TransformAr

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

Review of economic evaluations of CC, productivity losses and damage assessments for KCS

Deliverable 2.3

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TABLE OF CONTENTS

ABBREVIATIONS

Abbreviations	Description
CMIP	Coupled Model Intercomparison Project
COACCH	Co-designing the Assessment of Climate CHange costs
EU	European Union
GCM	General Circulation Model
GHG	GreenHouse Gas
H2020_INSURANCE	Oasis Innovation Hub for Catastrophe and Climate Extremes Risk Assessment
IPCC	Intergovernmental Panel on Climate Change
ISIMIP	Inter-Sectoral Impact Model Intercomparison Project
KCS	Key Community System
PESETA	Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis
RCP	Representative Concentration Pathway
SSP	Shared Socioeconomic Pathway
WP	Work Package
Participant acronym	**Description**
UA	University of Antwerp
CMCC	Euro-Mediterranean Center on Climate Change
ACTERRA	Acterra
E3M	E3-Modelling
PIK	Potsdam Institute for Climate Impact Research
VERHAERT	Verhaert
FEUGA	Fundación Empresa-Universidad Gallega
NCSRD	National Center for Scientific Research “Demokritos”
CZU	Czech University of Life Sciences Prague
LUT	LUT University
NTNU	Norwegian University of Science and Technology
UVIGO	University of Vigo
EPSILON	EPSILON
ADEME	ADEME Guadeloupe
WRT	Westcountry Rivers Trust
MEDSEA	Mediterranean Sea and Coast Foundation
CETMAR	Fundación CETMAR: Centro Tecnológico del Mar
LAPP	Lappeenranta Municipality
MOE	Egaleo Municipality
WE	Water Europe
EQY	Euroquality
MOG	Municipality of Gjøvik

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

The TransformAr project, launched on October 1st 2021, precisely aims to develop and demonstrate products and services to launch and accelerate large-scale and disruptive adaptive process for transformational adaptation in vulnerable regions and communities across Europe.

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

EXECUTIVE SUMMARY

The TransformAr WP2 data framework aims at providing a portfolio of future biophysical and socio-economic data trends for each Demo region to characterize climatic, hydrological and environmental variables, in line with a set of selected IPCC scenarios, as combination of shared socioeconomic pathway (SSP) and representative concentration pathway (RCP) scenarios. This document aims to indicate and describe data on damage assessments and productivity losses, which can be found and consolidated for the project as extensive datasets of risk and damage assessments for the main KCS more relevant to TransformAr activities (e.g. Agriculture, Fisheries, River flooding, Coastal Flooding, Tourism, Health and Labour). Part of this information is functionally linked to expenditures and could there be expressed directly in monetary terms (land loss, capital loss) and part in physical terms (land loss, people affected). In addition, the systematic review has consolidated, a EU-Wide dataset of impact assessment linked to specific expenditures for relevant KCS: 1) (capital and) land stock damage of river floods; 2) land stock damage of coastal floods; 3) change in agriculture productivity of main crops; 4) change in catch for fishery sectors; 5) change in tourism fluxes, in terms of arrivals and overnight stays, 6) and change in health indicators and labour productivity.

1. Introduction

Climate change impact assessments rely on climate damage information produced by different methodologies, which differ one from another depending on the type of assessment, its spatial scale, and the specific impact. Impact assessments could be classified in two broad types: biophysical and economic, while the spatial scale depends on the available data for the assessment conducted on a specific impact type. Therefore, data on damages can be found as extensive datasets containing information for the impacts associated with i) a physical indicator (e.g. inundation depth, sea-level rise), or ii) a climate indicator (e.g. temperature increase, GHG concentration). Moreover, that data can be expressed as a reduced-form damage function. For example, in the case of the risk assessment of natural hazards, a damage function translates the magnitude of an impact to a quantifiable damage (Prahl et al., 2016).

Both biophysical and economic modeling assessments make use of damage functions or damage data. Biophysical assessments use damage functions that usually depend on specific biophysical indicators and could be combined with economic modeling using damage functions depending on physical indicators such as in the economic assessment of a specific impact like sea-level rise (Hinkel et al., 2014) or riverine floods (Tiggeloven et al., 2020; Ward et al., 2013). Furthermore, economic modeling also relies on damage data and information from the biophysical assessments to produce macroeconomic estimates that summarize several climate change impacts following a specific methodology (e.g. Bosello et al., 2020; Bosello & Parrado, 2020; Szewczyk et al., 2020, Vrontisi et al. 2022). In turn, these assessments can be used to produce reduced-form climate change aggregated damage functions that are employed in integrated assessment models (e.g., Nordhaus, 2017; van der Wijst et al., 2023).

This document highlights and consolidates sources of damage assessments due to CC, mostly available throughout EU, for relevant KCS for TransformAr activities and solutions. D2.3 aggregates modeling assessments from T2.2, other relevant repositories (e.g., ISIMIP - the Inter-Sectoral Impact Model Intercomparison Project, the Climate Data Store of Copernicus) and outcomes of other previous EU projects (e.g., COACCH, PESETA, H2020_Insurance), and elaborates them to provide a valuation of biophysical damages, expenditures and economic modeling assessments, linked to climate hazard categories and ongoing activities relevant to the TransformAr project and the different demonstrators (e.g., river and coastal flooding, Agriculture, Tourism, Fisheries, droughts, infrastructure).

2. Climate and socioeconomic scenarios

2.1 Modelling Climate Change

Numerical models or General Circulation Models (GCMs) are used and implemented to simulate and represent physical processes in great detail within and between the atmosphere, ocean, cryosphere and land surface systems. The complexity, and high level of interactions involved to accurately represent the climate system, and processing limitations lead to still quite coarse resolution (70-100 km over land) for most impact assessments. Thus, the known properties and extremes of many physical processes must be averaged over a larger scale with such coarse pixel resolution. Moreover, many physical processes related to cloud formation and development also occur at a smaller scale and cannot be modeled accurately with most current pixel resolution. Altogether, there are several sources of uncertainties in the use of GCMs to simulate climate processes for the future and especially in relation to extreme events, and it becomes essential to improve reliability and confidence of climate modeling outputs.

Therefore, climate models are constantly updated and improved by different modeling groups around the world, both in terms of increased spatial resolution and more accurate parameterization and simulation of biophysical processes and biogeochemical cycles. A coordinated effort of these modeling groups is part of the Coupled Model Intercomparison Project (CMIP), aiming to improve climate models by cross-comparing different simulations and coordinating the update of the results around the schedule of the Intergovernmental Panel on Climate Change (IPCC) assessment reports. Thus, set of CMIP model results, known as runs, are released in the lead-up of IPCC reports: 2013 IPCC fifth assessment report (AR5) featured climate models from CMIP5, while the 2021 IPCC sixth assessment report (AR6) features new state-of-the-art CMIP6 models. While comparing results from most CMIP6 model runs, it has become evident that they have a notably higher climate sensitivity than models in CMIP5, which contributes to projections of greater warming this century – around 0.4C warmer than similar scenarios run in CMIP5.

2.2 Scenarios

In order to understand how our climate may change in future, we need to also predict how it may behave through some scenarios. Representative Concentration Pathways (RCPs) include transient predictions under different assumptions of future emissions and concentrations of greenhouse gasses (GHGs) and aerosols and chemically active gasses, as well as trends representing dynamics of land use/land cover. Each RCP provides a possible scenario, the trajectory over time extending up to 2100, defining specific radiative forcing characteristics. Several RCPs are produced and introduced from published literature, and used in Fifth IPCC Assessment as a basis for the climate predictions and projections, each categorized by the peak radiative forcing in 2100, thus:

- RCP2.6 peaks at approximately 3 W m-2 before 2100 and then declines;
- RCP4.5 and RCP6.0 represent intermediate stabilisation pathways in which radiative forcing is stabilised at 4.5 W m-2 and 6.0 W m-2 after 2100;
- RCP 7.0 and RCP 8.5 high pathway for which radiative forcing reaches greater than 7 or 8.5 W m-2 by 2100 and continues to rise for some amount of time.

