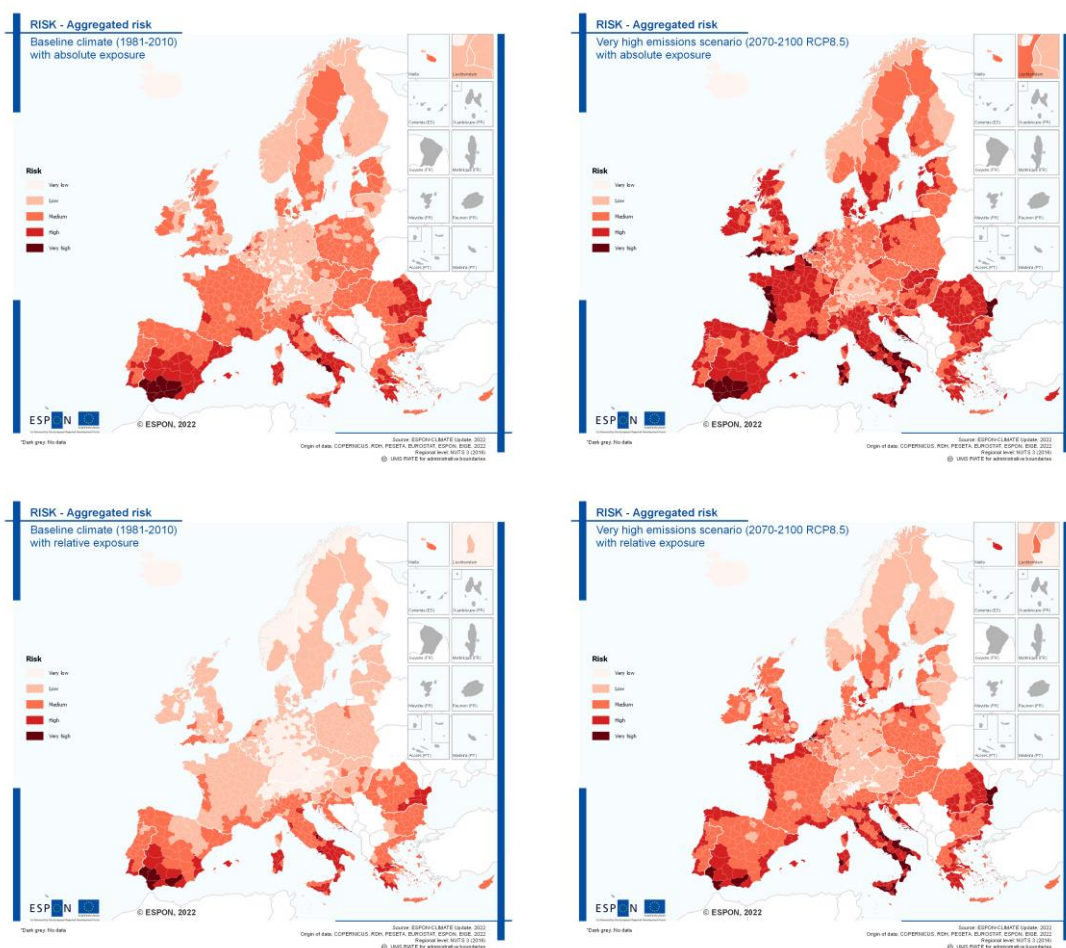
## 5.9 Aggregated risk

Aggregate risk maps (Map 9) are the result of combining the risks of the different impact chains for the same scenario (baseline climate, low emissions scenario, intermediate emissions scenario or very high emissions scenario in 2070-2100) and way of considering exposure (absolute or relative). The two maps on the top show the risk with absolute exposure, the ones on the bottom represent the relative exposure. While the two maps on the left show the risk for the baseline climate scenario, the ones on the right represent the risk for the very high emissions scenario.

It can be interpreted from Map 9, that the risk is expected to increase from the baseline climate (1981-2010) to the very high emissions scenario (2070-2100 RCP8.5). Nevertheless, it is noteworthy that already in the baseline scenario, there are regions with very high risk in the south of Spain and Italy, while those with high-risk regions can be found in the Netherlands, Romania, Bulgaria, Greece, Croatia, Italy, France and Spain.

