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Assessing Climate Change Risk in Europe

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Changes with respect to the DoA

There are no major changes with respect to the description of work outlined in Task 4.3 of the ACCREU Grant Agreement.

Dissemination and uptake

- Campagnolo Lorenza, abstract sent to the IAERE conference 2027. Presentation of the working paper paper “Within-country distributional effects of climate change and adaptation in EU”
- Campagnolo Lorenza, abstract to be sent to the EAERE conference 2027. Presentation of the working paper paper “Within-country distributional effects of climate change and adaptation in EU”
- Preinfalk Eva, presentation at EGU General Assembly 2026: “Spreading the risk, sharing the burden - Economy-wide and distributional impacts of flood risk financing under climate and socioeconomic change” [Abstract EGU26-14072](#)
- Bachner Gabriel, presentation at ECOMOD 2025: “Revealing the distributional effects of current and future flood risk under climate change in Austria”

Short Summary of results (<250 words)

An executive summary can be found on pages 5-6.

Evidence of accomplishment

Published Datasets & Code

- Model Code: The COIN-INT model documentation will be made available on ZENODO
- Dataset: The results of the COIN-AT Fiscal analysis (GDP, household distributional effects, fiscal space for Austria in 2050 and 2080 and for different risk financing scenarios (adaptation scenarios) and medium and high warming levels will be made available on the IIASA Accelerator (Results repository)
- Model Code: The ICES_MH household module documentation will be made available on ZENODO
- Dataset: The results of the ICES_MH distributional analysis (real household income per adult equivalent by income quintile and the Gini coefficient, by country and macro-region × time (five-year steps to 2070) × scenario (no climate change reference, RCP7, RCP4.5 with mitigation) × climate impact channel × adaptation level

(low, reference, high)) will be made available on the IIASA Accelerator (Results repository).

Manuscripts in Preparation

- Campagnolo Lorenza, “Within-country distributional effects of climate change and adaptation in EU” Manuscript in preparation for submission to Environmental & Resource Economics
- Preinfalk, E., Bachner, G., Knittel, N., Tesselaar, M. (2026). Spreading the risk, sharing the burden – A macroeconomic assessment of the distributional effects of flood risk financing schemes. In preparation for submission to Risk Analysis.

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Executive Summary

Task 4.2 of the ACCREU project analyses distributional implications of climate change impacts, adaptation and mitigation strategies across EU regions, economic actors and socio-economic groups. First, CMCC conducts a regional inequality assessment with a sub-national NUTS version of the ICES model (ICES-REG) (Chapter 1). Second, CMCC develops a multi-household model (ICES-MH) for the EU27+UK and uses it to disentangle the impacts of climate change on quintile-representative households under a severe and a moderate warming scenario, the latter combining climate change shocks, a mitigation policy and adaptation measures (Chapter 2). The University of Graz (UNIGRAZ) focuses on riverine flood damages in Austria. It uses a recursive-dynamic CGE model of the Austrian economy with 24 representative household groups, in which households bear recovery costs as compulsory reconstruction expenditures. The study compares three flood risk financing schemes in terms of household welfare, inequality, GDP and government consumption (Chapter 3).

Chapter 1: Climate change driven impacts on regional equity in the European Union

This study examines how climate change affects the regional distribution of per capita GDP across EU NUTS-2 regions, addressing a gap in earlier work that covered only a few impacts or relied on statistical downscaling of aggregate damages. Using the ICES-REG computable general equilibrium model (135 EU/UK subnational regions, 15 rest-of-world regions and 23 sectors), the authors combine nine impact categories from the ACCREU project: sea-level rise, riverine floods, agriculture, forestry, labour, energy demand, energy supply, biodiversity and wildfires. These are assessed under SSP2 combined with RCP2.6, 4.5 and 7.0 through 2070, with low, medium and high impact levels reflecting uncertainty. Inequality is measured with Gini and Theil indices, and a regression of GDP per capita change on log GDP per capita tests whether effects are regressive.

Southern and eastern regions lose the most, while some colder northern regions gain slightly, and the gap widens as climate change intensifies, with the strongest losses under RCP7.0. Poorer regions suffer proportionally larger losses, and this effect grows with both the impact level and the climate signal. Although baseline inequality falls over time, climate impacts push inequality above the baseline, especially under RCP7.0 after 2050 and more visibly at finer spatial resolution. Labour impacts are the main driver of rising inequality, followed by riverine floods and sea-level rise. The authors conclude that climate change is regressive across EU regions and recommend complementing the analysis with within-country studies to better identify vulnerable population groups.

Chapter 2: Within-country distributional effects of climate change and adaptation in EU

This chapter develops the ICES-MH model that splits the private household into five income quintiles per country for the EU27 and the United Kingdom. Each quintile has its own factor endowments, share of government transfers and consumption basket, calibrated by reconciling household microdata (EU-SILC and the Household Budget Survey) with national accounts. The model is used to compare a no-climate-change reference scenario under SSP2 with a severe (RCP7) and a moderate (RCP4.5) warming scenario, the latter achieved through a carbon tax combined with energy-efficiency improvements. Seven impact

channels are run separately under three levels of adaptation, and the distributional effect of mitigation is separated from that of the climate impacts.

The results show that climate impacts weigh most on the middle of the income distribution, mainly through labour supply and productivity, and that Central-Eastern and Southern Europe are the most exposed regions. Under RCP7, the EU27+UK loses 5.8%, 2.6% and 1.5% of mean real income per adult equivalent in 2070 under low, reference and high adaptation. Adaptation reduces the losses of every quintile but does not make them less regressive, because the shift in energy demand raises capital returns, which accrue mainly to the richest quintile. Mitigation lowers mean real income in the EU27+UK by 1.3% in 2070 but is progressive, since the carbon tax mainly reduces capital returns and resource rents at the top of the distribution. When mitigation, hazards and adaptation are combined under RCP4.5, the EU27+UK loses 4.3%, 1.9% and 1.2% of mean income under low, reference and high adaptation, so the lower warming reduces the loss relative to RCP7 by about 1.5, 0.6 and 0.3 percentage points. The effect on inequality depends on adaptation: slightly regressive with low adaptation, slightly progressive with high adaptation, with Central-Eastern Europe as an exception.

Chapter 3: Within-country distributional effects of flood risk (financing): a case study for Austria

Chapter 3 examines how three ways of financing flood recovery in Austria affect household welfare, inequality and the wider economy. It links GLOFRIS flood damage projections (SSP2-4.5) to a recursive-dynamic CGE model with 24 household groups, defined by income quartile, settlement type and flood exposure. Under a risk-based scheme, where exposed households bear their full recovery costs, losses are strongly regressive: low-income households, especially in rural flood zones, lose the most in relative terms, and within-country inequality rises. Non-exposed households are also affected indirectly through price and factor-income changes, with high-income households gaining and low-income ones losing. A government co-financing scheme modelled on the Katastrophenfonds lowers overall losses but leaves this regressive pattern largely intact. A solidarity-based scheme, which spreads costs across all households by income, largely removes the added inequality and substantially eases the burden on low-income exposed households.

These distributional gains come with macroeconomic and fiscal trade-offs. Government co-financing performs best for GDP but is the least favourable for public finances, while risk-based financing protects government budgets but produces the largest rise in inequality. Solidarity financing is the most effective against inequality but weakest for GDP and government consumption, because it reduces savings, investment and capital accumulation. The authors conclude that flood risk financing should be treated as part of climate adaptation policy, since how residual losses are paid for determines whether climate impacts deepen existing inequalities. They suggest targeted public support focused on low-income households could limit inequality while keeping economic and fiscal costs low, and that the findings are relevant for other European countries debating public compensation, insurance and solidarity mechanisms.

1 Climate change driven impacts on regional equity in the European Union

CMCC contributors: Ramiro Parrado, Francesco Bosello, Ramon Key, Gabriele Standardi

1.1 Introduction

The distributional impacts of climate change have gained attention in the last years (Mumtaz & Theophilopoulou, 2024; Paglialunga et al., 2022; Tol, 2021) as part of climate justice concerns (Ojha et al., 2026; Pollex, 2024; Schlosberg, 2007) encompassing different dimensions in its analysis. The extant literature analyses this issue either from a within country distributional perspective studied through impacts on income distribution across household income deciles (Chepeliev et al., 2021; Gilli et al., 2024; Mumtaz & Theophilopoulou, 2024; Tol, 2021) or the regional dimension assessing how climate change impacts can affect the spatial distribution of Gross Domestic Product (GDP) or income (Arbués et al., 2024; Dunne et al., 2026; Tol, 2021). These dimensions are complementary. The first one highlights the potentially regressive effects of climate change impacts and related policies on households' income, particularly the poorest deciles of the population. The second one takes a similar approach to analyse the spatial/regional effects. Both approaches contribute to identifying at-risk populations within and between regions and to improving the efficiency and effectiveness in the allocation of resources with policies supporting more vulnerable groups (Tol, 2021).

The methods used for distributional analysis in the context of climate change depend mostly on the available data and the granularity of the analysis. Climate change impact and policy assessments rely on three main methodologies: simulation models, econometric approaches and expert elicitation. Estimates are provided at the macro-regional, national, subnational and even gridded-level depending on the assessment approach (Bosello & Parrado, 2020; Tol, 2021). These estimates can be combined with additional data such as income distribution by deciles from household surveys or inequality measures such as the Gini and Theil indices to analyse the within-country income distribution effects (Campagnolo et al., 2023; Gilli et al., 2024; Mumtaz & Theophilopoulou, 2024; Paglialunga et al., 2022; Tol, 2021). In the case of between-country/region distributional effects, studies compare changes in welfare or GDP (Arbués et al., 2024; Tol, 2021) or in GDP per capita together with Theil and Gini indexes for a more formal inequality analysis (Butkus et al., 2018; Cartone et al., 2022; Dunne et al., 2026; Kurek et al., 2026; Tol, 2021).

This study considers a set of nine climate change impacts combined altogether to analyse the effects on the regional distribution of per capita GDP across NUTS-2 regions in the European Union (EU). Previous regional studies present two characteristics: some, using macroeconomic models, have focused just on a few impact categories, such as sea-level rise and riverine floods (Arbués et al., 2024; Dunne et al., 2026). Others do consider holistic climate change impacts, but their regional characterization is derived by applying statistical downscaling techniques to spatially aggregated climate change damages from the impact assessment literature (Tol, 2021). These studies can shed some light on the potential distributional impacts but, lacking a structural representation of impacts transmission through the regional economic system, remain more descriptive than explanatory in nature. Our study that couples a CGE model with a regional dimension and a wide set of climate change impacts improves upon both limitations.

1.2 Methods

The analysis considers variations in GDP originated by nine climate change impacts analysed in the ACCREU project: Sea-level rise, Riverine Floods, Agriculture, Forestry, Labour, Energy Demand, Energy Supply, Biodiversity, and Wildfires.

1.2.1 Model and reference scenarios

The economic assessment is performed with the ICES-REG Computable General Equilibrium model (Standardi et al., 2023) featuring 135 EU/UK subnational regions (between NUTS-0 and NUTS-2) plus 15 regions in the rest of the world and 23 sectors within each region with 2017 as the base year. Three scenarios based on the combination of the Shared Socioeconomic Pathway SSP2 and three Representative Concentration Pathways (RCPs: 2.6, 4.5 and 7.0) constitute the reference scenarios against which climate change impacts are assessed. The socio-economic drivers of the SSP2 scenario characterised as a “middle-of-the-road” pathway (Fricko et al., 2017) are the GDP and population projections from the SSP database v3.1 (Release July 2024). The climatic component in each reference scenario is introduced as the CO₂ emission levels corresponding to each RCP which are attained by means of a combination of exogenous energy efficiency trends and a carbon price in stabilization scenarios. The ICES-REG reference scenarios time horizon spans from 2025 to 2070 in 5-year time steps.

1.2.2 Climate change impact estimates

Direct impact estimates are sourced from specific process-based models detailed in Table 1. To account for uncertainty the assessment includes the estimates of the 5th, 50th and 95th percentiles of each impact associated with the low (l), medium (m) and high (h) impact levels, except for three impacts (energy supply, biodiversity and wildfires) where only the medium level was provided due to a reduced data availability.