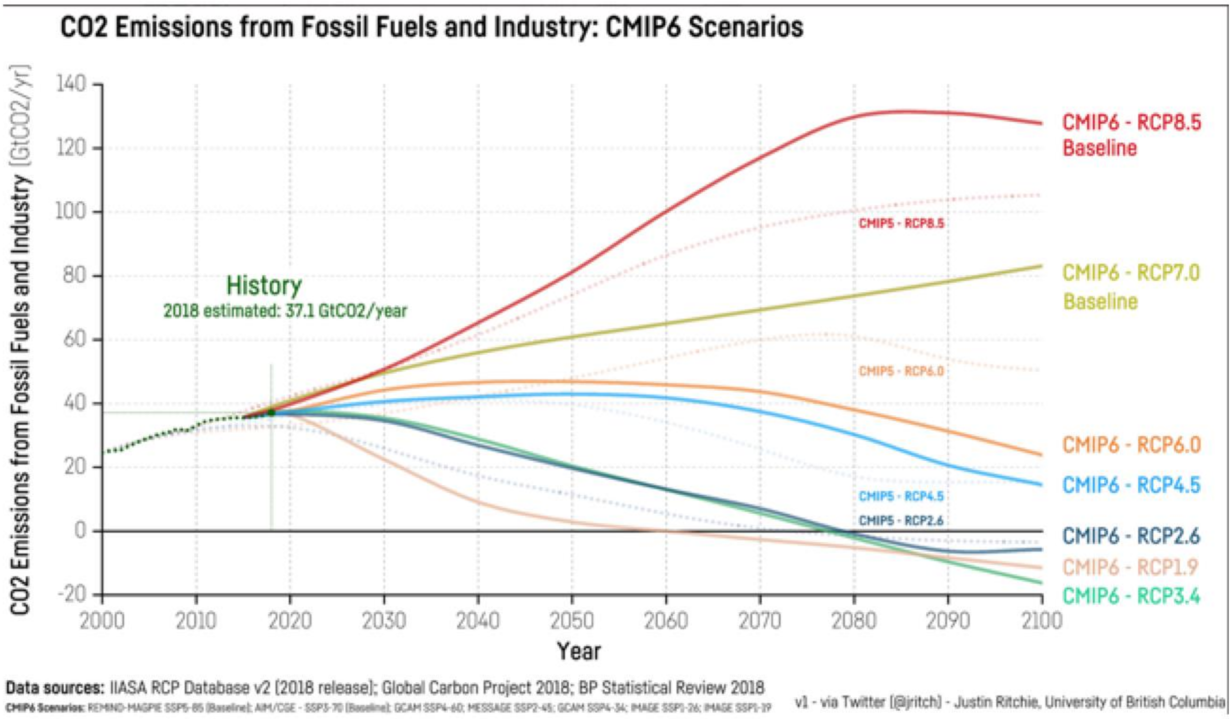

Figure 1. CMIP6 emission scenarios. Sourced from IAASA (2018).

A new set of climate scenarios has been developed for the sixth IPCC report (IPCC AR6), the "Shared Socioeconomic Pathways" (SSPs). The new scenarios represent narratives for different socio-economic pathways resulting in different increases of atmospheric greenhouse gas concentrations and leading to different levels of global warming. Five basic SSP scenarios were defined (Figure §§):

· SSP1: The sustainable and “green” pathway describes an increasingly sustainable world. Global commons are preserved, and the limits of nature are respected. The focus is more on human well-being than on economic growth. Income inequalities between states and within states are being reduced. Consumption is oriented towards minimizing material resources and energy usage.

· SSP2: The “Middle of the road” or medium pathway extrapolates the past and current global development into the future. Income trends in different countries diverge significantly. There is certain cooperation between states, but it is barely expanded. Global population growth is moderate, leveling off in the second half of the century. Environmental systems are facing a certain degradation.

· SSP3: Regional rivalry. A revival of nationalism and regional conflicts pushes global issues into the background. Policies increasingly focus on questions of national and regional security. Investments in education and technological development are decreasing. Inequality is rising. Some regions suffer drastic environmental damage.

· SSP4: Inequality. The chasm between globally cooperating developed societies and those stalling at a lower developmental stage with low income and a low level of education is widening. Environmental policies are successful in tackling local problems in some regions, but not in others.

· SSP5: Fossil-fueled Development. Global markets are increasingly integrated, leading to innovations and technological progress. The social and economic development, however, is based on an intensified exploitation of fossil fuel resources with a high percentage of coal and an energy-intensive lifestyle worldwide. The world economy is growing and local environmental problems such as air pollution are being tackled successfully.

In General, global warming increases from SSP1 to SSP5.

Figure 2. The SSPs of the IPCC guided scenario set. Source: O'Neill et al., (2016).

The SSPs roughly correspond to the RCP scenarios. The use of comparable developments of greenhouse gas emissions and radiative forcing allows for a direct comparison of CMIP5 and CMIP6 simulations. In contrast to RCP scenarios, the new SSP-based scenarios provide economic and social reasons for the assumed emission pathways and changes in land use.

In this study, the scenarios SSP1-2.6, SSP3-7.0 and SSP5-8.5 of the latest IPCC report (IPCC 2021) were applied to cover the widest possible range of (realistic) future conditions.

The SSP1-2.6 is close to the Paris Agreement goal, where global warming is limited to 2 °C above pre-industrial levels. The scenario is characterized by declining greenhouse gas (GHG) emissions to net zero until 2050, followed by varying levels of net negative CO2 emissions (IPCC, 2021). The SSP5-8.5 scenario is a high global warming scenario with continuing high fossil fuel development throughout the 21st century and consequently strong increases in GHG emissions. According to the United Nations (2021), the implementation of the Nationally Determined Contributions of countries would result in a global temperature increase of 2.7 °C until the end of the century.

3) Damage Assessment

Data and information generated by biophysical modeling is used in damage assessments related to specific climate impacts and produce a variegated set of information for different sectors depending on the type of climate impact. These damage assessments could be part of an economic evaluation as long as it is possible to monetize damages or could just express the damages in terms of deviation from a baseline considering specific indicators. For instance, in the case of agriculture the damage information could be about crop yield changes, crop distribution and/or land use, which could also be monetized as long as there is the corresponding information on crop prices. In the case of coastal and river floods, the damage assessment could produce data on land loss, capital loss, and the number of people affected and/or displaced. Part of this information could be expressed in monetary terms (land loss, capital loss) and part in physical terms (land loss, people affected). In addition, there could also be information about specific adaptation measures and the corresponding costs along with the residual damage after that adaptation has reduced the initial impact.

Modeling assessments of biophysical impacts of Climate Change for some sectors (e.g., agriculture, fishery, labour productivity) are driven mostly by climate projections (0.5 degrees) in order to characterize changes in productivity, while for few others (i.e., coastal and river flooding) a higher resolution is used to capture exposure distribution and damage to existing infrastructures, in addition to the climate signal. In general, such resolution is sufficient to characterize and consolidate damage estimates at NUTS2 level for 2050, linked to specific expenditures, as input for socio-economic modelling in task 2.4 and Integrated Risk Assessment in task 2.5. Modelled parameters included: 1) (capital and) land stock damage of river floods; 2) land stock damage of coastal floods; 3) change in agriculture productivity of main crops; 4) change in catch for fishery sectors; 5) change in tourism fluxes, in terms of arrivals and overnight stays, 6) and change in health indicators and labour productivity. Figure 3 offers a visual summary of the data, methods and metrics used in the damage assessments performed, along with the sources from which they were sourced.

	AGRICULTURE	FISHERIES	TOURISM	RIVER FLOODING	COASTAL FLOODING	HEALTH AND LABOUR
EU-wide Damage Sources	ISIMIP 3b, ISIMIP 2b, COACCH, Orlov et al. (2021), Van Passel et al. (2017)	ISIMIP 3b, ISIMP 2b, Cheung et al., (2016), COACCH	Matei et al. (2023), Amelung & Moreno (2012); Barrios & Ibáñez (2015)	COACCH, H2020_Insurance, Paprotny et al. (2020), PESETA IV, Dottori et al. (2020)	COACCH Lincke et al. (2019), PESETA IV, Tiggeloven et al. (2020)	ISIMIP 3b climate driver
	↓	↓	↓	↓	↓	↓
Selected Sectorial Impact Modelling Method	**ISIMIP 3b**: CROVER; CYGMA1p74; EPIC-IIASA; LDNDC; LPJmL; LPJ-GUESS; PEPIC; PROMET; SIMPLACE-LINTUL5	**ISIMIP 3b**: BOATS; EcoOcean	**Matei et al.:** Tourist Climate Index	**COACCH:** GLOFRIS, LISFLOOD, CLIMRISK_RIVER **TransformAr:** SWIM	**COACCH:** DIVA	**TransformAr:** wet-bulb globe temperature
	↓	↓	↓	↓	↓	↓
Type of Damage & Damage Metrics at EU Level	Change in crop yield (Tons/ha) and irrigation water requirement (mm/ha)	Change in total catch (g m-2)	Change in tourist fluxes & related demand	Change in Expected Annual Damage on Land Use stock (billion€)	Change in Expected Annual Damage on Land Use stock (billion€)	Change in Comfort & Labour productivity (% full working capacity)

Figure 3. Schematic summary of the revised sources, selected methods and metrics used in the damage assessments for different sectors relevant to TransformAr KCS.

3.1 Agriculture

Recent studies and projects have provided different forms of damage assessments for the EU agricultural sector. The COACCH project has produced estimates of climate change impacts on agriculture considering different models summarized in two studies driven by CMIP5 climate projections. The first one (Boere et al., 2019) analyses the impacts of slow-onset climate change on agriculture with a focus on the European Union from both the biophysical impact and the economic damage perspectives using a range of crop (EPIC, GEPIC and LPJmL 5) and bio-economic (MAgPIE 4 and GLOBIOM) models. The second study (Bosello et al., 2020) provides a macroeconomic assessment using a regionalized CGE model with the data and results from (Boere et al., 2019). Input information for the CGE model are yield changes expressed as changes in land productivity derived from two different assessments. One, produced by IIASA, based on the application of the biophysical model EPIC whose gridded outputs are aggregated to the CGE model regional resolution and crop categories with the GLOBIOM model (Havlík et al, 2011). The second, produced by PIK, computing yield changes by applying the biophysical model LPJmL. The results and data used for these assessments are available at the COACCH repository (https://iiasa.github.io/COACCH/en/master/index.html#coacch-data-repository).

Figure 4 shows the fractional change in yield for maize and winter wheat in continental Europe in 2030, 2050 and 2070 under RCP4.5 radiative forcing modeled by Boere et al., (2019). Significant yield changes (-50% to +100%) are projected for both crops by 2030 and these intensify further in time. A north-south difference in yield response exists for both crops, with southern (northern) Europe experiencing a decrease (increase) in yield growing with time. The yield changes and the north-south gradient are more marked for maize than winter wheat as the former, being a C4 plant, is more affected by the increasing CO2 concentration and the resulting CO2 fertilization effect.