On the other hand, the very high emissions scenario with relative exposure shows regions with very high risk in the UK, the Netherlands, Romania, Italy and Spain, and regions in the same countries plus Croatia and France in the scenario with absolute exposure. In addition, regions with high risk are found in the majority of countries, including Ireland, Belgium, Denmark, Germany, Sweden, Finland, Estonia, Latvia, Lithuania, Poland, Czech Republic, Bulgaria, Greece, Cyprus, Slovenia and Portugal, in addition to those mentioned above with very high risk.

**Map 9 Aggregated risk scenarios. In rows, absolute and relative exposure. In columns, baseline climate and very high emissions scenario.**



The spatial pattern of risk is similar between scenarios with absolute and relative exposure, with minor differences in some regions which changed to high or very high risk in between. For example, regions with a high absolute exposure present aggregated risk with relative exposure significantly attenuated compared to

the aggregated risk with absolute exposure, being the case of certain regions in Denmark, Sweden, Finland, France or Ireland, among others.

Thus, a general pattern of risk is observed in the baseline scenario with higher risk in southern countries and lower risk in northern countries. However, in the very high emissions scenario at the end of the century, risk increases across many countries, with a certain pattern in coastal areas. In other words, it is expected that climate risks typically associated with southern countries will become more widespread in the rest of Europe in the very high emissions scenarios. This spatial distribution is explained by the risk distribution of the seven impact chains considered. Specifically, in each impact chain and scenario, high risk is due to the spatial coincidence of high hazard, high exposure and high vulnerability.

In general, it can be summarised that the impact chains associated with temperature and water availability also show a clear pattern of risk from south to north (Heat stress on population; Wildfire on environment; Droughts on primary sector) with Romania, Bulgaria, Greece, Italy, Spain and Portugal standing out. On the other hand, in flash floods on the cultural sector the risks are less well distributed than in the temperature and water availability impact chains, although a certain north-south pattern can also be identified. Finally, the impact chains of river flooding (River flood on population; River flood on infrastructure, industry and service sectors) spatial pattern is more homogeneously distributed. The Netherlands, France, UK, Ireland and Sweden stand out. Whereas in coastal flooding the distribution is very similar in all countries, with only the Netherlands standing out.

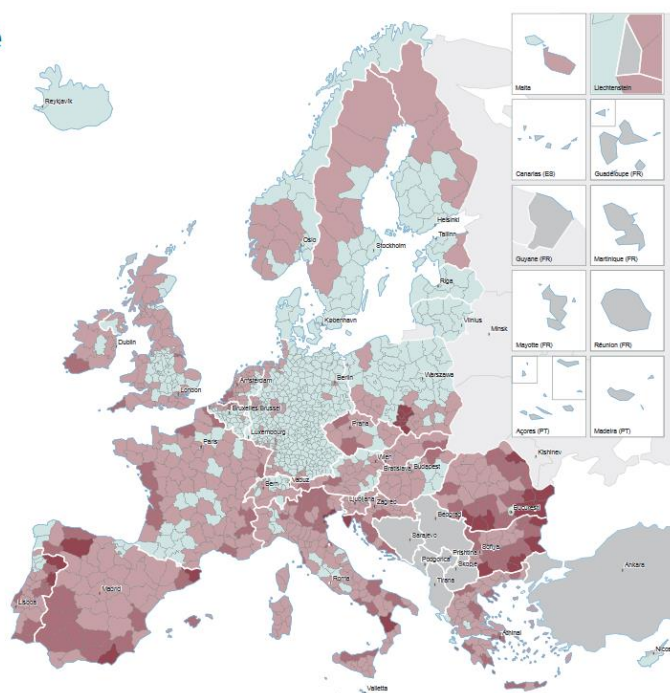
Additionally, it is of interest to compare these results (Map 9) with the previous version of ESPON-CLIMATE from 2014 (Figure 8)<sup>53</sup>. It is necessary to recall at this point, the differences between ESPON-CLIMATE 2011 & 2014 approach and **ESPON-CLIMATE Update 2022** revised approach (Figure 1). Therefore, the risk considered in **ESPON-CLIMATE Update 2022** would be equivalent to the vulnerability of ESPON-CLIMATE 2014. Although there are differences in region-by-region comparisons, the overall territorial pattern results to be similar, despite the significant update in terms of conceptual approach, data and methodology. Territories in Romania, Italy, Spain, France and the south-west of the UK and Ireland highlight in both cases, followed by regions in Bulgaria, Greece and Croatia. Perhaps the biggest differences fall in the risk scenario with absolute exposure, where territories in the Baltic States, Poland, Denmark and Sweden are at high risk and were not listed as such in the previous 2014 update.