Table 1: Climate change impacts considered for the spatial distributional analysis in ACCREU

Impact type	Model	Source	Climate change scenarios								
			SSP2-RCP2.6			SSP2-RCP4.5			SSP2-RCP7.0		
			<i>l</i>	<i>m</i>	<i>h</i>	<i>l</i>	<i>m</i>	<i>h</i>	<i>l</i>	<i>m</i>	<i>h</i>
Sea level rise	DIVA	GCF	✓	✓	✓	✓	✓	✓	✓	✓	✓
Riverine floods	GLOFRIS	Stichting VU	✓	✓	✓	✓	✓	✓	✓	✓	✓
Agriculture	GLOBIOM	IIASA	✓	✓	✓	✓	✓	✓	✓	✓	✓
Forestry	GLOBIOM	IIASA	✓	✓	✓	✓	✓	✓	✓	✓	✓
Labour	Empirical estimate	CMCC	✓	✓	✓	✓	✓	✓	✓	✓	✓
Energy demand	Empirical estimate	CMCC	✓	✓	✓	✓	✓	✓	✓	✓	✓
Energy supply	Empirical estimate	CMCC	.	✓	.	.	✓	.	.	✓	.
Biodiversity	CMCC	IIASA/CMCC	.	✓	.	.	✓	.	.	✓	.
Wildfires	ForeFire	DTU	.	✓	.	.	✓	.	.	✓	.
All impacts	ICES-REG	CMCC	✓	✓	✓	✓	✓	✓	✓	✓	✓

Each process-based impact model produces specific information which has been used as input for the ICES-REG model through the corresponding entry points identified in ACCREU’s Deliverable 4.1 and in previous climate change impact assessment studies carried out with the same model (Bosello et al., 2020; Standardi et al., 2023; van der Wijst et al., 2023). All impacts have been combined altogether to produce the required nine scenarios

covering the wide spectrum of uncertainty from low to high impact levels for each reference scenario. For the case of the three impacts providing only a medium impact level (energy supply, biodiversity and wildfires), this level is used also as the low and high levels to use all available information.

1.2.3 Regional distribution indicators

To assess the regional distributional impacts of climate change at the EU NUTS-2 level, the GDP and population of each EU NUTS-2 region in 2017 is mapped to the corresponding ICES-REG region and then projected over time according to the ICES-REG results, to obtain the GDP per capita in each EU NUTS-2 region from 2025 to 2070. All simulations have been produced using the GEMPACK economic modelling software (Horridge et al., 2018), while results reporting have been produced using GEMPACK and R (R Core Team, 2025) statistical software and the dineq package.

Inequality at the regional level is estimated by means of two equity indices (Gini and Theil) computed using the information on GDP per capita by NUTS-2 region. The Gini index is defined as:

$$G = \frac{\sum_{i=1}^R \sum_{j=1}^R |y_i - y_j|}{2R^2 \bar{y}}$$

while the Theil index is defined as:

$$T = \sum_{i=1}^R \left[\frac{N_i}{N} \cdot \frac{y_i}{\bar{y}} \cdot \ln\left(\frac{y_i}{\bar{y}}\right) \right]$$

Where R is the number of regions, N_i is the population in region i , N is total population ($N = \sum_{i=1}^R N_i$), y_i is the GDP per capita in region i and $\bar{y}$ the mean GDP per capita.

1.3 Results

This section presents results first at the aggregated level by comparing changes in regional GDP per capita at the NUTS-2 level by scenario, over time and with general trends differentiated by impact level. Then, the regional equity dimension is analysed by means of two inequality measures at different aggregation of EU NUTS levels.

1.3.1 Climate change distributional impacts at the EU NUTS-2 level

The regional distribution of GDP per capita by EU NUTS-2 regions is depicted in Figure 1 for the ICES-REG base year (2017) and for the 2070 SSP2 baseline with darker regions reporting the higher GDP per capita. The Northern EU and regions where the country's capital city is located are the richer areas. Western and southern EU areas show mid GDP per capita levels while eastern regions show the lowest GDP levels. This pattern is consistent across time even though there is a twofold increase in the scale from 2017 until 2070.

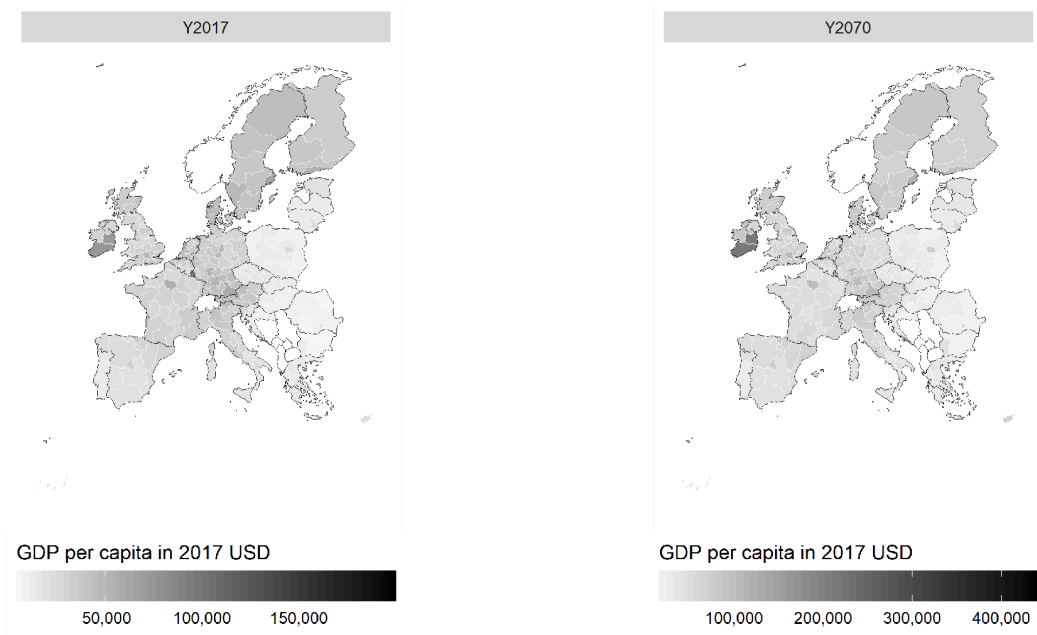


Figure 1: GDP per capita by EU NUTS-2 region in 2017 and 2070

The percentage changes of per capita GDP in the three climate scenarios, and for all nine climate change impacts considered, is presented in Figure 2 for the medium impact level in the years 2030, 2050 and 2070. It emerges that the most affected regions are in the southern and eastern EU, while Northern EU colder regions show some potential improvements in GDP per capita.

A clear pattern emerges also looking at climate-changes trends over time and across climate scenarios. As climate change intensifies, the GDP per capita gap among EU NUTS-2 regions widens. This is reflected in the scale of each panel: the spread of relative changes in per capita GDP is $[-2.9\%, 1.2\%]$ in 2030, $[-8.1\%, 2.9\%]$ in 2050, and $[-18.7\%, 4.1\%]$ in 2070 across the three reference scenarios. The GDP per capita gap also widens when moving from a stabilization scenario (RCP2.6 – top panels of Figure 2) to a more emissive one (RCP7.0 – bottom panels). In this case, the spread across years for each climatic scenarios is $[-13.9\%, 1.3\%]$ in SSP2-RCP2.6, $[-15.2\%, 1.9\%]$ in SSP2-RCP4.5, and $[-18.7\%, 4.1\%]$ in SSP2-RCP7.0. This confirms the regressive effects of climate change on regional GDP per capita found in previous studies at the EU regional (Dunne et al., 2026) and the world level (Tol, 2021).



Figure 2: Climate change impacts on GDP per capita for the medium level impact by EU NUTS-2 regions, year, and reference scenario

In 2070, for the high climate-signal scenario (SSP2-RCP7.0) and the medium impact level case, the most negatively impacted regions with per capita GDP relative losses around 10% or higher are: Veneto, Puglia, Emilia-Romagna, Campania, Sicilia, Marche and Molise in Italy; Sud-est and Nord-est in Romania; Andalucia, Valencia, Asturias, Aragon and Madrid in Spain; Algarve and Alentejo in Portugal; Nisia and Attiki in Greece; Nord-Pais di Calais, Languedoc-Roussillon, and Haute-Normandie in France, and Croatia. Figure A1 in the Annex I complements these findings by showing the percentage changes of per capita GDP in 2070 considering the three impact levels and the three climate scenarios, indicating that relative losses of per capita GDP could be higher than 25% when considering the high impact case.

To confirm the regressive effect of climate change on regional GDP per capita, a linear regression model is also estimated linking the percentage change in per capita GDP in each NUT-2 region induced by climate impacts (∂GDP_{pc}) to per capita GDP (GDP_{pc}), while α is the intercept, and β is the slope of the linear model. The available data is fit using samples differentiated by impact level, climate scenario and year, as in the following equation:

$$\partial GDP_{pc} = \alpha + \beta \ln \ln (GDP_{pc})$$

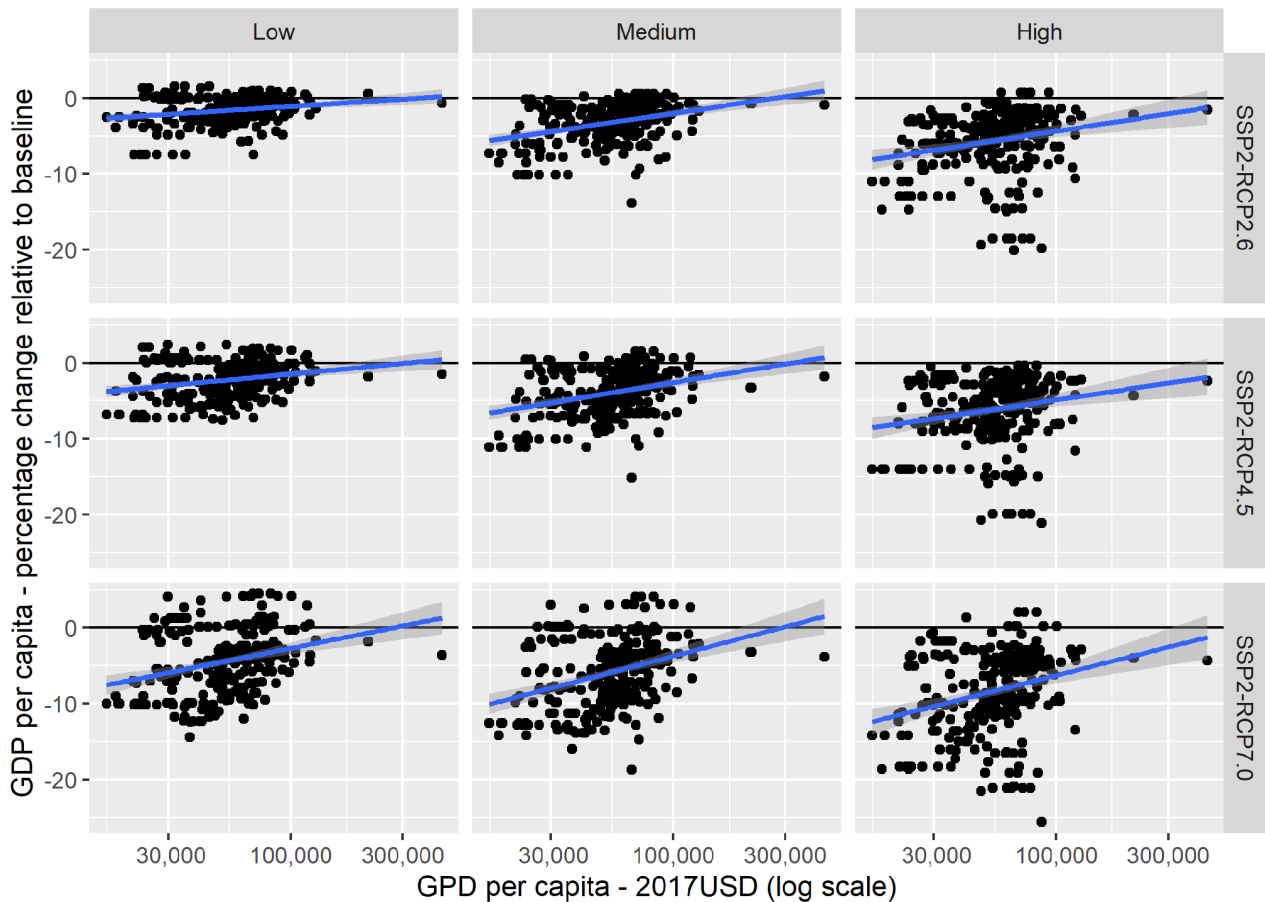


Figure 3: Climate change impacts on GDP per capita as a function of GDP per capita in 2070

Figure 3 shows the different estimated models for 2070 by impact level and scenario. The positive slope of the regression line implies that lower GDP per capita regions are more negatively affected by climate change while richer regions face lower relative losses. Table A1 in the Annex I shows the complete set of estimated parameters.