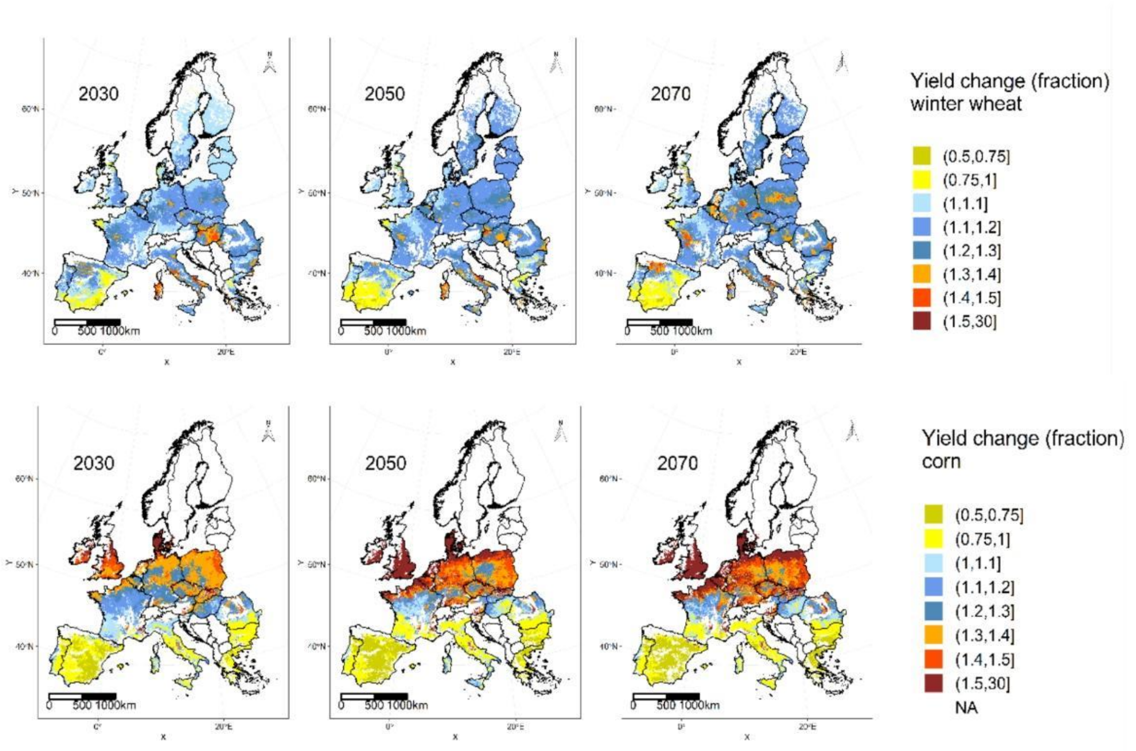

Figure 4. Yield change due to climate change, as fraction, for wheat and corn. Sourced from Boere et al., (2019).

There are also recent studies with additional assessments of climate change impacts on agriculture. Orlov et al. (2021), provide projections for the integrated climate-induced impacts on crop yields and worker productivity on the agro-economy in a global multi-sector economic model GRACE and (Van Passel et al., 2017) use a Ricardian analysis to estimate the impact of climate change on European agriculture.

A damage assessment for agriculture has been also produced under TransformAr task 2.3 and is based on the newly released projections produced by the third simulation round of the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP3B), driven by CMIP6 climate projections. The ISIMIP database provides modelling output of agricultural production in terms of crops cultivated for both food and energy purposes at global scale. Fourteen impact models participate in the ISIMIP simulation round 3B for this sector, but to the present day only eight of them have released data for all the future emission scenarios and the variables relevant for this work: CROVER, Regional Production and Circulation Coupled model (Okada et al., 2018); CYGMA1p74 (Iizumi et al., 2017); EPIC-IIASA, Environmental Policy Integrated Climate (EPIC) model developed by the International Institute of Applied Systems Analysis (Balkovic et al., 2014) ; LDNDC, Landscape De-Nitrification De-Composition (Haas et al., 2013); LPJmL, Lund-Potsdam-Jena managed Land (von Bloh et al., 2018); LPJ-GUESS, Lund-Potsdam-Jena General Ecosystem Simulator

(Lindeskog et al., 2013); PEPIC, Python-based EPIC model (Liu et al., 2016); PROMET (Mauser et al., 2015); SIMPLACE-LINTUL5 (Webber et al., 2015). Crop modelling simulations are based, on forcing driven by five ISIMIP3B-bias-corrected climate model inputs: UKESM-01 LL, GFDL-ESM4, IPSL-CM6A LR, MPI-ESM1-2-HR and MRI ESM2-0. Within ISIMIP3B, the impact models mentioned above generate quantitative information on yield for 9 crops, namely Beans, Cassava, Maize, Millet, Potato, Rice, Sorghum, Soy and Wheat managed in both rainfed and in fully irrigated conditions.

The selected agricultural model simulations consider the future CO2 fertilization effect to account for the effect on crop physiology of changing CO2 concentration, according to SSP scenarios. Changes in management up to 2015 are also considered for the chosen socio-economic scenarios (i.e., human influence and land-use scenarios in terms of variation of land use, water abstraction, nitrogen deposition and fertilizer input; human influence and land use scenario: 2015CO2, CO2). Data are delivered yearly per growing season with a resolution of 0.5°. The variables selected from the ISIMIP3B database are:

- Crop Yield (tons ha-1 of dry matter)
- Cumulative Potential Net Irrigation Water Requirement (kg ha-1, or mm), defined as the soil water demand to avoid water stress cumulated across the growing season, excluding any water losses associated with application or transport and without constraints due to water availability.

The crop model simulations have a global spatial coverage under the assumption that all crops are cultivated everywhere. The data are available for the historical (1850-2014) and future (2015-2100) climate. The scenarios SSP126, SSP370, and SSP585 are used to represent future climate change and socio-economic conditions.

To relate the projected change in crop yields to the economic dimension, the present study estimated the contribution of each studied crop (i.e., winter wheat, spring wheat, sorghum, soy, rice, potato, maize) to the total crop basket for each NUTS2 in terms of harvested area (ha). Data on Arable Land for the total crop basket and the individual extent of the studied crops were sourced from the EUROSTAT database and averaged over the period 2010-2020. Where these were not available, data on harvested area were collected from the SPAM 2010 database (You et al., 2019). The harvested area (HA) is used as a proxy of the significance of each crop at NUTS2 level and is used to weight the cumulative yield change (%) for each NUTS2. The cumulative yield change is expressed as the percentage difference in the total yield of all studied crops with respect to the 1985-2015 average, weighted by their current (2010-2020) average harvest area. This quantity allows us to relate the changes in crop yields projected by the ISIMIP impact models to the current production practices at NUTS2 level, hence representing a fundamental component of an integrated risk assessment for the European agricultural sector. The weighting procedure was carried out for each NUTS2 region as illustrated in equation 1:

$$Weighted\ Cumulative\ Yield\ Change\ (\%) = \frac{\sum Y_i * HA_i}{Total\ HA} \quad (1)$$

where Yi is the yield of any of the considered crop (i) and HAi is the harvested area of that same crop. The same procedure is applied to estimate the total change in the cumulative potential net irrigation water requirement.

Figure 5 shows the weighted cumulative yield change in 2030 (2015-2045 average) and 2050 (2035-2065 average) under the ssp1.26 and ssp5.85 greenhouse-gas emission scenarios.