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<sup>53</sup> Atlas for the Territorial Agenda 2030. Available in <https://www.atlasta2030.eu/en/index.php#c2-1-3>

## Vulnerability to climate change

### Potential vulnerability to climate change



**Figure 8 Previous vulnerability to climate change from ESPON-CLIMATE Update 2014. Vulnerability in AR4 is equivalent to Risk in AR5 and AR6. Source: Atlas for the Territorial Agenda 2030**

While these aggregated risk results give a first insight of the distribution of the risks analysed, it is convenient to also review the impact chains (Table 1) considered independently, even though, depending on the issue to be addressed, specific risk components such as vulnerability, hazard or exposure may be of interest, for which it is recommended to analyse the Annex of maps.



## 6 Conclusions and recommendations

### 6.1 Assumptions and limitations

The results of this ESPON project, provide an overview of the risk associated with climate change in the ESPON-space regions. The current ESPON CLIMATE Update 2022 can be considered an assessment of climate change risks at NUTS3 scale, with European coverage, using an indicator-based risk methodology (Table 2, Figure 2 and Figure 3). In this context, the study delivers an outlook of the spatial patterns of sectorial risks through a set of impact chains (Table 1) and risk scenarios (Table 3).

Yet, there are limitations and assumptions presented in this section that need to be considered when interpreting the results. Particularly if used for evidence-based decision making and planning at regional and local level, which might require detailed analysis with higher resolution, counting with these results as a first risk screening.

#### *Methodological approach and data matter*

**ESPON-CLIMATE Update 2022** is a revision of data and maps, as well as of the approach and methodology, compared to the previous ESPON-CLIMATE 2011 and its subsequent ESPON-CLIMATE Update 2014. There is an important conceptual difference, compared to previous projects, in the consideration of risk, due to the transition from AR4 to AR5 (Figure 1). This has implied to assume that risk already existing in the baseline climate (1981-2010) and that the risk is expected to evolve under different scenarios, as a consequence of climate change. This has made the analysis more complex, and multiplied the number of results (Table 3 and Annex of maps), which is intended to cover a larger number of possible future scenarios. Additionally, the update has sought to align indicators and data sources with other current initiatives at European level, like PESETA IV, Risk Data Hub, Copernicus and Climate-Adapt (Table 4, Table 6, Table 7 and Table 8).

Despite the different approaches applied and data used in the above mentioned ESPON CLIMATE studies, the outcomes and results show certain level of consistency (see section 5.9) that positively contributes to the robustness of the analysis.

Hence, the type of analysis presented in this research can help to inform the prioritization of efforts in areas in need for particular attention, due to their identified risks, so called hotspots. Still, ad-hoc zoom-in analysis in those areas would be needed to better explore the results before incorporating them into decision making processes at regional and local level.

The **ESPON-CLIMATE Update 2022** findings also allow for identification of areas to strengthen cooperation for transboundary spatial planning, to face certain risks in a climate change context, particularly those related to river and coastal flooding.

#### *Spatial and temporal scales matter*

The scale of analysis is a determining factor when interpreting the results, more precise sources will be required and there may even be indicators that are more appropriate for analysis at the urban or finer territorial scale. Some of the indicators have a lower spatial resolution than the ones used, being at NUTS2 level (or even NUTS0 in some cases), and in other cases, the date on which the data were generated is previous to the one taken as the reference. In this sense, future updates of the original data sources used in the indicators calculation may refine the analysis.

The **ESPON-CLIMATE Update 2022** constitutes an update in terms of the most recent data, an approach consistent with the current risk approach of the IPCC and an alignment with other European initiatives. However, it should be mentioned that there are limitations due to the scale of the analysis. Therefore, more detailed studies may be needed, including indicators of higher spatial resolution, together with non-climate scenarios (i.e. future scenarios of exposure and vulnerability), as well as the consideration of other impact chains not included in this study.