The regression results also show that the slope of the curve is higher the higher the level of the climate change impacts (moving from left to right) and the higher climate change signal represented by the RCP scenario (moving from top to bottom). Similarly, the intercept of the line with the y-axis is lower indicating more negative impacts the higher the impact level or the climate signal.

A variant of the linear regression model is fit with a dummy variable to identify the corresponding year D_t isolating the effects of climate change over time as follows:

$$\partial GDP_{pc} = \alpha + \beta \ln(GDP_{pc}) + D_t$$

Table 2 summarises the results of the second linear regression model differentiated by climate scenario and impact level. Pooling all observations to obtain a general trend as shown in the last line of the table confirms the negative intercept in the y-axis and a positive slope of the model, while the value of the dummy coefficients representing the time effects is decreasing over time indicating a shift downwards, or higher losses over time. Results differentiated by impact level and climate scenario support the conclusion that climate change has a regressive effect widening the GDP per capita gap between regions due to a higher slope and a more negative intercept with the y-axis.

Table 2: Linear regression estimates of climate change impacts on GDP per capita as a function of GDP per capita by climate scenario, impact level and a time dummy

Scenario	level	Intercept	Slope	D 30	D 35	D 40	D 45	D 50	D 55	D 60	D 65	D 70	R2	Obs
SSP2-RCP2.6	Low	-8.15	0.78	-0.17	-0.31	-0.48	-0.65	-0.85	-1.08	-1.34	-1.65	-1.99	0.21	2760
SSP2-RCP2.6	Medium	-14.78	1.41	-0.36	-0.65	-1	-1.36	-1.75	-2.2	-2.7	-3.25	-3.85	0.36	2760
SSP2-RCP2.6	High	-16.68	1.58	-0.54	-1	-1.54	-2.13	-2.77	-3.5	-4.31	-5.21	-6.19	0.37	2760
SSP2-RCP2.6	all	-13.2	1.26	-0.36	-0.65	-1	-1.38	-1.79	-2.26	-2.79	-3.37	-4.01	0.26	8280
SSP2-RCP4.5	Low	-8.9	0.85	-0.17	-0.29	-0.43	-0.57	-0.74	-1.1	-1.53	-2.05	-2.63	0.23	2760
SSP2-RCP4.5	Medium	-14.94	1.43	-0.34	-0.63	-0.94	-1.28	-1.66	-2.25	-2.92	-3.71	-4.58	0.37	2760
SSP2-RCP4.5	High	-15.93	1.51	-0.51	-0.96	-1.45	-2	-2.59	-3.43	-4.38	-5.47	-6.66	0.38	2760
SSP2-RCP4.5	all	-13.26	1.26	-0.34	-0.63	-0.94	-1.28	-1.66	-2.26	-2.95	-3.74	-4.62	0.29	8280
SSP2-RCP7.0	Low	-14.1	1.35	-0.28	-0.53	-0.83	-1.14	-1.47	-2.22	-3.06	-3.97	-4.95	0.29	2760
SSP2-RCP7.0	Medium	-19.7	1.88	-0.44	-0.85	-1.3	-1.79	-2.3	-3.27	-4.33	-5.49	-6.71	0.38	2760
SSP2-RCP7.0	High	-20.74	1.97	-0.59	-1.16	-1.81	-2.52	-3.28	-4.57	-5.98	-7.5	-9.09	0.45	2760
SSP2-RCP7.0	all	-18.18	1.73	-0.44	-0.85	-1.31	-1.82	-2.35	-3.35	-4.46	-5.65	-6.92	0.36	8280
all	Low	-10.38	0.99	-0.21	-0.38	-0.58	-0.79	-1.02	-1.47	-1.98	-2.56	-3.19	0.22	8280
all	Medium	-16.48	1.58	-0.38	-0.71	-1.08	-1.48	-1.9	-2.57	-3.32	-4.15	-5.05	0.35	8280
all	High	-17.78	1.69	-0.55	-1.04	-1.6	-2.21	-2.88	-3.84	-4.89	-6.06	-7.31	0.39	8280
all	all	-14.88	1.42	-0.38	-0.71	-1.09	-1.49	-1.94	-2.62	-3.4	-4.26	-5.18	0.29	24840

1.3.2 Climate change driven effects on regional equity

The overall effect on inequality due to climate change can be summarised by the Gini and Theil inequality measures where values equal to zero indicate a uniform distribution (maximum equality) of the analysed variable, in this case GDP per capita. Figure 4 depicts the evolution of both indices computed using data of the EU NUTS2 level for the reference and

climate scenarios along with the impact levels to give an idea of the uncertainty in each climate scenario.

In the baseline both indices decline witnessing an improvement in the regional distribution of GDP per capita over time. However, climate change impacts increase the regional inequality as shown by the three areas representing the evolution of each climate scenario lying above the baseline trend. The RCP 2.6 and 4.5 scenarios are very similar, almost overlapping, during most of the simulation period. In the case of the RCP7.0 scenarios, there is a clearer inequality increase over time and especially after 2050.

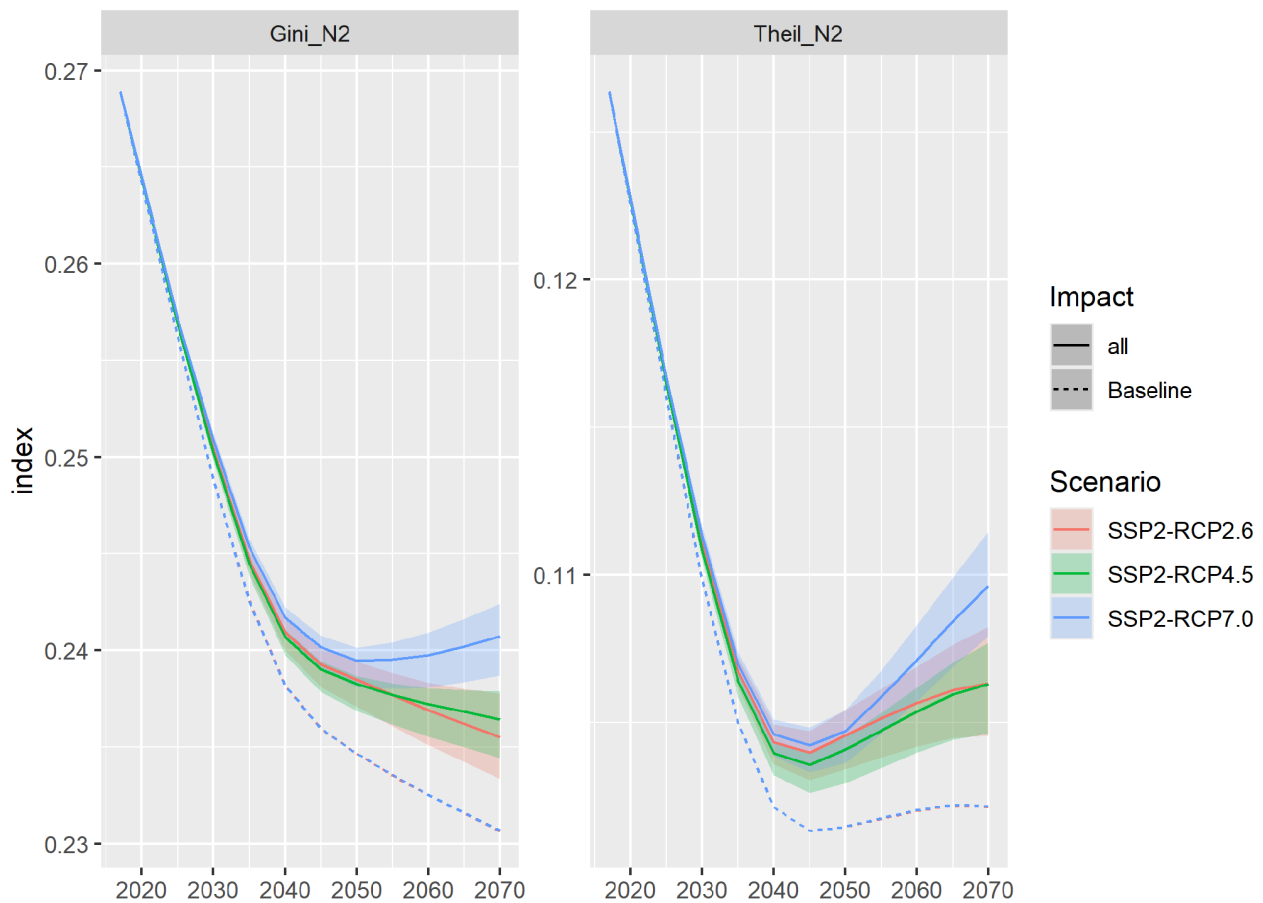


Figure 4: Gini and Theil inequality measures based on EU NUTS-2 regions by scenario and impact level from 2020 to 2070

It is also interesting to compute and compare the performances of these indices under different level of spatial granularity, i.e. NUTS-0 (national), NUTS-1 and NUTS-2 as shown in Figure 5. The behaviour of both indices is robust across all resolution levels. Inequality tends to decrease in the baseline scenario, but it is higher under the climate change scenarios. However, moving from the lower (NUTS-0) to a higher (NUTS-2) spatial detail reveals a higher inequality. Similarly, the inequality gap between the baseline and climate scenarios increases at a faster pace. This stresses the need and usefulness of using more granular data for assessing distributional issues to support policy design.

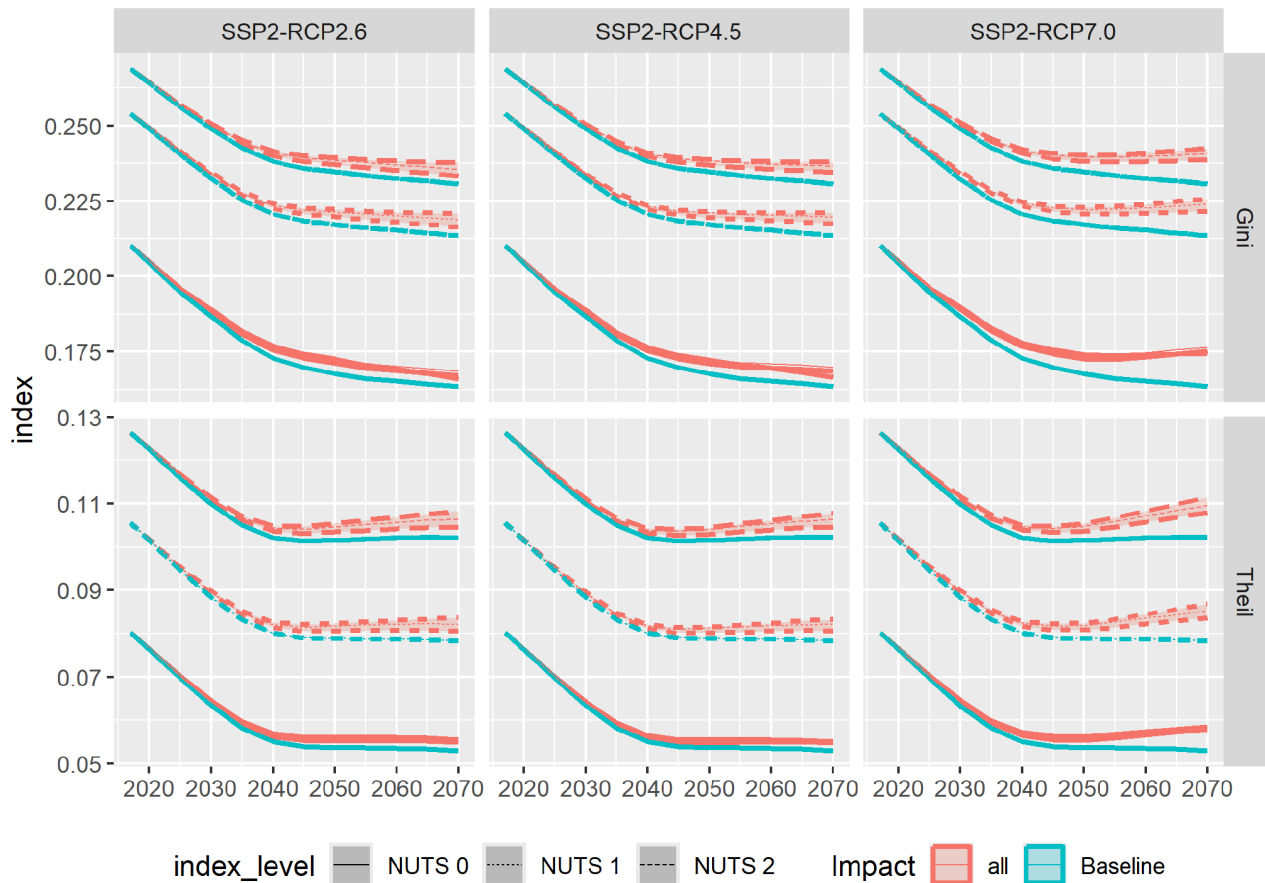


Figure 5: Gini and Theil inequality measures for the EU by NUTS regions, scenario, and impact level from 2020 to 2070

A final dimension of distributional impacts of climate change regards the relative contribution of each individual impact to the overall regional inequality. Results of this inspection are reported in Figure 6. The main contributors to widening the regional equity gap are climate change impacts on the labour force that highlight clear positive impacts on labour productivity and supply in northern and colder regions, and negative in the southern and warmer EU regions with similar cascading effects on the regional GDP per capita. Other impacts with a relevant contribution to the EU regional inequality increase are riverine floods and sea-level rise, while the rest of impacts have a minor role.