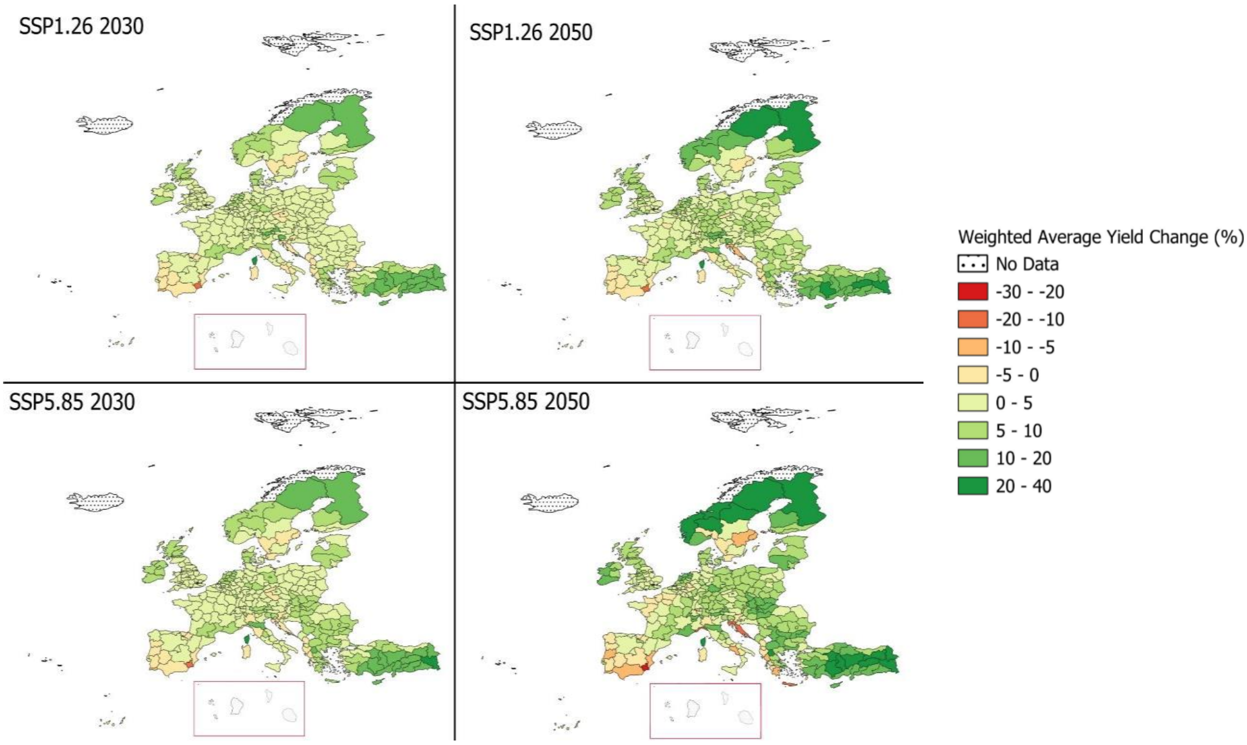

Figure 5. Cumulative yield change (%) at NUTS2 level in 2030 and 2050 following ssp1.26 and ssp5.85 emission scenarios. The yield change refers to the weighted sum of maize, potato, rice, sorghum, soy and winter wheat yields and is expressed as the percentage difference from the same quantity averaged over 1985-2014.

Figure 6 shows the weighted cumulative potential net irrigation water requirement change (%) in 2030 (2015-2045 average) and 2050 (2035-2065 average) under the ssp1.26 and ssp5.85 greenhouse-gas emission scenarios.

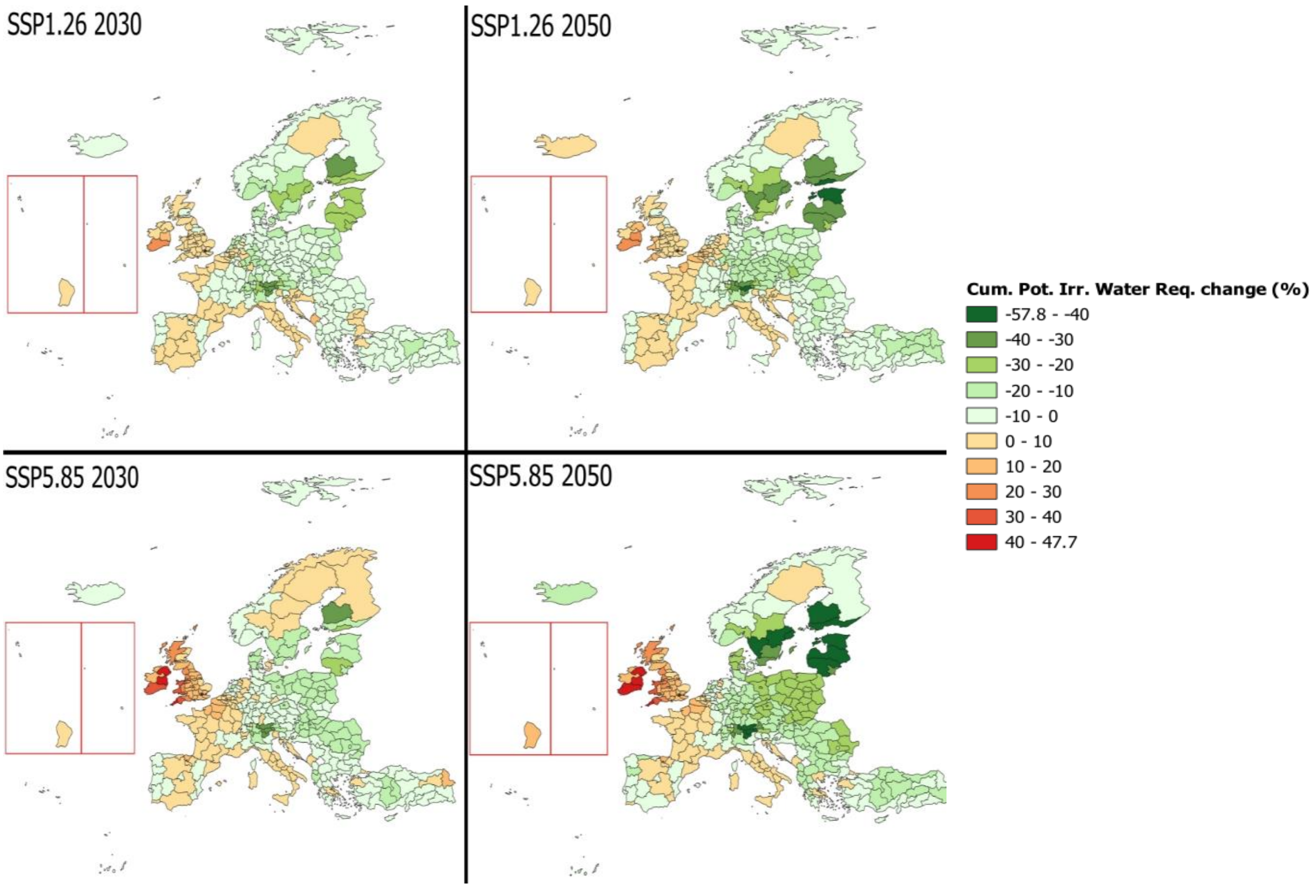

Figure 6. Cumulative Potential Net Irrigation Water Requirement change (%) at NUTS2 level in 2030 and 2050 following ssp1.26 and ssp5.85 emission scenarios. The yield change refers to the weighted sum of maize, potato, rice, sorghum, soy and winter wheat yields and is expressed as the percentage difference from the same quantity averaged over 1985-2014.

3.2 Fisheries

The impact of climate change on fisheries is a well-established field of research in the literature (Cheung et al., 2016) and it has been recently addressed by the COACCH project. The biophysical impact of climate change on fisheries is addressed in COACCH using data from Barange et al 2018. This study simulated the change in total catch potential at global scale using two different modeling approaches for fisheries population, one based on fish size (Dynamic size-based food web model) and one on fish distribution and ecology (Dynamic bioclimate envelope model). Both models agree on a reduction in catch potential in the Iberian coast (-25%), the North Sea (-25%) and, to a lesser extent, in the Mediterranean (0 to -25%).

COACCH also produced a global damage assessment resulting from future changes in fisheries using the GLOBIOM and MAgPIE4 resource management models, with input data on fish catch sourced from

FAOSTAT and Cheung et al., (2016). Both models agree on the decrease of total fisheries production on a global scale and on a sharp difference between tropical (strong reduction) and high-latitude (increase) regions. Within the EU, the study finds an overall decrease in marine capture production ranging between 685 and 1229 thousand tonnes by 2050. The most impacted countries are Spain (-267 ktons), France (-258 ktons) and the UK (-183 ktons), while Iceland and Norway production will benefit from sea warming. In general, the climate-change-induced sea warming will have negative impacts in Mediterranean countries (0 to -3%) while significantly benefiting production at high latitudes (+9% to +30%). Based on these changes in catch potential, the authors predict losses of 1-2 billion euros in the EU by 2050 depending on the emission scenarios.

As for the agricultural sector, the damage assessment for fisheries reported for macro-economic modeling and the integrated risk assessment is based on data from the ISIMIP3B database. Nine impact models participate to the ISIMIP3B simulation round for this sector, but only two provide a comprehensive dataset relevant for this work: BOATS, The BiOeconomic mArine Trophic Size-spectrum model (Carrozza et al., 2016); EcoOcean (Coll et al., 2020). Modeling on cc impact on fishery is based on forcing from two ISIMIP3B bias-corrected climate model projections, namely GFDL-ESM4 and IPSL-CM6A LR.

The ISIMIP3B simulations apply a human forcing (i.e., land use, nitrogen deposition, fertilizer input and fishing effort) fixed at 2015 levels. Data is available at a monthly timescale and resolution of 0.5°. The variable selected from the ISIMIP database is the Total Catch (g m-2), defined as all commercial landings plus discards of fish and invertebrates and expressed over the sea surface. The fisheries model simulations have a global spatial coverage under the assumption that fishing occurs everywhere at sea. The data are available for the historical (1850-2014) and future (2015-2100) climate. The scenarios SSP126 and SSP585 are used to represent the future climate change and socioeconomic pathways (SSP370 not currently available for this sector). Future impacts on fisheries are assessed for all the coastal NUTS2 regions. The fishing area considered represents the projection of the NUTS2 regions boundaries towards the sea for 100 km. The Total Catch value extracted for each region represents the average of the ISIMIP3B raster pixels falling within the region boundaries (Figure 7).