#### *A new paradigm for facing risks*

The resulting risk maps of the **ESPON-CLIMATE Update 2022** show the potential adverse consequences and it must be properly interpreted. The risk may vary from very low to very high, although the risk always exists in the analysed territories. In other words, the fact that the risk in a territory is very low or low, does

not imply that it is exempt from adverse consequences. Rather, it means that the risk is lower because the probability of occurrence of the hazard is lower, the exposure is lower and/or the vulnerability is lower, but still adverse consequences might happen. In addition, the level of uncertainty, both from climate models and from exposure and vulnerability information is high, so that the results should be interpreted cautiously, as a first screening and indication of hotspots to be analysed in detailed at regional and local scales.

### ***General trends versus outliers***

The aggregated risk maps show a general trend towards increasing risk from the baseline climate to the very high emissions scenario (Map 9). In other words, in general terms, the risks associated with the analysed impact chains (Table 1) are expected to increase according to the climate model data used in the hazard indicators (Table 4). However, there are specific cases where the risk is expected to decrease, such as the risk of river flood on population in southern Europe (section 5.4), or the risk of droughts on primary sector in northern Sweden and Finland (section 5.8).

This must be considered when interpreting the results, particularly if it will be used as place-base evidence for planning decisions.

### ***Dealing with uncertainty matters: future risks versus current exposure and vulnerability***

Another consideration is that the future scenarios consider the projection of hazard indicators based on climate models, but do not include the dynamic characterisation of exposure and vulnerability. In other words, the risk of the future scenarios obtained can also be interpreted as the risk of the future climate on the current society and territory, i.e. with the present vulnerability and exposure.

Nevertheless, responsible and effective decision-making must incorporate the management of the associated uncertainty and ultimately, as in sustainability policies, the precautionary principle. Therefore, it is always better to use risk results at the scale and geographical coverage provided by the study, assuming certain level of uncertainty, than not having any information at all.

Consideration of uncertainty can also be decisive for the adoption of adaptive management approaches, so that responses to problems arising from climate change are progressively implemented, as they are verified or evidenced.

## 6.2 Policy insights

The results derived from **ESPON-CLIMATE Update 2022** may positively contribute to a number of EU policies and initiatives in support of multiple policy objectives. Amongst the most relevant contributions of the ESPON CLIMATE Update 2022 project to the policy context, the following stand out.

### *Climate change mitigation and adaptation and disaster risk prevention: policies.*

In relation to the European framework for climate change, it is worth mentioning the **Paris Agreement (2015)**<sup>54</sup>, the **Urban Agenda 2030** for sustainable development of the United Nations (2015)<sup>55</sup>, and the **New Urban Agenda (2017)**<sup>56</sup>, the **Sendai Framework for disaster risk reduction (2015)**<sup>57</sup> and the **European Strategy for Adaptation to Climate Change (2021)**<sup>58</sup>. Like the previous 2013 strategy, spatial and urban planning stand out as the main disciplines in which climate action must be implemented due to their ability to coordinate sectoral policies and land use decisions.

But this is just one of the European initiatives that reflect this fact among which we can highlight also the Commission's proposal for the **first European Climate Law**<sup>59</sup>, which aims to turn into law the objective set out in the **European Green Deal**<sup>60</sup>: that the European economy and society become climate neutral by 2050; and the **Global Covenant of Mayors for Climate and Energy**<sup>61</sup>, with the objective, among others, of preparing for the impacts of climate change.

ESPON-CLIMATE Update 2022 provides evidence for States and Regions in Europe to take action towards substantial reduction of disaster risk and of losses caused by climate related hazards, both in lives, means of subsistence and health and in economic, physical, social, cultural and environmental assets of people, companies, communities and countries, and therefore for compliance with **Sustainable Development Goal 13. Take urgent action to combat climate change and its impacts.**

However, as recognized by the Sendai Framework the responsibility that must be shared with other actors, such as local governments, the private sector and other interested groups. So good climate governance is still needed.

In a wider- ambitious sense, ESPON-CLIMATE Update 2022 results could also inform European regions in their pathway towards climate resilience in the framework of **EC Mission Adaptation to Climate Change**<sup>62</sup>. The mission will foster the development of innovative solutions to adapt to climate change and encourage regions, cities and communities to lead the societal transformation.

### *Cohesion Policy and recent regional and urban policies*

ESPON-CLIMATE Update 2022 has generated substantial and relevant data and results to inform the **EU Cohesion Policy 2021- 2027** particularly in relation to policy objectives 2. *a greener, low carbon transitioning towards a net zero carbon economy* and 5. *Europe closer to citizens by fostering the sustainable and integrated development of all types of territories*. The project particularly offers inspiration for considering cross-border climate related risks and adaptation opportunities.