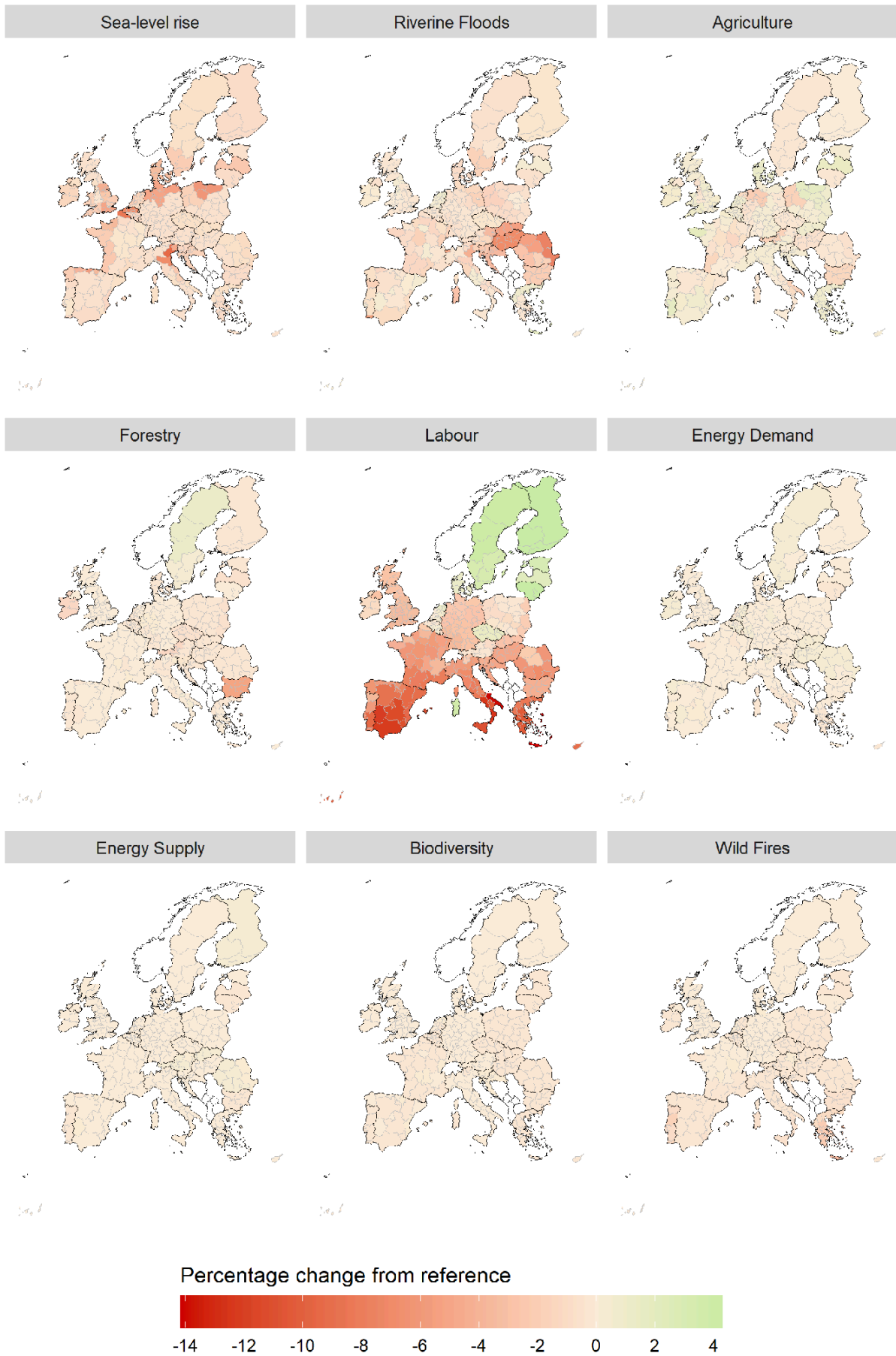


Figure 6: Climate change impacts on GDP per capita for the medium level impact of the SSP2-RCP7.0 scenario in 2070 by climate impact and EU NUTS-2 regions

1.4 Conclusions

This section focuses on the between region distributional impact of climate change. The regional and spatial dimensions enable us to identify vulnerability to climate change not only in terms of adverse impacts on per capita GDP, but also in terms of increased inequality. This study used results from a macroeconomic assessment of climate change impacts performed at the NUTS-2 level to provide insights into the regional distributional effects of climate change on the EU regions. The macroeconomic assessment used information from bottom-up process-based models that provided direct impacts for nine impact categories for low, medium and high impact cases and for three climate scenarios represented by RCPs 2.6, 4.5 and 7.0.

Results confirm the regressive effects of climate change on the regional distribution of GDP per capita, which widens the equity gap between EU NUTS-2 regions as climate change intensifies over time and by climatic scenario. The higher the climate signal, the higher the economic impact and the wider the regional equity gap. These regressive effects are led mainly by labour, riverine floods and sea-level rise impacts. At the regional level the most affected regions are in the southern and eastern EU with some northern and colder regions experiencing some benefits from higher temperatures.

These results should be complemented with within-country and within-region analyses to improve the identification of the most vulnerable population groups within the EU countries and their regions for a better design of climate policies and the corresponding supporting instruments.

2 Within-country distributional effects of climate change and adaptation in EU

CMCC contributors: Lorenza Campagnolo

2.1 Introduction

Climate change affects households unevenly, and most economy-wide assessments cannot show it. Standard computable general equilibrium (CGE) models describe each country's private sector as a single representative household that owns all primary factors, receives all transfers and consumes one national basket. In such a framework, a shock that lowers labour productivity, raises energy prices or shifts returns from labour to capital has the same consequence for everyone, so questions about who gains and who loses cannot be asked. This matters because the sources of household income and the structure of consumption differ systematically along the income distribution: low-income households rely on government transfers and unskilled labour, while top-income households rely mainly on capital returns.

This chapter addresses that limitation by developing ICES-MH, a multi-household extension of the ICES model for the EU27 and the United Kingdom. Building on the ICES-XPS database, which separates the private household from the government, ICES-MH further splits the private household into five income quintiles per country. Each quintile has its own endowments of primary factors, its own share of government transfers and its own consumption basket. These are calibrated by reconciling household microdata (EU-SILC and the Household Budget Survey) with national accounts through a cross-entropy procedure. Because the model works with five groups, inequality is measured with a Gini coefficient that retains within-quintile dispersion, so that it can be compared with official statistics. The results are therefore read as between-quintile effects.

Using this framework, the chapter first sets out how income and inequality evolve in a no-climate-change reference scenario under SSP2. It then disentangles the distributional effects of climate impacts (sea-level rise, flooding, health, agriculture, labour, biodiversity loss and wildfires) under a severe (RCP7) and a moderate (RCP4.5) warming scenario. The RCP4.5 pathway is achieved through a mitigation policy that combines a global carbon tax with energy-efficiency improvements, and the chapter separates the distributional effect of this policy from that of the climate impacts. Each impact channel is run separately under three levels of adaptation (low, reference and high), so the analysis shows which hazards drive losses, who bears them and whether adaptation changes the distribution of outcomes as well as its size. Results are reported for four European macro-regions and for the EU27+UK as a whole.

2.2 Method

2.2.1 The ICES-MH model

The starting point is the extended database of ICES-XPS (Delpiazzi, 2017), which splits the regional household of the standard framework into a private household and a government, and introduces the intra-regional and inter-regional transfers that connect them. Private household income is the sum of the remuneration of primary factor endowments,

government transfers, interest payments on domestic and foreign debt, and a share of the accounting items that reconcile the national accounts with IMF statistics; government income is tax revenue plus aid inflows, net of aid outflows, interest paid to foreign and domestic holders of public debt, and transfers to households. Each agent faces its own budget identity, so that income is exhausted by expenditure on domestic and imported goods, the associated consumption taxes, and savings; investment is split into a private and a public component, each with its own accumulation rule, and the gap between public savings and public investment is closed by government borrowing, which accumulates into a debt stock across simulation years. By making the public accounts explicit in this way, ICES-XPS allows the flows between the two agents to be represented and tracked. The private household, however, remains a single agent that owns all of the country's primary factors, receives the whole of the transfer flow and consumes one national basket, so that every question about distribution is still foreclosed: a policy that raises energy prices, or that shifts returns from labour to capital, has identical consequences for every household in the model, because there is only one. ICES-MH replaces that agent with five income quintiles per country, each holding its own portfolio of factor endowments, receiving its own share of transfers, and consuming its own basket of goods. What ICES-XPS did for the boundary between the public and the private sector, ICES-MH does within the private sector itself.

The extension adapts the methodology of the MyGTAP model (Walmsley and Minor, 2013), in which private consumption is disaggregated across multiple households specified either as a Constant Difference of Elasticities or as a Linear Expenditure System. Four features define the multi-household structure. The first, and the one that carries most of the distributional content, is household-specific ownership of endowments and supply of factors to firms: each household supplies its own endowments, subject to the requirement that the supplies sum to the country total of the original database, and household labour supply and unemployment can be specified, which in turn requires labour demand to be modelled. The remaining three are additional endowments, transfers among households and between households and the government, and taxes.

Formally, the private household account is indexed by household type h , so that income sources and expenditure choices can differ across the household groups within a region:

$$YH(h,r) = \sum_e ENDOW(e,h,r) + TRN_GOV(h,r) + INTD(h,r) + INTFI(h,r) + \alpha \cdot OEXP(h,r) - \beta \cdot OINC(h,r)$$

where h denotes the household type, r the region and e the primary factor; $YH(h,r)$ is the income of household type h ; $\sum_e ENDOW(e,h,r)$ is the remuneration of the primary factor endowments the household owns; $TRN_GOV(h,r)$ is the transfer it receives from the government; $INTD(h,r)$ and $INTFI(h,r)$ are the interest payments accruing to it on domestic and on foreign public debt; and $OEXP(h,r)$ and $OINC(h,r)$ are the other government expenditure and other government income that reconcile the database with IMF deficit and surplus figures, of which only the shares α and β flow to households — shares tuned so that the resulting household income matches statistics on disposable income. The corresponding identity on the uses side is:

$$YH(h,r) = \sum_i VDPM(i,h,r) + \sum_i VIPM(i,h,r) + \sum_i PSTAX(i,h,r) + SAV_HHLD(h,r)$$

where i denotes the commodity; $\sum_i \text{VDPM}(i,h,r)$ and $\sum_i \text{VIPM}(i,h,r)$ are the household's expenditure on domestic and on imported goods, $\sum_i \text{PSTAX}(i,h,r)$ are the taxes levied on its consumption, and $\text{SAV_HHLD}(h,r)$ are its savings.

Most of the variables in these identities derive directly from household survey data, and establishing them is the subject of the next section. Two components cannot be observed at household level and are allocated by rule instead: interest payments on domestic and foreign debt are distributed across household types in proportion to their ownership of capital, since it is capital ownership that confers a claim on debt service; and the accounting items that reconcile the database with IMF deficit and surplus figures, having no household counterpart at all, are distributed in equal shares. Country savings are the sum of household and government savings,

$$\text{SAVE}(r) = \sum_h \text{SAVE_HHLD}(h,r) + \text{SAVE_GOV}(r), \quad \text{with} \quad \text{SAVE_HHLD}(h,r) = YH(h,r) - \text{EXPH}(h,r)$$

where $\text{SAVE}(r)$ are total savings in region r , $\text{SAVE_GOV}(r)$ are government savings — the difference between government income and government expenditure — and $\text{EXPH}(h,r)$ is the total expenditure of household type h . Each household group's savings are thus determined residually, so that its budget identity holds by construction.