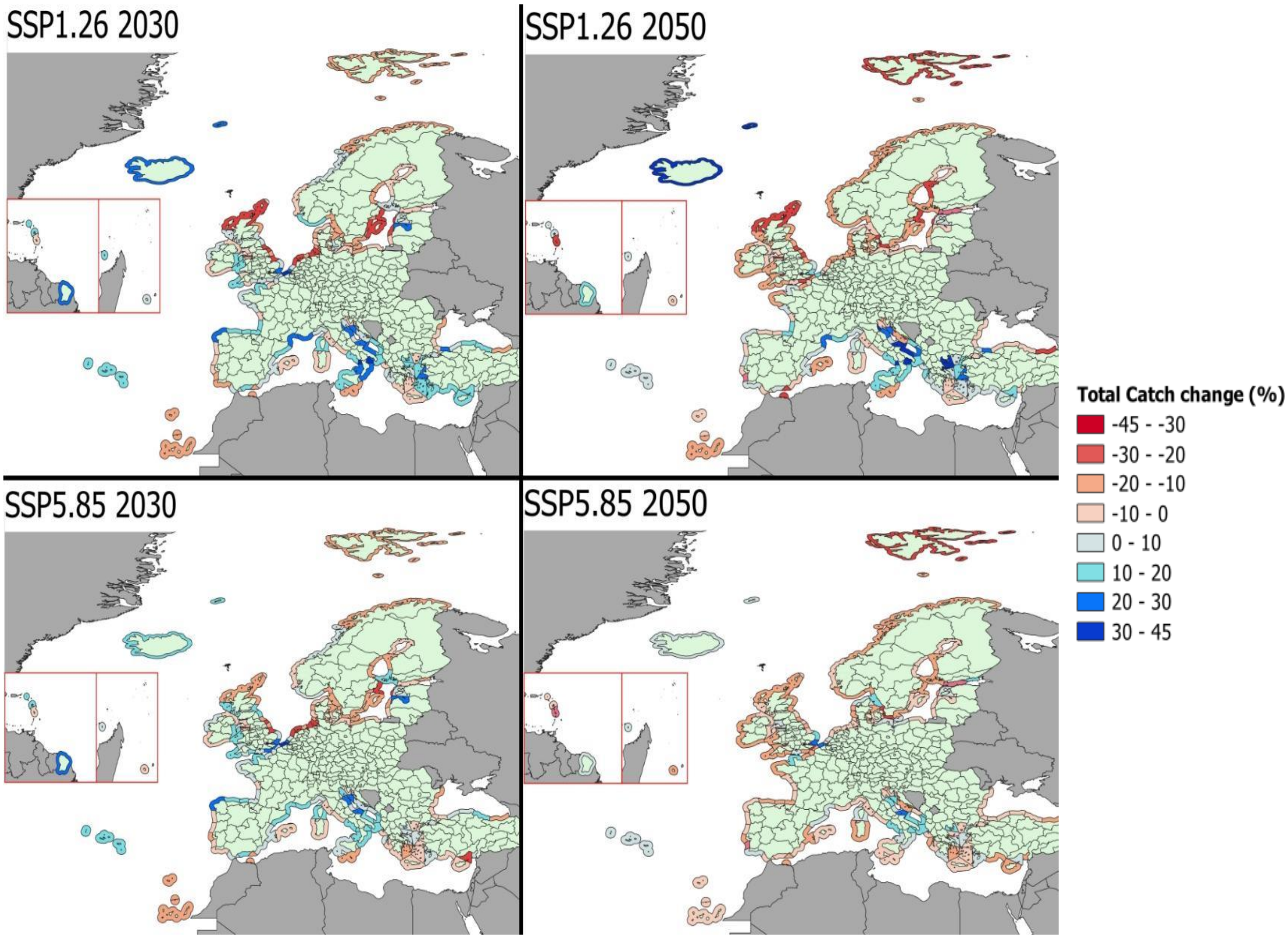

Figure 7. Change in fisheries Total Catch (%) in 2030 (2015-2045 average) and 2050 (2035-2065 average) under emission scenarios ssp126 and ssp585 with respect to the 1985-2015 average.

The projections of the ISIMIP3b models generally agree with the analysis of Cheung et al., (2016), who assessed future changes in global fisheries using a multi-model ensemble approach. The strongest agreement is found along the Iberian coast, in the Celtic Sea and in the North Sea, where very similar reductions in total catch are projected for 2050 under RCP8.5 radiative forcing. Similarity in the results also applies to the Mediterranean, which here shows both regions of increasing and decreasing total catch and was found neutral to slightly decreasing by Cheung et al., (2016). In contrast, the main differences emerge in the Black and the Baltic Sea, with Cheung et al., (2016) showing an increase in potential catch opposed to the slight decrease observed here.

3.3 River Flooding

Floods extremes in recent years, culminating in the disastrous events in Central Europe in 2021 with damages of around 30 billion and the catastrophic events in the Eastern Mediterranean in summer 2023 with precipitation intensities beyond any known statistics, illustrate that we are in the midst of climate change and how vulnerable societies and infrastructures are.

Amongst the costliest natural disasters in Europe, flooding has been registering increasing damages due to the increased exposure of population and built-up areas (Leiter et al. 2009; EEA, 2017, Alfieri et al. 2018, Paprotny et al. 2018). In addition, the damages from extreme events are also expected to increase due to climate change, and socioeconomic development (Winsemius et al. 2016, Dottori et al. 2018) and due to an increase of the magnitude and frequency of intense precipitation events in many parts of Europe (Alfieri et al. 2015, 2018) with increasing flood risks in most countries in Europe (Dottori et al 2023).In a first step, flood damages under scenario conditions are derived from the COACCH project, where they are provided at the NUTS-2 level for the entire Europe (Ignjacevic 2021). They consider the direct impacts of river flooding using the CLIMRISK-RIVER model, including losses of built environment and infrastructure. The damage is expressed as a change in expected annual damage with respect to 2010. The files include two adaptation assumptions: no additional adaptation and optimal adaptation (using Cost-Benefits Analyses estimates).

In a second step, these data will be amended and complemented by flood damages developed in the EU project H2020_Insurance and linked to the model SWIM (Paprotny et al. 2020, Hattermann et al. 2018), for example to compare against newer climate scenario results of the latest Coupled Model Intercomparison Project (CMIP6) of the World Climate Research Programme and to increase the spatial resolution of the results.

On a study of losses for the past 150 years, and correcting for changes in flood exposure, Paprotny et al. (2018) concluded that there has been an increase in annually inundated area as well as in the number of persons affected since 1870, although there has also been a substantial decrease in flood fatalities. In a recent study, Dottori et al, (2023) estimated current annual damages from river flooding amounting to €7.6 (5.6–11.2) billion per year, exposing circa 166,000 (124,000–276,000) people per year in the EU and the UK. If climate change is not addressed with mitigation measures, and assuming no additional adaptation measures, flood damages could rise to €44(30–61) billion per year by 2100, with nearly half-a-million Europeans (370,000–675,000) who could be exposed to river flooding each year.

As in the case of coastal flooding, river floods have been assessed in the PESETA and COACCH projects. The PESETA IV project produced one specific report (Dottori et al., 2020) analysing river flood risks in the EU with the accompanying macroeconomic assessment (Szewczyk et al., 2020). The COACCH project used several models to study river flood risks (GLOFRIS, LISFLOOD, CLIMRISK_RIVER) as well as the impacts on transport infrastructures (Lincke et al., 2019). The macroeconomic analysis used inputs from the GLOFRIS model to produce economy-wide estimates for the EU and the rest of the world (Bosello et al., 2020) with results available at the COACCH data repository (https://iiasa.github.io/COACCH/en/master/index.html#coacch-data-repository).

Estimates from the GLOFRIS model report that the EAD for the EU as a whole would rise steadily over the period 2010-2080. While in 2010 the EAD is €9.5 billion, it could increase in the range of €71-80 billion in 2080 for five scenarios based on combinations of SSPs and RCPs (SSP1-RCP2.6, SSP2-RCP2.6, SSP2-RCP4.5, SSP2-RCP6.0 and SSP3-RCP8.5), and considering the SSP5-RCP8,5 that estimate could be around €255 billion mainly due to a major exposition of assets and population (Lincke et al., 2019).

Table 1 presents the results of the PESETA IV study (Dottori et al., 2020) with EAD in monetary terms and as a percentage of GDP for the EU +UK considering current and future economic conditions along with different global warming levels). Flood costs could rise to €21.3 billion in 2050 for a 2°C scenario and to €33.1 billion for the same temperature increase in 2100 which could rise to €47.8 billion for a 3°C scenario, representing 0.11% of GDP.

The detail for each EU country is available in table 2 showing the EAD relative to each EU country GDP, for the same current and future socioeconomic conditions and three different temperature increases. Countries with higher EAD as percentage of GDP for a 2°C scenario in 2050 are Latvia (1.08%), Hungary (0.51%), Croatia (0.49%), Czechia (0.35%), way above the average of 0.10% of GDP for the EU+UK.