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<sup>54</sup> <https://unfccc.int/es/process-and-meetings/the-paris-agreement/el-acuerdo-de-paris>

<sup>55</sup> <https://www.un.org/sustainabledevelopment/es/2015/09/la-asamblea-general-adopta-la-agenda-2030-para-el-desarrollo-sostenible/>

<sup>56</sup> <https://habitat3.org/wp-content/uploads/NUA-Spanish.pdf>

<sup>57</sup> <https://www.preventionweb.net/files/resolutions/N1516720.pdf>

<sup>58</sup> [https://ec.europa.eu/clima/policies/adaptation/what\\_en#tab-0-1](https://ec.europa.eu/clima/policies/adaptation/what_en#tab-0-1)

<sup>59</sup> [https://ec.europa.eu/clima/policies/eu-climate-action/law\\_en](https://ec.europa.eu/clima/policies/eu-climate-action/law_en)

<sup>60</sup> [https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal\\_en](https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en)

<sup>61</sup> <http://pactodealcaldes-la.eu/>

<sup>62</sup> [Adaptation to climate change \(europa.eu\)](https://adaptationtoclimatechange.europa.eu/)



ESPON-CLIMATE Update 2022 also contributes to the priorities of the **2030 European Territorial Agenda**<sup>63</sup>: the strategic policy document for spatial planning in Europe, its regions and communities that seeks to contribute to sustainable development and to keeping Europe together, and to achieve the Sustainable Development Goals in Europe. The results could contribute to the Territorial Agenda aim of providing orientation for strategic spatial planning, strengthening the territorial dimension of sector policies at all governance levels.

At the urban level it is worth mentioning the **New Leipzig Charter 2020**<sup>64</sup>: a key policy framework document, strongly linked to the Cohesion Policy, for sustainable urban development in Europe, which, emphasizes that cities must establish integrated and sustainable urban development strategies and guarantee their implementation for the city, from its functional areas to its neighbourhoods. ESPON-CLIMATE Update 2022 results could also inform the strategic thinking when facing the challenge of developing urban development strategies, incorporating climate related risks as a key component.

#### *Other relevant EU sector policies.*

ESPON-CLIMATE Update 2022 provide meaningful insights for the consideration of climate change, mainly from the adaptation perspective, in a number of EU sector policies i.e. **EU Biodiversity Strategy for 2030**<sup>65</sup>, the **EU Water Framework Directive**-integrated River basin management for Europe <sup>66</sup> **EU Nature Directives**<sup>67</sup>, The **common agricultural policy**<sup>68</sup>, **EU Floods Directive** <sup>69</sup>.

In particular, ESPON-CLIMATE Update 2022 results could provide inspiration for enhancing biodiversity and ecosystem services for climate change adaptation in those areas with most capacity and potential.

#### *Sustainable investment opportunities considering climate change hazards and risks.*

ESPON-CLIMATE Update 2022 could have the ambition of positively contributing to the reflexions on territorial climate related impact of economic activities in EU, and the future **EU taxonomy for sustainable activities**- an EU-wide classification system for sustainable activities<sup>70</sup>. In this context the EU is an important enabler to scale up sustainable investment and to implement the European Green Deal- see green financing

<sup>71</sup>.

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<sup>63</sup> <https://www.territorialagenda.eu/home.html>

<sup>64</sup> [https://ec.europa.eu/regional\\_policy/en/newsroom/news/2020/12/12-08-2020-new-leipzig-charter-the-transformative-power-of-cities-for-the-common-good](https://ec.europa.eu/regional_policy/en/newsroom/news/2020/12/12-08-2020-new-leipzig-charter-the-transformative-power-of-cities-for-the-common-good)

<sup>65</sup> [https://ec.europa.eu/environment/strategy/biodiversity-strategy-2030\\_en](https://ec.europa.eu/environment/strategy/biodiversity-strategy-2030_en)

<sup>66</sup> [https://ec.europa.eu/environment/water/water-framework/index\\_en.html](https://ec.europa.eu/environment/water/water-framework/index_en.html)

<sup>67</sup> [https://ec.europa.eu/environment/nature/info/pubs/directives\\_en.htm](https://ec.europa.eu/environment/nature/info/pubs/directives_en.htm)