The newly introduced income components follow their own within-period dynamics. As in ICES-XPS, aid outflows are a share of government income scaled by a parameter reflecting variation in the global volume of aid, and aid inflows are rescaled to satisfy a clearing condition at world level. Government transfers to households are a fixed share of government income, so that their growth follows the growth of the public budget rather than being exogenous, and the two accounting items are fixed shares of government and household income respectively.

2.2.2 Household characterisation in ICES-MH

Each of the features described above requires information that the GTAP database does not contain. The first element is how each primary factor payment distributes across households, i.e. what share of a country's capital income, or of its unskilled wage bill, accrues to the poorest fifth. The second is how the transfers introduced in ICES-XPS as an aggregate flow divide among those same households, since the incidence of public support is the counterpart to the incidence of a price shock. The third is how consumption baskets differ, since the budget share of food, energy and services varies systematically with income and determines who bears the cost of a price change. None is observable in GTAP, which reports only national totals; all three are observable in European household microdata. The household characterisation therefore combines two surveys with the national accounting framework, using each for what it can establish.

The two surveys are complementary and neither is sufficient alone. EU-SILC records household income in detail and by source — employee earnings, self-employment income, pensions and benefits — but says almost nothing about expenditure. The Household Budget Survey records expenditure in detail by consumption category but carries only a thin income measure. They cover the same populations and countries, and can be used in parallel provided they rank households identically. In both surveys households are ordered by disposable income per adult equivalent on the OECD-modified scale, and quintiles are cut on weighted distributions within country and survey year, so that the first quintile of the income

side and the first quintile of the expenditure side describe the same part of the distribution. A single reference year is selected per country, on data coverage rather than convenience, since pooling years would mix nominal income levels across waves and blur the boundaries.

On the income side, EU-SILC variables are first harmonised: income is collected gross in some country-years and net in others, and the two are reconciled through a country-year implied tax rate estimated from households' own reported tax and contributions. Income is then decomposed into the factors the model recognises. Employee earnings are split by skill, using the occupational classification mapped to GTAP's labour categories, and by sector. Self-employment income, which mixes a return to the owner's labour with a return to the business's capital, is divided by valuing the labour component at the employee hourly wage in the same country, sector and occupation, scaled by hours worked and discounted to reflect the lower returns observed among the self-employed; the remainder is capital. Rental income is apportioned between land and capital, and the benefit categories are grouped as transfers. On the expenditure side, the COICOP classification is mapped to GTAP sectors and collapsed to the model's sectoral aggregation, recognising that households buy processed and retail products rather than raw commodities, so that food spending maps to processed food rather than to crops.

The two surveys establish distributions, not magnitudes. Survey aggregates do not reproduce national accounts, so the division of labour with GTAP is explicit: the surveys supply the shape, e.g. how a factor payment or a consumption total distributes across quintiles and, where observable, across sectors, and GTAP supplies the levels. The two are joined by a cross-entropy procedure, following the approach developed for estimating and updating social accounting matrices from incomplete and inconsistent information (Golan et al., 1996; Robinson et al., 2001). The survey evidence is treated as a prior, a first and imperfect estimate of an unknown distribution, and the national accounts as constraints that estimate must satisfy. Among all distributions satisfying the constraints, the procedure selects the one that departs least from the prior, where distance is measured by the Kullback–Leibler divergence:

$$\min \sum x(f,s,q) \cdot \ln [x(f,s,q) / \bar{x}(f,s,q)]$$

where f indexes the primary factors, s the sectors and q the quintiles; $\bar{x}(f,s,q)$ is the prior, the share of factor f 's payment from sector s accruing to quintile q as the survey records it; and $x(f,s,q)$ is the reconciled estimate of that same share. Minimising this quantity is a minimum-information criterion: it imposes no structure on the result beyond what the survey already contained and what the constraints require, so that every departure from the household data is attributable to a binding national-accounts total rather than to an assumption of the analyst. The problem is solved separately for each country as a non-linear program.

Two sets of constraints bind. The column constraints require that each factor payment in the database is fully allocated across the five households, so that summing a factor-sector cell over quintiles reproduces the corresponding entry exactly; this is the adding-up requirement of the multi-household structure (household endowment supplies summing to the country total) imposed at the calibration stage rather than left to be checked afterwards. The row constraints require that each quintile's shares sum to one, scaled by that quintile's share of total factor income, so that the household aggregates reproduce the distribution the survey

observed. The two sets are mutually consistent by construction, since the quintile totals are shares of the same aggregate that the factor payments sum to, and a diagnostic verifies this rather than assuming it. Cells for which the database records no payment are fixed at zero, so that no household receives income from a factor-sector pair that pays nothing; cells for which it records a payment the survey never observed carry no household information and are determined entirely by the constraints. Income that the survey records without a sector (interest, dividends, private pensions and transfers, which EU-SILC does not attribute to an industry) is distributed according to the sectoral composition of the corresponding factor payment in the database, that being the only information available about it. The expenditure side is reconciled in the same way against sector totals. A snapshot of the final base year factor income, sectoral income and consumption distributions across household quintiles in EU27+UK can be found in Annex IIA.

The reconciliation delivers shares, and a final rescaling step turns them into a balanced database. Each share is applied to the corresponding aggregate of the original database, so that the single private household row and column are replaced by five of each, indexed by h . Because the shares sum to one within every account by construction, the row and column totals of the original matrix are preserved exactly: the split is internal to the household block, and every other account (firms, government, investment, and the rest of the world) is left untouched, so that the social accounting matrix remains balanced without any further adjustment to its non-household entries. What does not follow automatically is the budget identity of each individual household, since income shares and expenditure shares come from two different surveys and are reconciled against two different sets of GTAP margins. The residual is absorbed by savings, consistently with the model's own definition of household savings as the difference between a household's income and its expenditure. Savings therefore carry the accumulated difference between the two surveys, which is also why the resulting savings rates, rather than the income or expenditure shares, are the quantity to inspect first when judging whether a country's split is plausible.

2.2.3 Income distribution in the no climate change reference scenario

The calibration above fixes the income distribution in the base year. In the reference scenario the model is then solved forward, and the distribution evolves endogenously: each quintile's income grows with the returns to the factors it owns and with the transfers it receives, so that changes in the sectoral composition of output and in relative factor prices translate directly into changes in the shape of the distribution.

The model represents households in five income groups, so the Gini coefficient cannot be read directly off the simulated incomes. A Gini computed on five group means captures only the inequality between quintiles. It would understate the observed coefficient considerably, because a substantial part of measured inequality, particularly at the top of the distribution, lies within the top group. Comparing such a figure with a published Gini would mean comparing two different quantities. The indicator reported here therefore retains within-quintile dispersion. A lognormal distribution is placed inside each quintile, centred on the model's quintile mean, and its dispersion is calibrated for each country so that the 2017 Gini reproduces the Eurostat figure. The reported indicator is thus commensurable with the statistics against which it is benchmarked. In 2017, the average Gini coefficient of disposable income in the EU27 is 30.3, and it ranges from 23.2 in Slovakia to 40.2 in Bulgaria, a spread of 17 points. Inequality is lowest in Slovakia, Slovenia, Czechia, Finland, and Belgium, and highest in Bulgaria, Lithuania, Latvia, Spain and Portugal. Twelve countries are above the EU

average, including the Baltic States, the Southern European economies (Spain, Portugal, Greece, Italy and Cyprus), Romania, the United Kingdom and Ireland. The Annex IIB compares the Gini computed from the quintiles alone with the official Eurostat statistics.

In the reference scenario within-quintile dispersion is held constant at its 2017 calibrated value. The simulation has no information on how inequality inside a quintile evolves, so all changes in the Gini over the projection period come from movements in the quintile means and population weights. The results should therefore be read as the contribution of the model's own distributional channel, and not as a forecast of total inequality. For example, the model can show that a shock shifts income from the bottom quintile to the top, and by how much, because that movement works through the returns to the factors each group owns and the transfers each group receives. It cannot show a policy compressing or widening the dispersion inside a group. Distributional results are thus to be understood as between-quintile effects, and as a lower bound on the total change in inequality wherever the mechanism at work also operates within groups.

Our reference scenario assumes no climate change and follows SSP2 for its socio-economic assumptions. SSP stands for Shared Socioeconomic Pathways, the set of five scenarios that describe alternative futures of societal development (O'Neill et al., 2014, 2017). SSP2, the "Middle of the Road" pathway, is one in which social, economic and technological trends do not depart markedly from historical patterns (O'Neill et al., 2017; Fricko et al., 2017). Income converges across countries only slowly, institutions evolve without major reform, and productivity growth is moderate. Population peaks around midcentury and declines thereafter, and inequality within countries persists rather than narrowing.

In the reference scenario under SSP2, real income per adult equivalent rises in every EU27 country and the UK between 2017 and 2070, from roughly 20% in Luxembourg to more than 200% in Bulgaria. Incomes are deflated by a single country-level consumption price index common to all quintiles, so differences between quintiles reflect differences in nominal income growth, not in price baskets. Growth is fastest in Bulgaria and Romania, followed by the Baltic and central European economies, Ireland, Greece and Hungary. It is slowest in Luxembourg and in Belgium, France and Austria (Figure 7). Faster growth does not translate into a particular distributional outcome. The Gini coefficient falls in 21 of the 28 countries and rises in the other seven (Lithuania, Slovakia, Latvia, Bulgaria, the Netherlands, Poland and Ireland). Most changes are within two Gini points. The notable exceptions are Estonia, where the Gini falls by nearly four points, Luxembourg (about three) and Lithuania, where it rises by about 1.7 points. Among the largest economies, Germany, France, the United Kingdom, Italy and Spain all lie below zero, so most of the EU population moves toward lower inequality, and Poland is the only large country with a (marginal) rise. The direction of change follows which end of the distribution grows faster. In every country where the poorest quintile (Q1) outgrows the richest (Q5), the Gini falls, and where Q5 outgrows Q1 it rises.

Growth and inequality, 2017 to 2070

Horizontal: change in mean real income per adult equivalent.

Vertical: change in the Gini. Point size: country size (adult equivalents, 2070).

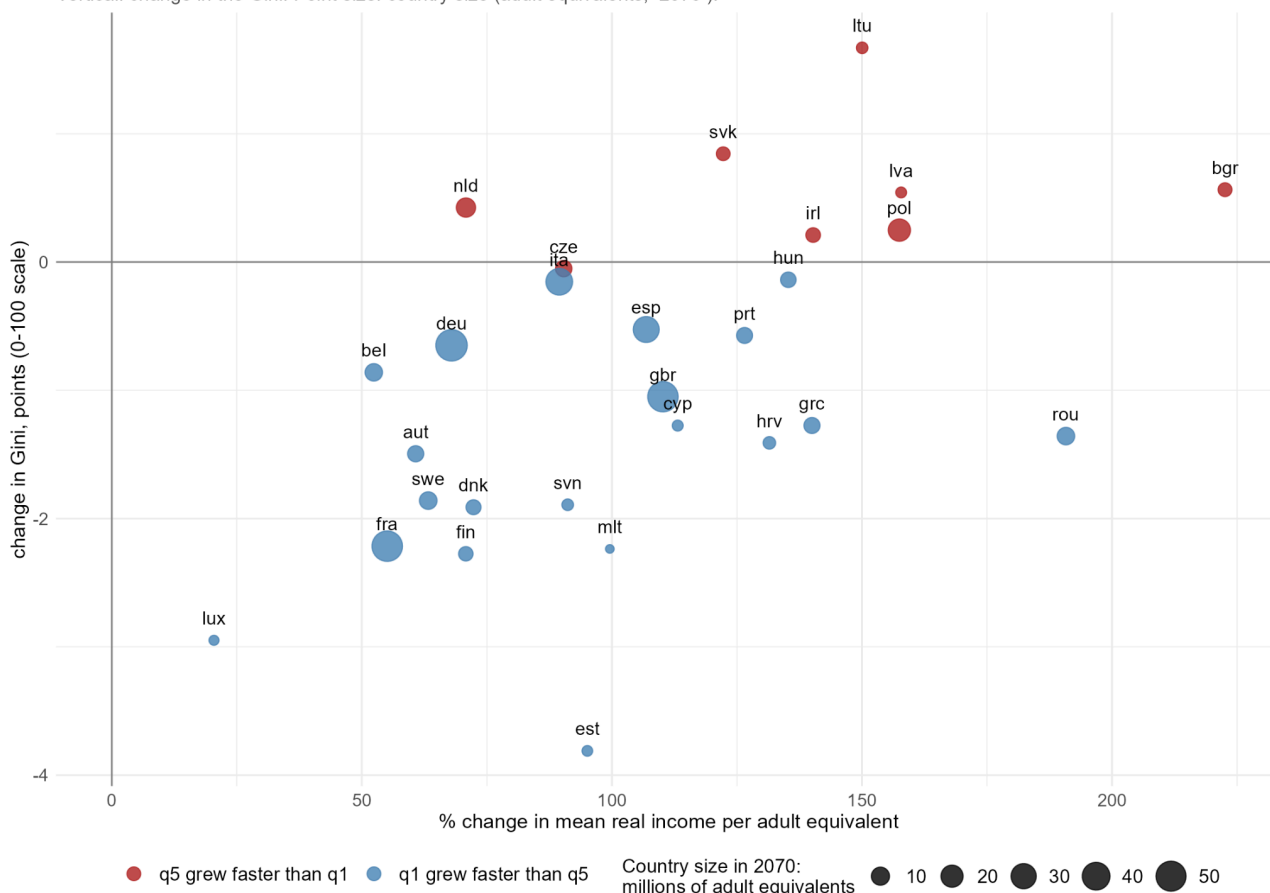


Figure 7: percentage change of average income per adult equivalent growth and change in Gini coefficient (pp) in the no climate change reference scenario