Table 1: Summary of Expected Annual Damage and population exposed for the EU and UK under present (base), and future (2050, 2100) socioeconomic conditions and climate scenarios (1.5°C, 2°C, 3°C warming)

	Base economy				Economy 2050		Economy 2100		
EU+UK	**base**	**1.5°C**	**2.0°C**	**3.0°C**	**1.5°C**	**2.0°C**	**1.5°C**	**2.0°C**	**3.0°C**
EAD in €billion (2015)	7,8	12,5	16,8	24,8	15,6	21,3	24,1	33,1	47,8
EAD as % GDP	0.06	0.10	0.13	0.20	0.07	0.10	0.05	0.07	0.11
EAPE in 1000 people	172	269	358	521	280	374	252	338	482

Source: Dottori et al (2020)

Table 2: Summary of Expected Annual Damage relative to country's GDP for all EU countries under present (base), and future (2050, 2100) socioeconomic conditions and climate scenarios (1.5°C, 2°C, 3°C warming)

	Base economy				Economy 2050		Economy 2100		
Country	**base**	**1.5°C**	**2.0°C**	**3.0°C**	**1.5°C**	**2.0°C**	**1.5°C**	**2.0°C**	**3.0°C**
Austria	0.08%	0.11%	0.13%	0.17%	0.09%	0.11%	0.07%	0.09%	0.12%
Belgium	0.05%	0.09%	0.12%	0.19%	0.07%	0.10%	0.05%	0.07%	0.11%
Bulgaria	0.20%	0.26%	0.33%	0.44%	0.21%	0.26%	0.17%	0.22%	0.30%
Croatia	0.40%	0.71%	0.96%	1.31%	0.35%	0.49%	0.31%	0.43%	0.61%
Cyprus	0.03%	0.03%	0.02%	0.02%	0.02%	0.01%	0.01%	0.01%	0.01%
Czechia	0.26%	0.39%	0.49%	0.71%	0.28%	0.35%	0.20%	0.25%	0.38%
Denmark	0.01%	0.01%	0.01%	0.02%	0.00%	0.01%	0.00%	0.00%	0.01%
Estonia	0.27%	0.34%	0.46%	0.66%	0.14%	0.15%	0.11%	0.13%	0.14%
Finland	0.13%	0.15%	0.23%	0.34%	0.12%	0.17%	0.09%	0.13%	0.19%
France	0.06%	0.11%	0.16%	0.20%	0.08%	0.12%	0.06%	0.09%	0.11%
Germany	0.03%	0.06%	0.09%	0.13%	0.05%	0.07%	0.04%	0.06%	0.09%
Greece	0.04%	0.05%	0.07%	0.09%	0.03%	0.04%	0.02%	0.03%	0.05%
Hungary	0.26%	0.45%	0.65%	1.13%	0.35%	0.51%	0.28%	0.42%	0.72%
Ireland	0.04%	0.05%	0.07%	0.14%	0.04%	0.05%	0.03%	0.04%	0.07%
Italy	0.05%	0.09%	0.10%	0.15%	0.06%	0.08%	0.05%	0.06%	0.08%
Latvia	0.86%	1.04%	1.32%	1.70%	0.85%	1.08%	0.70%	0.90%	1.15%
Lithuania	0.29%	0.38%	0.46%	0.62%	0.28%	0.33%	0.21%	0.25%	0.32%
Luxembourg	0.04%	0.06%	0.09%	0.12%	0.03%	0.05%	0.03%	0.04%	0.05%
Malta	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Netherlands	0.01%	0.02%	0.05%	0.07%	0.02%	0.04%	0.02%	0.03%	0.04%
Poland	0.14%	0.20%	0.25%	0.40%	0.15%	0.19%	0.15%	0.19%	0.29%
Portugal	0.03%	0.03%	0.04%	0.03%	0.02%	0.02%	0.02%	0.02%	0.02%
Romania	0.23%	0.33%	0.45%	0.68%	0.22%	0.29%	0.17%	0.23%	0.34%
Slovakia	0.19%	0.32%	0.40%	0.59%	0.24%	0.30%	0.20%	0.25%	0.37%
Slovenia	0.16%	0.25%	0.35%	0.52%	0.19%	0.26%	0.14%	0.20%	0.30%
Spain	0.04%	0.05%	0.05%	0.05%	0.04%	0.04%	0.03%	0.03%	0.03%
Sweden	0.05%	0.10%	0.18%	0.35%	0.06%	0.12%	0.05%	0.08%	0.16%
United Kingdom	0.03%	0.05%	0.07%	0.12%	0.04%	0.05%	0.03%	0.04%	0.06%
EU+UK	**0.06%**	**0.09%**	**0.13%**	**0.19%**	**0.07%**	**0.10%**	**0.05%**	**0.07%**	**0.10%**

Source: Dottori et al (2020)

3.4 Sea level rise and Coastal flooding

The impacts of climate change induced sea level rise have been widely assessed in the literature (Desmet et al, 2021, Hinkel et al., 2014, Diaz, 2016) and in recent research projects such as PESETA IV and COACCH (Bosello et al., 2020, Lincke et al., 2019). The PESETA project analyses coastal flood risk without climate change adaptation as well as scenarios including adaptation measures that reduce the initial impact for the EU and UK. Annual damages considering current levels of protection could amount between 0.24% of GDP (€111 billion) for RCP 4.5 and 0.52% of GDP (€239 billion) for RCP8.5 in 2100 (Vousdoukas et al., 2020). This analysis is complemented with the macroeconomic assessment performed in the project providing economy-wide estimates of coastal flood risk (Szewczyk et al., 2020). Similarly, Schinko et al (202) perform a multi model assessment of the macroeconomic impacts of sea-level rise including adaptation measures for RCP 2.6 and RCP4.5.

On another study, Tiggeloven et al. (2020) estimate the expected annual damages (EAD) of coastal flood risks with and without adaptation at the global scale using a cost-benefit framework that accounts for the influence of different risk drivers (sea-level rise, subsidence, and socioeconomic change), with results available at the ZENODO repository (https://zenodo.org/record/3475120).

The COACCH project also offers an assessment of sea-level rise using the DIVA model (Hinkel et al., 2014) for several future scenarios based on nine SSP-RCP combinations and including three levels of sea- level rise for each scenario to account for uncertainty in sea-level rise (Lincke et al., 2019). These estimates are used in the same project to produce a macroeconomic assessment considering scenarios based on current adaptation and additional adaptation (Bosello et al., 2020). Using the same information, Bachner et al. (2022) analyse adaptation scenarios by including migration as an additional element to the assessment. The data and results are available in the COACCH data repository https://iiasa.github.io/COACCH/en/master/classes/climate_impact_assessment.html.

Coastal flood damages under scenario conditions are derived from the COACCH project, where they are provided at the NUTS-2 level for the entire Europe (Lincke et al., 2019). They consider the direct impacts of coastal flooding using the DIVA model, including losses of built environment and infrastructure. The damage is expressed as a change in expected annual damage with respect to 2010. The files include two adaptation assumptions: No additional adaptation (or current adaptation levels) and adaptation scenarios.

Figure 8 shows the results of the COACCH project regarding national coastal flood and protection costs. That study considers both no additional adaptation (or current adaptation levels) and adaptation scenarios for different RCPs accumulated until the end of the century. In the No adaptation scenario. The highest coastal flood costs are in the United Kingdom, Germany, France, Italy, the Netherlands, and Belgium. Under the high-end sea level rise without adaptation, coastal flooding costs could be up to €64 trillion for the UK, €38 trillion for Germany, €32 trillion for France, €28 trillion for Italy and €27 trillion for the Netherlands. However, the effectiveness of adaptation is evident in the adaptation scenarios where the coastal flooding costs are kept at the minimum as shown in the bottom-right panel of Figure 8. For instance, the protection costs for the UK in the adaptation scenarios amount to €620 billion being the higher protection costs for the analysed European countries.

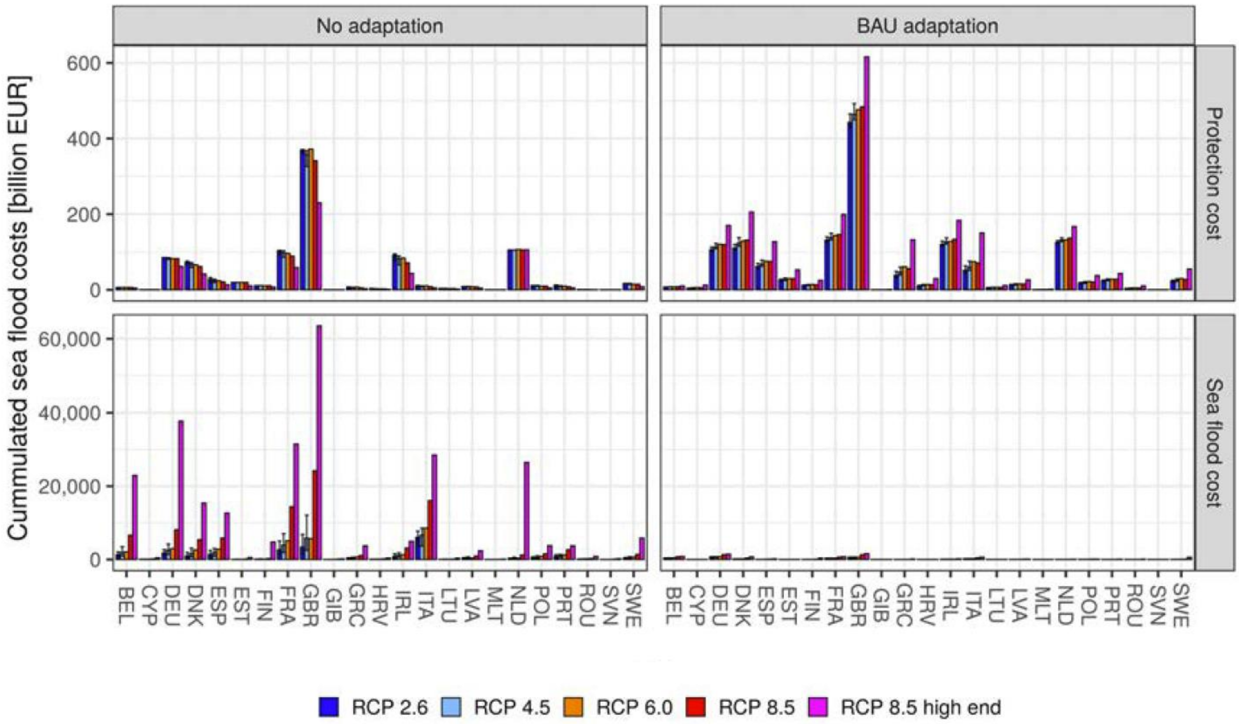

Figure 8: Accumulated national coastal flood and protection cost over 21st century (2015-2100) for EU 28 countries. Error bars for RCP2.6 and RCP4.5 show the uncertainty range over all runs done for these RCPs. Source: Lincke et al., (2019).