<sup>68</sup> [https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy\\_en](https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy_en)

<sup>69</sup> [https://ec.europa.eu/environment/water/flood\\_risk/implem.htm](https://ec.europa.eu/environment/water/flood_risk/implem.htm)

<sup>70</sup> [https://ec.europa.eu/info/business-economy-euro/banking-and-finance/sustainable-finance/eu-taxonomy-sustainable-activities\\_en](https://ec.europa.eu/info/business-economy-euro/banking-and-finance/sustainable-finance/eu-taxonomy-sustainable-activities_en)

<sup>71</sup> [https://ec.europa.eu/info/business-economy-euro/banking-and-finance/green-finance\\_en](https://ec.europa.eu/info/business-economy-euro/banking-and-finance/green-finance_en). More information on the Sustainable finance taxonomy - Regulation (EU) 2020/852 here [https://ec.europa.eu/info/law/sustainable-finance-taxonomy-regulation-eu-2020-852\\_en](https://ec.europa.eu/info/law/sustainable-finance-taxonomy-regulation-eu-2020-852_en)

### 6.3 Further research related to risks in a climate change context

This subsection provides suggestions on further climate change related research based on the findings and identified gaps derived from **ESPON-CLIMATE Update 2022**:

#### *Improving data and overcoming data gaps*

Continuous monitoring and data acquisition at appropriate scale is required for obtaining reliable and up-dated indicators in the assessment of climate related risks.

#### *Methodological refinement*

Advances in relation to both methodological approaches to risk assessment, and the generation and availability of climate information, would necessarily lead to a methodological refinement. This would imply:

- Analysis of new hazards and updated variables to assess them.
- Definition of additional impact chains. Despite the recent studies with regards to biodiversity role for climate change mitigation and adaptation, there would be interesting to have impact chains analysed at European level on the effect on different climate hazards on green infrastructures and ecosystem services.
- Identification of new indicators, update of data model.
- Consideration of impact modelling which could be classified into:
  - Biophysical models for the characterization of climate hazards.
  - Land use and demographic models to generate future non-climatic scenarios and to somehow allow the evaluation of future vulnerability (SSPs).
  - Socioeconomic impact models for impact evaluation and generation of damage curves associated to probability of occurrence and return periods.

#### *Consideration of complexity and interdependencies*

The effects of climate change not always respond to linear cause-effect relationships, and there several interdependencies between the socio-ecological systems and subsystems that may derive in possible cascading effects. This perspective of complexity and interdependencies, although challenging, must be considered in future research to define comprehensive adaptation strategies. This would imply:

- The consideration of combined hazards and threats (i.e. fluvial, coastal and pluvial flooding).
- The analysis of cascading effects (i.e. a flood beyond material losses can have triggering effects if it affects energy supply or transport networks).

#### *Future vulnerability against future climate*

It is important to highlight that today, the studies on climate change consider the characterization of the vulnerability of the current systems or territorial areas to the potential effects of future climate.

Although the IPCC RCP already incorporate projections of socio-economic variables to define emission scenarios, very few and incipient studies integrate socio-economic, demographic or land use change scenarios and projections, in the vulnerability analysis.

Therefore, it is suggested to encourage further research to analyse the vulnerability of the future system to the future climate. Even though this might have associated a greater degree of uncertainty, but worthy to be assumed.

#### *Improve visualization and data exploitation*

An optimization of the ESPON data platform is here proposed, with an interactive visualization tool for exploring and undertake dynamic searching on climate related data in Europe. An ad-hoc dynamic data viewer for climate vulnerability and risks might be considered.

In this respect, a new dashboard and interactive map is currently being developed and is expected to be available by the end of the year on the ESPON Portal.

It is also suggested to consider a potential exploitation of the **ESPON-CLIMATE Updated 2022** through CLIMATE-Adapt platform.

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## **ESPON 2020**

ESPON EGTC  
11 Avenue John F. Kennedy  
L-1855 Luxembourg  
Grand Duchy of Luxembourg  
Phone: +352 20 600 280  
Email: [info@espon.eu](mailto:info@espon.eu)  
[www.espon.eu](http://www.espon.eu)

The Single Operation within the programme is implemented by the ESPON EGTC and co-financed by the European Regional Development Fund, the EU Member States, the United Kingdom and the Partner States, Iceland, Liechtenstein, Norway and Switzerland.

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