These results depend on the composition of household income in the base year and on how primary factor revenue and transfers evolve in the reference scenario. In 2017, Q1 and Q5 earn their income from different sources. Q1 income is largely determined by net government transfers, roughly 60–80% in Sweden, Finland, Belgium, Denmark, Germany and Estonia and about 30–50% in much of Central and Eastern Europe. The factor income of Q1 is mostly labour, above all unskilled labour (roughly 50–75% of it in most countries), with skilled labour and capital each making up most of the rest. Q5 income is predominantly factor income net of depreciation, usually 75–95% of the total, and that factor income is almost entirely capital, 95–100% in most countries. Q1 income therefore depends on government transfers and labour earnings, and Q5 income follows the returns to capital. Between 2017 and 2070 the composition of Q5 income changes more than that of Q1. Q5 becomes somewhat less dependent on returns to production factors and more dependent on financial income and government flows, while Q1 income stays tied to net government transfers in most countries. Where Q1 holds land or natural-resource income (Romania, Poland, Estonia, Croatia), that share rises, which supports Q1's growth.

The largest rises in inequality occur where Q5 outgrows Q1: Lithuania (about +1.7 points), Slovakia (+0.9) and, by smaller margins, Latvia and Bulgaria (about +0.5) and the Netherlands (+0.4). Q5 income in these economies is almost entirely capital income, and capital income grows faster than labour income, while Q1 relies on labour and government transfers, which

grow at a similar pace to labour. In Poland and Ireland the Gini rise is close to zero (about 0.2 points). In Western and Northern Europe, where Q1 grows slightly faster than Q5, the Gini falls by one to two points.

2.3 Results

2.3.1 Distributional implication of climate change under a severe global warming scenario

To assess the income and distributional implications of climate change, we run the model under the RCP7 scenario and compare it with the reference scenario without climate change (the no-climate-change baseline). The impacts included are sea-level rise, flooding, health, agriculture, labour, biodiversity and fire. Each impact channel is simulated separately, and each is run considering three levels of adaptation (low, reference and high). A complete description of climate change impact and adaptation channels can be found in deliverable D4.1 and D4.3 and the implemented adaptation measures are summarised in Table 3.

Table 3. Impact dimensions and adaptation levels considered in the ICES model.

Impact category	WP2 data source (model)	General configuration	Meaning Translation of adaptation levels		
			Low	Reference	High
Sea level rise (SLR)	DIVA	GCM uncertainty: 50th quantile, including migration	Constant dike heights	Constant flood protection standards	Quadrupling flood protection standards
Flooding (FLOOD)	GLOFRIS	GCM IPSL-CMSA-LR, no zoning	Constant dike heights	Constant flood protection standards	Optimal flood protection standards
Agricultural impacts (AGRI)	GLOBIOM	GCM IPSL, including RCP mitigation effects	Limited expansion of irrigation to already equipped areas	Sustainable irrigation expansion in equipped areas	Sustainable expansion of irrigation in equipped areas and conversion of rainfed areas
Labour (LAB)	Impact: Labour productivity (CMCC) Adaptation: Sectoral energy demand estimated for agricultural, industrial and commercial sectors (CMCC)	GCM uncertainty: 50th quantile	Shift in sectoral energy demand under current income and no climate change (intensive margin)	Shift in sectoral energy demand to adapt to climate change under current income (intensive and extensive margin)	Shift in sectoral energy demand under climate change and income growth (intensive and extensive margin)
	Labour supply (CMCC)	GCM uncertainty: 50th quantile	No adaptation considered (not available from sectoral modeling)		
Health (HEALTH)	Impact: Health (mortality and morbidity) Adaptation: Private household energy demand	GCM uncertainty: 50th quantile	Shift in household energy demand under current income and no climate change (intensive margin)	Shift in household energy demand to adapt to climate change under current income (intensive and extensive margin)	Shift in household energy demand under climate change and income growth (intensive and extensive margin)
Biodiversity loss	Yield shock due to	CLIM_RCP	No adaptation considered		

(BIOD)	pollination-related biodiversity loss (CMCC)	configuration: 50th quantile	
Wildfire (FIRE)	Land loss due to wildfire	GCM uncertainty: 50th quantile	No adaptation considered

For every EU27 country and the United Kingdom, we compute the real income per adult equivalent of each household quintile, deflated by a consumer price index, and the Gini coefficient. The impact of each climate channel is the percentage difference in real income per adult equivalent between the simulation and the no-climate-change baseline, by country and quintile, together with the change in the Gini in points. For clarity, results are shown at the level of four macro-regions and the EU27+UK. Country-level results are reported in Annex IIC.

Under RCP7, climate impacts reduce real income per adult equivalent in 2070 relative to the baseline for most households, but how much depends on the adaptation level (Figure 8). For the EU27+UK as a whole, net losses are largest for the middle quintiles (7.6% for Q3 with low adaptation) and smallest for the richest quintile, Q5. Q5 loses 3.3% with low adaptation and gains 0.1% and 1.0% with reference and high adaptation. The poorest quintile, Q1, loses 6.2%, 3.3% and 2.4% under low, reference and high adaptation respectively. The main source of loss is the impact on labour supply and labour productivity, which reduces income by between 2.9% (Q5, high adaptation) and 6.7% (Q3–Q4, low adaptation). It acts on both labour and capital income, and lower consumer prices cushion part of the loss. The health channel works in the opposite direction, adding between 2.1% and 4.0% to income per adult equivalent. This counterintuitive outcome derives from the modelling choice for the mortality shock, which is applied to population only, and not to employment, and does not attach any further estimated losses for the value of a statistical life. Total real income therefore changes little (about +0.3%), while the number of adult equivalents falls (by about 2.2% in the median country), so the same income, and in particular the income from capital, is shared among fewer people. A fall in consumer prices explains only a small part of the gain (about 0.4 points of a 2.9-point median gain). Flooding and sea-level rise add smaller losses of about 1.2–1.7 points for Q1–Q4 under low adaptation, which shrink substantially with adaptation. Adaptation, by reducing impacts, mitigates the outcome for all quintiles.

The EU pattern hides clear differences between regions. Central-Eastern Europe is the most exposed, with net losses of 7.6–10.2% under low adaptation. Q1 and Q2 lose the most there, and the loss falls with income up to Q4. Southern Europe follows, with losses of 4.8–8.6% and the same gradient from the poorest to the richest. In Western and Northern Europe the loss is hump-shaped, falling at both ends. The middle quintiles lose most (up to 6.5% in the West and 8.3% in the North under low adaptation), because the labour channel hits them hardest, while Q1 and especially Q5 lose less. Agriculture matters mainly in Central-Eastern Europe, where it lowers the income of Q1 and Q2 by about 1.3–1.5 points and raises that of Q4 and Q5, which adds to the regressive pattern there. With reference or high adaptation, the richest quintile (Q5) breaks even or gains in Western and Northern Europe. In Southern Europe Q5 still loses 0.5% under reference adaptation and gains 0.8% only under high adaptation. In Central-Eastern Europe it loses 2.0% under reference adaptation and only breaks even (+0.1%) under high adaptation. Even under high adaptation, the poorest quintile

(Q1) still loses in all regions, from 0.8% in Western Europe and 2.0% in Northern Europe to 3.9% in Southern Europe and 4.5% in Central-Eastern Europe.

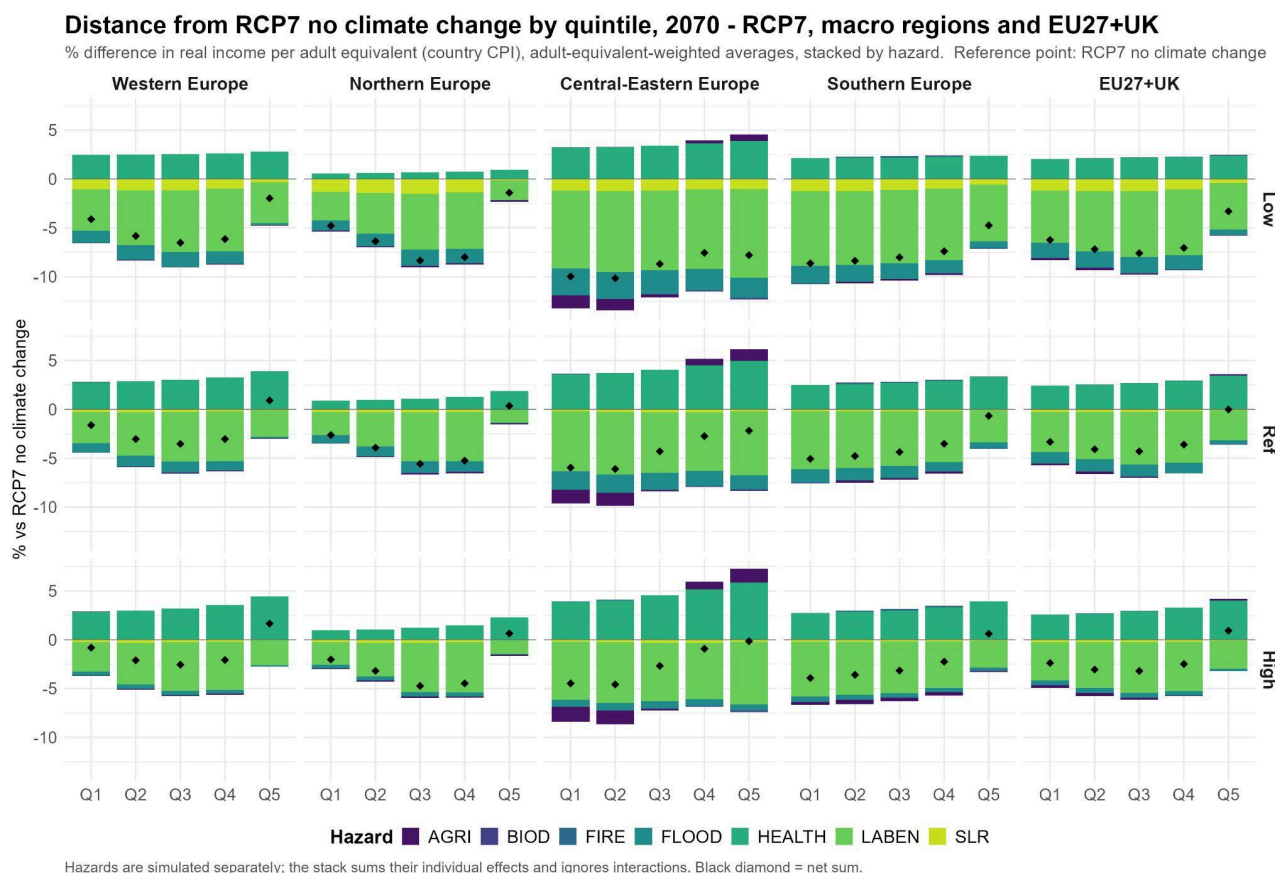


Figure 8: percentage change average income per adult equivalent growth by macroregion and quintile across impact channels and different levels of adaptation under RCP7

Figure 9 relates the change in mean real income per adult equivalent to the change in the Gini index for each country and hazard in 2070. Under low adaptation, changes in inequality are small: for most country-hazard pairs the Gini moves by less than 0.5 points, and none exceeds 1 point. The labour channel produces the largest income losses (up to about 12%) and the widest dispersion in inequality outcomes, widening inequality in some countries and narrowing it in others, depending on whether the loss falls mainly on the labour income of lower quintiles or on the capital income of higher ones. Flooding is mildly regressive, with losses of up to about 3.6% and Gini increases of up to about 0.4 points. Biodiversity loss and wildfire have negligible effects on both income and inequality, and sea-level rise matters only in a few exposed countries, where it reduces income by up to about 2% and raises the Gini by up to about 0.3 points. Agriculture matters mainly in some Central-Eastern European countries, where it widens inequality.