To provide an idea of the regional hotspots of coastal flooding, Table 3 presents the annual expected cost for the 25 most affected regions (considering impacts for RCP8.5) for the socio-economic scenario SSP2 and different climatic scenarios (RCPs). The highest coastal flood costs are in the Veneto region of Italy, while other affected regions are in the UK, Belgium, France and Germany.

Table 3. Annual expected sea flood cost in 2100 (EUR billion, without additional adaptation) for the 25 most affected (under RCP8.5) regions (NUTS2) in the EU. The values for RCP2.6 and RCP4.5 refer to SSP2 and medium sea-level rise.

NUTS2 unit	Country	RCP2.6	RCP4.5	RCP6.0	RCP8.5	High end
Veneto	ITA	109.5	119.2	136.8	333.4	506.3
Lincolnshire	GBR	17.9	39.7	45.7	252.2	307.4
East Yorkshire	GBR	15.8	39.2	45.3	240	322
Antwerpen	BEL	24.7	42.6	46.8	217.9	629
Weser-Ems	DEU	22.7	38.4	40.1	202	836.9
Nord-Pas de Calais	FRA	11.9	25	30.1	191.9	303.9
Surrey East and West Sussex	GBR	10.5	22.6	22.9	147	245.4
West-Vlaanderen	BEL	13	24	27.4	141.5	294.8
Hovedstaden	DNK	5.3	12.8	59.7	136.3	320.3
Emilia-Romagna	ITA	39.6	44.4	53.2	128	202.6
Pays de la Loire	FRA	16.4	37.7	39.3	127.8	169.8
Aquitaine	FRA	18.8	36	38.2	125.5	180.4
Hampshire and Isle of Wight	GBR	7.4	17.2	14.8	120.8	273
Southern	IRL	31.1	38.8	38.3	92.6	120.5
Schleswig-Holstein	DEU	8.8	17.4	21	81.8	284.1
Kent	GBR	6.1	12.9	15.1	77.1	430.4
East Anglia	GBR	4.8	9.1	10.7	75.3	125.9
Bretagne	FRA	10.8	19.4	19.7	70.5	102.9
Gloucestershire	GBR	6.9	11.6	10.2	68.4	197.9
Poitou-Charentes	FRA	11.5	21.1	22	64.7	88.4
Eastern Scotland	GBR	3.9	11.4	6.3	63	73.4
Syddanmark	DNK	12.7	17.9	18.5	62.8	134.7
Devon	GBR	6.1	17.9	14.2	55.9	65.9
Sjaelland	DNK	10.4	17.1	19.9	53.4	92.7
Dorset and Somerset	GBR	4.4	11.2	9.5	46.6	84.5

Source: Lincke et al., 2019

3.5 Tourism

Climate change impacts on tourism can be gauged by a) looking at physical changes deemed crucial for the viability of tourist activities; b) building indexes capturing various aspects of climate relevant for the wellbeing of tourists; c) estimating statistically the relationship between climate and tourist flows and projecting them in the future using climate change scenarios. While not directly yielding a damage function, some of these methods can be integrated within economic models to assess the resulting changes in value terms. A typical result is that climate change may worsen the appeal of traditionally popular destinations, while improving the one of destinations traditionally regarded as too cold and rainy for some tourist activities; for the latter, net benefits rather than costs are expected.

Evaluation through physical changes:
Climate-sensitive physical conditions are key prerequisites for tourist activities. Some impacts can be captured by means of quantitative indicators: snow reliability can be measured in terms of the availability of a minimal depth of snow cover on ski slopes for a certain number of days (e.g., 100 days of permanence of adequate snow cover), or in particularly significant moments of the skiing seasons (around Christmas). Linking the altitude of ski holiday destinations with projections of snow reliability (reliable snow cover typically migrates to higher elevations under climate change) sheds light on the future viability of ski destinations. Recent studies factor in snowmaking systems and the persistence of conditions for their operation in the future (Steiger, Scott, Abegg, Pons, & Aall, 2019). Other direct physical impacts relevant for tourist destinations are algal blooms, jellyfish proliferation, beach erosion, higher forest fires risk, biodiversity loss, emergence of infectious diseases, changes in the quality of infrastructure, in water availability, and loss of cultural heritage (Arabadzhyan et al., 2020).

Tourism Comfort Indexes build on the Tourist Climate Index (TCI) (Mieczkowski, 1985) the first and the most used so far in the literature. The idea is to identify ranges of comfortable climate conditions for tourist activities; if destinations consistently fall outside of these ranges, tourists may choose alternatives where climatic comfort is perceived to be higher. More recent indexes, such as the Holiday Comfort Index (Scott, Rutty, Amelung, & Tang, 2016) can capture the relevant comfortable climatic configurations for different types of tourism: visiting a city centre would be not so enjoyable under the same conditions that are perfect for a day on the beach.
All these indexes assume that changes in climate features affecting tourists, can be captured by sub-indexes and summarized as a single indicator. TCI is a weighted sum of sub-indicators[1], with each sub-

[1] The original formulation required: maximum daily temperature and minimum daily relative humidity (%), which combined yield the daytime comfort index; mean daily temperature and mean daily relative humidity (%) which combined yield the daily comfort index; precipitation (mm); sunshine (hrs) and wind (km/h). The Holiday Comfort Index (Scott, Rutty, Amelung, & Tang, 2016) includes other climate variables such as cloud cover.

indicator capturing specific climate features, each ranked on a scale ranging from 0 to 100. The weights in the original TCI were determined by expert judgment. Second generation indexes such as the Holiday Comfort Index use weights based on empirical evidence (tourists' surveys) and assume that extreme weather conditions, in terms of wind speed and precipitation, cannot be compensated by otherwise ideal conditions of other sub-indexes, typically temperature.

Aggregate Demand Models use climate variables to estimate tourists flows and expenditures in response to climate changes. The Hamburg Tourist Model (HTM) (Hamilton, Maddison, & Tol, 2005) estimates international tourist departures and arrivals for a specific year, and then simulates the flows between 207 destination and origin countries. These flows are then projected over this century using socioeconomic and climate change scenarios.

Recent studies integrate tourist comfort indexes with demand models. The PESETA project derives projections of tourist flows and stays based on TCI for EU NUTS2 regions, introducing several refinements in subsequent studies (Amelung and Moreno, 2012; Barrios and Ibáñez 2015; Matei et al., 2023). In its latest version (Matei et al., 2023) PESETA estimates the effect of current climatic conditions as captured by TCI on tourism demand, considering types of tourism prevalent in the various regions, and simulates the impacts of future climate change on tourism demand for four warming levels (1.5°C, 2°C, 3°C, and 4°C) under RCP4.5 and RCP8.5 emissions pathways. The study confirms that northern regions will benefit from climate change while southern regions will experience significant decreases in tourism demand, a pattern that gets starker under higher warming (Figure 9). Seasonal patterns of tourism demand shift as well, with less tourists in summer and more holidaymaking during the rest of the year.