Adaptation reduces income losses, but it does not make the impacts less regressive. In the EU27+UK, the largest labour losses (in the third quintile) fall from 6.7% under low adaptation to 5.4% and 5.2% under reference and high adaptation, respectively. The increase in the Gini is not reduced, however: it is 0.51 points with low adaptation and 0.57 with reference and high adaptation, so adaptation, if anything, slightly increases the regressive effect. The channels move in opposite directions. Adaptation removes the regressive effect

of flooding and sea-level rise, whose contributions to the Gini fall from 0.16 to 0.04 points and from 0.12 to 0.03 points, respectively. But it increases the regressive effect of the labour channel (from 0.14 to 0.21 points) and of the health channel (from 0.05 to 0.21 points), because the richest quintile gains more from adaptation than the poorest. In both cases, adaptation measures imply a shift in energy demand that raises capital returns, which are concentrated in Q5, while the poorest quintile depends mainly on unskilled labour income, which recovers less. The regressive and progressive channels largely cancel each other, leaving the overall increase in inequality unchanged or slightly larger.

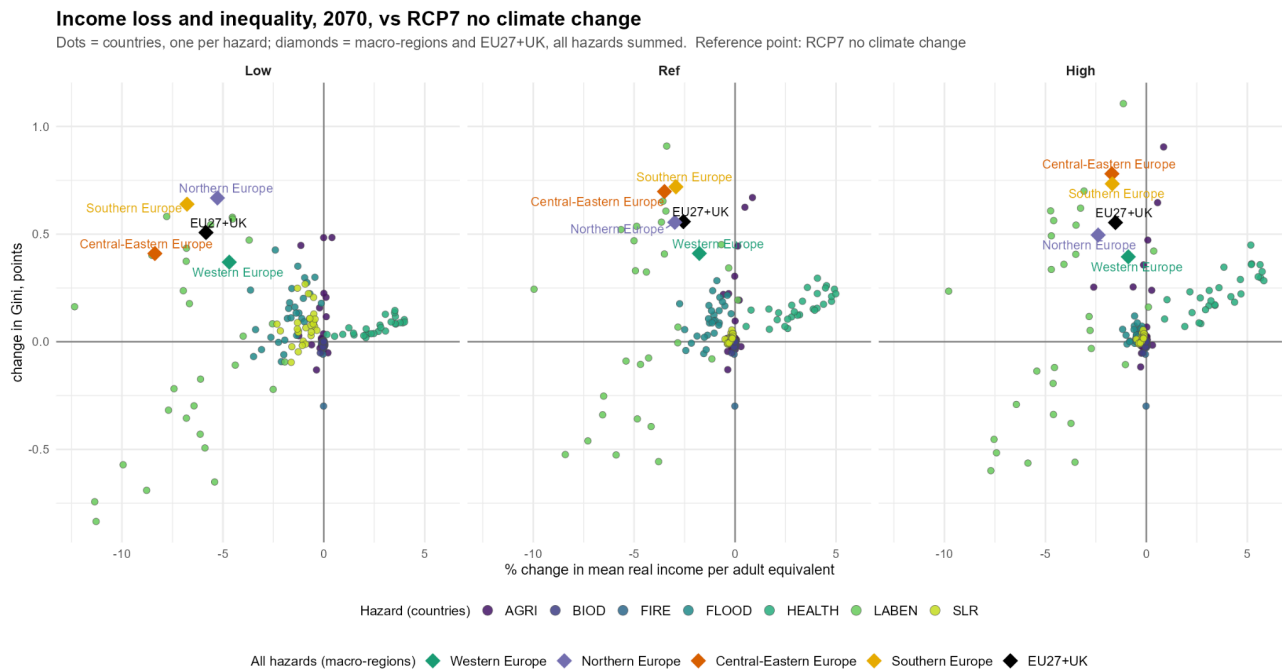


Figure 9: percentage change of average income per adult equivalent growth and change in Gini coefficient (pp) across different impact channel scenarios (RCP7) with respect to the no climate change scenario

2.3.2 Distributional implication of climate change under a medium global warming scenario

This section compares the distributional effects of a medium climate change scenario, consistent with RCP4.5, to the same scenario without climate change. The scenario is achieved through a policy mix of energy-efficiency improvements and a global carbon tax, which reduces global CO₂ emissions to about 30 Gt in 2070. The carbon tax revenues are not recycled to the economy but flows to the government income and contribute to reducing the net borrowing. Lower emissions imply lower climate change impacts than in the RCP7 baseline, and these are assessed under the three adaptation levels (low, reference and high), as in the previous section. All country-level results are reported in Annex IID.

The first important result is the progressive effect of the mitigation policy by itself, relative to the reference scenario without climate change. Its two components work in opposite directions. The efficiency improvement raises real income per adult equivalent by about 0.7% on average by 2070, with the largest gain for the poorest quintile (+1.2% for Q1, against +0.8% for Q5), and it lowers the consumer price level by about 2.3%. The carbon tax raises consumer prices by about 2.3%, and the increase is almost the same for all quintiles. It lowers real income per adult equivalent by about 1% for Q1 and 4.0% for Q5 (–2.1% on

average). Since prices rise by the same amount for everyone, the difference between quintiles does not come from what households pay for goods but from what they earn: the tax reduces the income of the richest quintile much more than that of the poorest. Taken together, the mitigation policy lowers mean real income per adult equivalent in the EU27+UK by 1.3% by 2070 (Western Europe -2.0%, Northern -1.3%, Southern -1.1%, Central-Eastern Europe +0.1%), but it is progressive: Q1 gains 0.3% and Q5 loses 3.3%, and the Gini falls by 0.50 points (grey bars in Figure 10). The pattern is consistent with the tax reducing returns to capital and resource rents, which are concentrated in the top quintile.

This result derives from the fact that ICES-MH captures the implication of the mitigation policy both on the source and use side. According to the literature, the uses side is regressive; carbon pricing raises the price of energy and carbon-intensive goods, and poorer households spend a larger share of income on them. This is the standard result in partial-equilibrium and microsimulation studies for the EU (Maier et al., 2024). On the sources side, carbon pricing changes wages, capital returns and resource rents, and richer households depend more on capital income, so the tax is progressive. General-equilibrium models that include both sides often find the source side dominates (Rausch et al., 2011; Goulder et al., 2019). To summarize, ICES-MH results are progressive for two reasons. First, the model includes the sources side, with endowments differing across quintiles. Second, transfers are fixed and the price index is the same for all quintiles (country CPI), so the regressive uses-side is smoothed.

On top of the mitigation scenario, we add the climate impacts consistent with RCP4.5 and the adaptation measures. Figure 10 compares the combined results with the reference scenario without climate change, and separates the contribution of mitigation (grey bar) from that of each hazard, measured against the mitigation-only run. By 2070 the EU27+UK suffers a net loss of mean real household income per adult equivalent of 4.3% with low adaptation, 1.9% with reference adaptation and 1.2% with high adaptation. Mitigation alone accounts for 1.3 percentage points of this. The hazards add -3.0%, -0.6% and +0.1%, as losses and gains offset each other. Labour productivity (-3.5, -2.6 and -2.6%) and flooding (-1.0, -0.8 and -0.3%) lower income. Sea-level rise lowers it under low adaptation (-0.7%) and is close to zero at higher levels (-0.2 and -0.1%). Agriculture is close to zero (-0.1% to 0.0% across levels). Health raises income (+2.2, +2.9 and +3.2%), but this mainly reflects a smaller population and so a higher income per adult equivalent, and is not a welfare gain. The RCP7-consistent hazards, shown as black triangles, imply larger losses across the EU (-5.8, -2.6 and -1.5% under low, reference and high adaptation), so the RCP4.5 pathway reduces the total loss by about 1.5, 0.6 and 0.3 percentage points respectively. Adaptation substantially reduces the income losses, but with diminishing returns. Moving from low to reference adaptation cuts the net EU loss in mean real income per adult equivalent from 4.3% to 1.9%, and high adaptation brings it to 1.2% (Figure 10).

In the EU27+UK in 2070, the total effect relative to the scenario without climate change is U-shaped across quintiles, with the middle of the distribution worse off, as we observed also in the RCP7 scenario. With low adaptation the loss is about 3.9% for Q1, 4.5% for Q2, 5.0% for Q3 and Q4, and 3.4% for Q5. The pattern holds with reference and high adaptation, and adaptation shrinks the losses of every quintile but does not change their ranking. Two opposite distributional forces combine. Mitigation is progressive (Q1 +0.3%, Q5 -3.3%). The hazards alone are regressive: with low adaptation they cost Q1 to Q4 about 4 to 5% and Q5 almost nothing (-0.1%), and with reference and high adaptation they leave Q5 slightly better

off (+1.8 and +2.1%). Labour productivity is the main driver. It lowers income by about 4% for Q2 to Q4 but by about 2.2% for Q5 under low adaptation. Flooding and sea-level rise are also concentrated in Q1 to Q4 (about -1 to -1.6% each, against about -0.1% and 0.0% for Q5). The health term is roughly uniform across quintiles (about +2.1 to +2.3%), and agriculture is negligible.

Central-Eastern Europe has the weakest outcome under low adaptation (about -6% for Q1 and Q2 and -4.4% for Q5), driven by labour productivity (-5 to -5.5%) and flood (-1.8 to -2.6%) losses that outweigh the health term (+3.4 to +3.9%). Adaptation improves all quintiles, but unevenly: with reference and high adaptation Q4 and Q5 move to about zero or above (Q5 +0.4% and +2.2%), while Q1 and Q2 stay negative (-2.5% and -1.0%). The gap between the top and the bottom quintile therefore widens, mainly because agriculture loses for Q1 and Q2 and gains for Q4 and Q5, and because the health term is larger for the top quintile. Western Europe moves from losses of about 2 to 4.5% across the distribution with low adaptation to near zero for Q1 with reference adaptation (-0.2%) and a small gain with high adaptation (+0.5%). With reference adaptation the upper quintiles still lose 1.4 to 2.2%, and the Q5 loss is essentially the cost of mitigation (-4.5%), partly offset by the hazards. Northern Europe has the largest middle-class losses under low adaptation (Q3 and Q4 about -6.3 and -6.4%, against -3.9% for Q1 and -3.2% for Q5). Southern Europe has near-uniform losses of about -5% for Q1 to Q4 and -3.8% for Q5, which ease to about -2.4% (Q5 -1.7%) with reference adaptation.