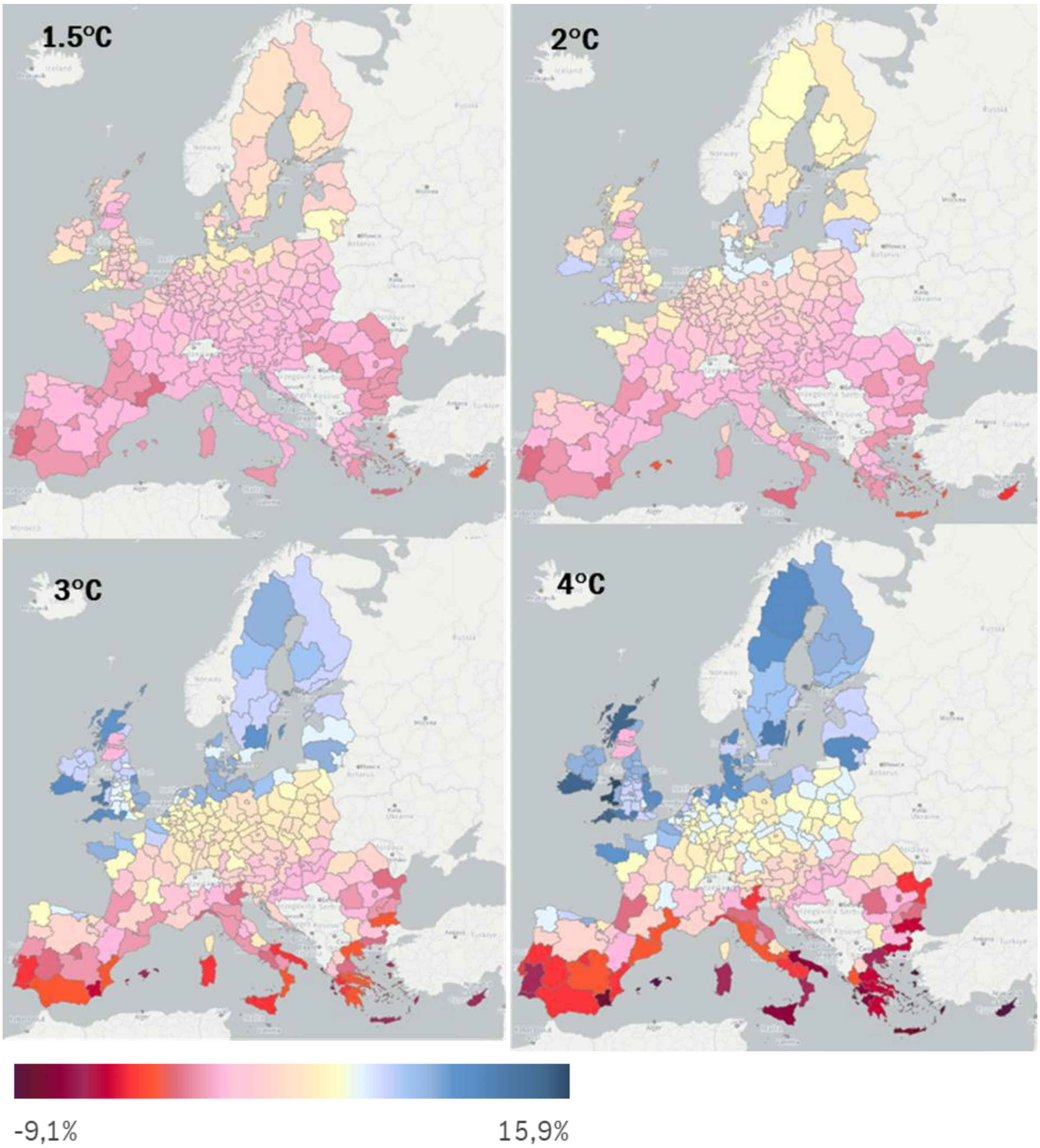

Figure 9. PESETA's Projected evolution of the European regional tourism demand for all the global warming scenarios, compared to the present (2019) in percentage terms. *Source: Matei et al., (2023).*

From tourist flows to economic assessment of costs and/or benefits

Back-of-envelope economic estimates of these impacts draw on the average expenditure per bed night. The PESETA I assessment finds that "up to 59 million bed nights more or some 8% of the total of 777 million nights registered for 2005 in the NUTS2 regions we examined. Additional potential revenues could be in the order of 4–18 billion euros" (Amelung and Moreno, 2012). Econometric modeling can be used to estimate willingness to pay for each component of the TCI using a hedonic price approach as in (Barrios and Ibáñez 2015), but this approach, while providing a detailed depiction of the demand side, is unable to capture the reaction of the supply side and the indirect adjustments in all other sectors of the economy which have economic relations with tourism, as the information provided is too granular.

In principle the output of physical assessments and demand models can be fed into economic modeling frameworks. However, the only comprehensive attempt to implement this for the whole world, dates to the first decade of this century. The HTM model provides tourist flows and expenditures to be included as exogeneous shocks for the market services sector demand and to consumers' income into the GTAP-EF CGE modeling framework (Berrittella, Bigano, Roson, & Tol, 2006), to evaluate the economic impacts on the global economy in 2030 and 2050 climate change scenarios (Bigano, Bosello, Roson, & Tol, 2008). More recently, for the EU countries, ToPDAd uses projections of TCI indexes under alternative assumptions about adaptation options to evaluate climate change impacts on beach and mountain tourism[2]. (Damm, Greuell, Landgren, & Prettenthaler, 2017).

The effect of current climatic conditions as captured by TCI on tourism demand for the whole of Europe at NUTS2 level are derived from the PESETA project and consolidated for EU-wide further TransformAr project activities, considering types of tourism prevalent in the various regions, and associated impacts of future climate change on tourism demand for four warming levels (1.5°C, 2°C, 3°C, and 4°C) under RCP4.5 and RCP8.5.

3.6 Health and Labour

The wet-bulb globe temperature (WBGT) is a measure of environmental heat as it affects humans and is used by industrial hygienists, athletes, sporting events and the military to determine appropriate exposure levels to high temperatures. Unlike a simple temperature measurement, WBGT accounts for all four major environmental heat factors: air temperature, humidity, radiant heat (from sunlight or sources such as furnaces), and air movement (wind or ventilation).

[2] ToPDAd highlights that climate-induced increases of summer overnights in alpine areas are unlikely to counterbalance the losses of winter overnight stays, resulting in net losses in stays and revenues. For beach tourism, Mediterranean destinations will no longer be dominant, although shifting the season to shoulder months will reduce losses. Northern destinations will become moderately more appealing for beach holidays.

According to Sprangler et al. (2020), epidemiologic research on extreme heat consistently finds significant impacts on human morbidity and mortality. Newths and Gunasekera (2018) conclude that the climate change impacts on WBGT vary across areas, with the populations living in warmer economies are expected to be disproportionately affected. The WBGT shows in all scenarios an increase, but the increases in WBGT and its associated impact on human health and well-being are substantially reduced in scenarios considering climate action.

Figure 10 illustrates the effect of a rising WBGT on working capacity considering different levels of job exertion.

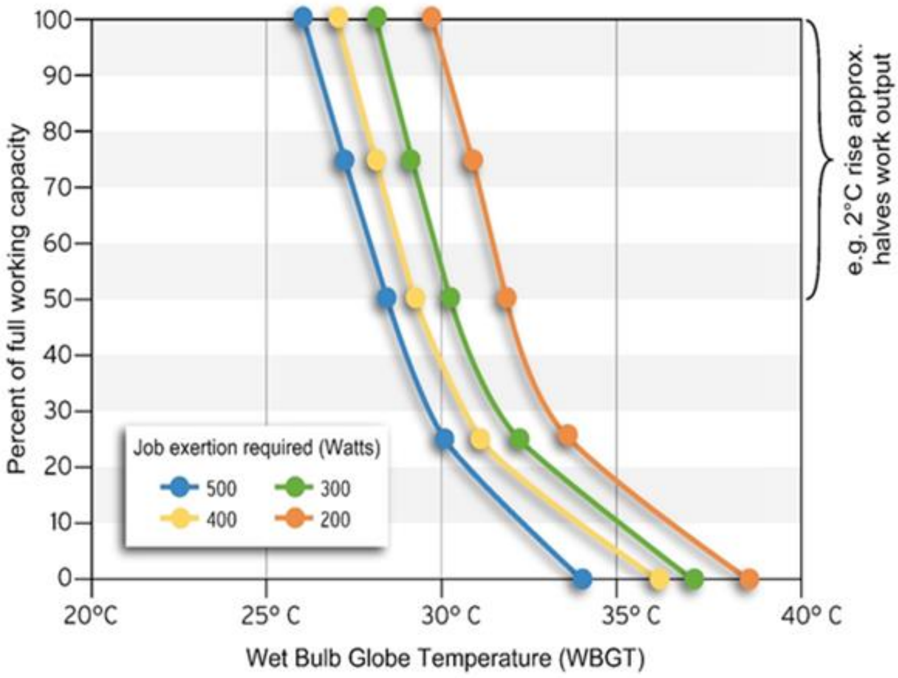

Figure 10: The effect of rising WBGT on working capacity with different levels of job exertion.

WBGT values above 25 °C are considered to be high risk in any kind of daily activities, values above 28 °C a severe risk, and values above 31 °C are considered to be hazardous according to the Japan Society of Biometeorology "Guidelines for prevention of heat disorders in everyday life" 2013[3].

The data compiled in TransformAr WP2 cover entire Europe and are available for the three SSPs and 10 GCM outputs of CMIP6, based on ISIMMIP3b climate scenario data. They are aggregated to NUTS2 level for subsequent application in economical assessments.

[3] https://www.otsuka.co.jp/en/health-and-illness/heat-disorders/wbgt/

4) Conclusions and contribution to other project activities

The main aim of this deliverable, and in general for task 2.3, was to provide knowledge base and projections of EU-wide direct damage assessment due to climate change for sectors relevant to TransformAr KCS at NUTS 2 scale following biophysical modeling. Dataset was consolidated from different sources, namely ISIMIP, COACCH PROJECT, in addition to some specific modeling activities being developed under WP2 of TransformAr. There is undoubtedly a great body of analyses and modeling outcomes being developed under EU funding schemes and research institutes spread across Europe.

As CMIP5 climate projections have been available for about a decade, a full impact assessment chain is available for several sectors from a pleura of projects and modelling activities. The latest CMIP6 simulation runs instead have become available recently, in comparison to CMIP5, and provide therefore only a partial coverage of sectorial impact assessment. One of the main TransformAr priorities has been to integrate available impacts and damage projections driven by CMIP6, when possible, also including further ad hoc project activities in task 2.2 with eco-hydrological modeling and impact assessment on health and labor productivity at EU level driven by CMIP6 climate projections.

Such results have been processed to structure climate change biophysical assessment as inputs into specific economic parameters (e.g., capital stock damage, sectoral productivity reduction, changes in consumption patterns) for the whole of EU and available at NUTS2 level that will be then integrated into the macro-economic modeling impact assessment in T2.4. Similarly, these evaluations are going to be included as integrated evaluation of hazard and sensitivity (intermediate impact) for the integrated Risk Assessment of task 2.5. This task will also support calculation of costs/benefits (T3.2.2) and analysis of avoided damage (T3.3). The projections will support stakeholder’s perception of knowledge and basic data characterizing biophysical-human nexus aspects, damage evaluation across the relevant KCS and facilitate stakeholder preferences for adaptation practices and refine fitness of solutions elaborated from the project TransformAr.

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

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

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

TransformAr

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