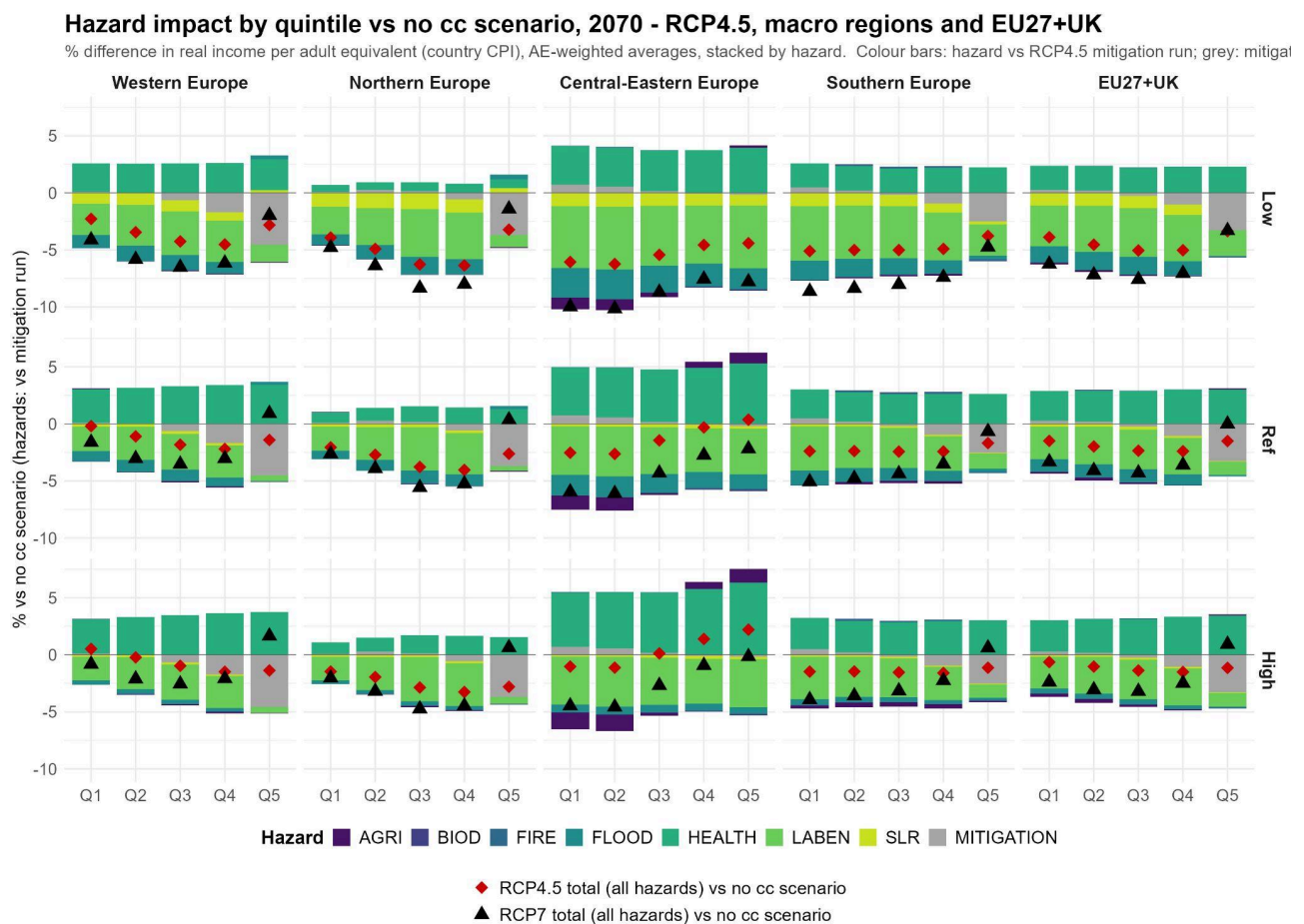


Figure 10: percentage change average income per adult equivalent growth by macroregion and quintile across impact channels and different levels of adaptation under RCP4.5 compared to the no climate change reference scenario

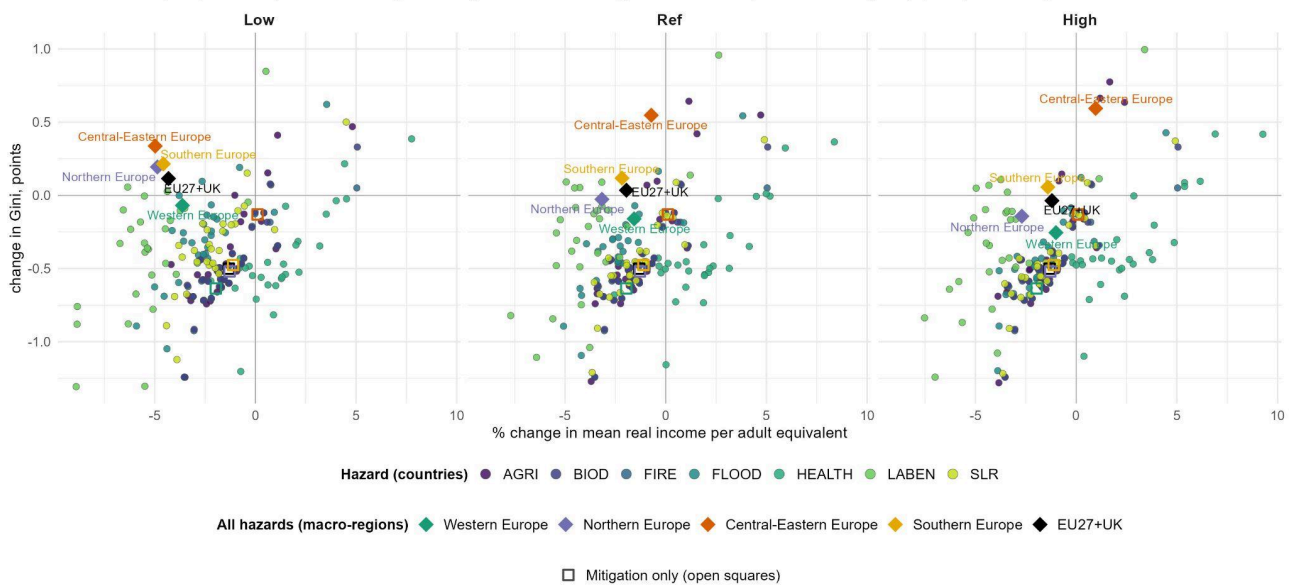
Figure 11 relates the change in mean real income per adult equivalent to the change in the Gini by 2070 under RCP4.5, relative to the scenario without climate change. Each country dot is the RCP4.5 result for one hazard (mitigation plus that hazard), the open squares are the mitigation policy alone, and the diamonds are the RCP4.5 totals of the macro-regions and the EU27+UK (mitigation plus all hazards). Mitigation alone lowers income and reduces inequality (in the EU27+UK by 1.3% and 0.5 Gini points, respectively). The hazards then lower income further and raise inequality, so the totals combine an equalising mitigation effect with a regressive hazard effect.

With low adaptation all regions lose income, and the Gini change is small (regressive): +0.11 points in the EU27+UK, positive in Central-Eastern Europe (+0.34), Northern (+0.19) and Southern Europe (+0.21), and slightly negative in Western Europe (−0.07). Stronger adaptation moves the diamonds to the right and, in most regions, downwards (progressive). In the EU27+UK the Gini change falls to +0.03 and −0.04 points, so with high adaptation the hazards no longer offset the equalising effect of mitigation, and in Western and Northern Europe the Gini falls below its no climate change level. Central-Eastern Europe is the exception: its Gini change rises with adaptation (+0.55 and +0.59 points) and it is the only region with an income gain at high adaptation.

Focusing on the country results per hazard, each dot combines the effect of the hazard with that of mitigation. Mitigation lowers the Gini in 26 of the 28 countries, so for every hazard the Gini change of the dots is negative in most countries. The exceptions are Greece and Poland, where mitigation itself raises inequality and the dots stay positive for every hazard. A few other countries show an increase, mainly with labour productivity (Cyprus, Malta, Portugal and Romania), agriculture (Czechia, Latvia and Romania) and health (Bulgaria, Czechia and Romania). For the hazards with small effects (fire, biodiversity, sea-level rise and, mostly, agriculture), the dots lie close to the mitigation outcome of their country, so their scatter mainly reflects how unevenly mitigation affects countries. Labour productivity is the most dispersed hazard, moving dots to the left with Gini changes of both signs. Health moves dots to the right, mainly because of the smaller population, and it is slightly regressive, more so with stronger adaptation. Flooding moves dots to the left, mostly under low adaptation.

Income loss and inequality vs no cc scenario, 2070 - RCP4.5

Dots = countries, one per hazard (each includes mitigation once); diamonds = macro-regions and EU27+UK, all hazards + mitigation; open squares = mitigation alone. All vs the no cc scenario



Open squares = mitigation alone (RCP4.5 carbon tax + efficiency vs no cc), the same in the three panels.
Dot minus square of the same region = effect of that single hazard; diamonds = mitigation + sum of the hazards (interactions ignored).

Figure 11: percentage change of average income per adult equivalent growth and change in Gini coefficient (pp) across different impact channel scenarios (RCP4.5) with respect to the no climate change scenario

2.4 Conclusions

This chapter presents ICES-MH, an extension of the ICES-XPS model in which the private household is disaggregated into five income quintiles for each country. Because each quintile has its own endowments of primary factors, its own share of government transfers and its own consumption basket, the model makes it possible to disentangle the distributional effects of climate shocks and policies across different types of households. It is applied to examine how the costs of climate change are distributed across households in the EU27 and the United Kingdom, and whether mitigation and adaptation policies alter that distribution.

Under RCP7, climate impacts reduce real income per adult equivalent in 2070 for most households. Labour supply and productivity are the main source of loss, and the loss falls most heavily on the middle quintiles. Adaptation reduces the losses of every quintile, but it does not make the impacts less regressive. It removes the regressive effect of flooding and sea-level rise, but raises that of the labour and health channels, so the EU Gini increase is about 0.5 points whatever the level of adaptation.

Mitigation in the RCP4.5 pathway lowers mean real income in the EU27+UK by 1.3% by 2070, but it is progressive: the poorest quintile gains slightly, the richest loses 3.3%, and the Gini falls by 0.5 points. Consumer prices rise almost equally for all quintiles, so the progressive effect comes from the income side, with lower returns to capital and resource rents hitting the top quintile.

Adding the RCP4.5 hazards on top of mitigation, the EU27+UK loses 4.3%, 1.9% and 1.2% of mean income with low, reference and high adaptation, of which mitigation accounts for 1.3 points. RCP4.5 reduces the loss relative to RCP7 by about 1.5, 0.6 and 0.3 points. The two policies pull in opposite directions on inequality: hazards are regressive and mitigation is

progressive. With low adaptation the Gini rises slightly, while with high adaptation it falls slightly, and in Western and Northern Europe it falls below its no-climate-change level. Central-Eastern Europe is the exception: its Gini change rises with adaptation, because the richest quintile gains much more than the poorest.

The analysis highlights five main points for policy. First, climate impacts weigh most on the middle of the income distribution. Under both RCP7 and RCP4.5 the largest losses fall on the central quintiles, whose income depends heavily on labour earnings. Schemes that return carbon-tax revenues to households, such as the EU Social Climate Fund, are directed to vulnerable households, and the results suggest that their design should also reach the middle quintiles, otherwise a large part of the loss remains uncovered. Second, adaptation reduces the size of the losses for every quintile but does not change their distribution: the labour and health channels become more regressive as adaptation increases, because the resulting shift in energy demand raises capital returns, which accrue mainly to the richest quintile. Adaptation therefore needs to be designed so that its benefits reach lower-income households and workers, for instance by supporting their access to adaptation measures (such as cooling in homes and workplaces) or by redistributing part of the gains, instead of relying on market-driven adjustment alone. Third, mitigation by itself is not regressive in this framework, since the carbon tax lowers capital returns and resource rents, which are concentrated in the top quintile. Its income cost is nevertheless substantial for the richest quintile and for Western Europe. Fourth, when mitigation, hazards and adaptation are combined, the outcome for inequality depends on adaptation. Mitigation reduces inequality while the hazards increase it, so with low adaptation the hazards slightly outweigh mitigation and inequality rises, whereas with high adaptation the effect of mitigation prevails and inequality falls slightly. Fifth, there is a regional divide. With strong adaptation, Western Europe becomes more equal and its poorest quintile gains, whereas in Central-Eastern Europe inequality rises because the richest quintile gains much more than the poorest, and in Northern and Southern Europe the poorest quintile still loses about 1.5% of income. Compensation policies may therefore need to be adapted to the regional pattern of losses, not applied uniformly across the EU.

These conclusions should be read in light of the model's limitations, which affect the results in specific ways. The first concerns the measurement of inequality. The Gini coefficient retains within-quintile dispersion at its 2017 value, so it captures only between-quintile effects. The changes reported are therefore a lower bound, especially at the top of the distribution, where much of observed inequality lies, and the small Gini changes of the combined RCP4.5 results should be read as the direction of the effect more than its size.

The second concerns the progressive effect of mitigation, which is the result most sensitive to the model's assumptions. All quintiles are deflated by a single country-level consumer price index, and government transfers are a fixed share of government income. Poorer households spend a larger share of their income on energy and food, so a quintile-specific price index would probably reduce the progressivity of the carbon tax and make its effect on the poorest households less favourable.

The third concerns the health channel. The mortality shock is applied to the population but not to employment, and lost life years are not valued. The income gain per adult equivalent that results is therefore not a welfare gain, and the net losses reported in the totals are lower

than the corresponding welfare losses. This also affects the distributional results, since the health term raises the Gini slightly under strong adaptation.

The fourth concerns the treatment of uncertainty. Hazards are simulated one at a time and summed without interactions, so the totals approximate the combined effect, which could be larger or smaller if several hazards hit the same households. Climate impacts are also based on the median climate model projection (50th percentile) for each hazard, so the range of possible outcomes is not explored. Results should therefore be read as central estimates.

3 Within-country distributional effects of flood risk (financing): a case study for Austria

UNI GRAZ contributors: Eva Preinfalk, Gabriel Bachner, Nina Knittel

3.1 Introduction

Climate change is increasing the frequency and severity of extreme weather events, leading to growing economic losses and placing greater pressure on households, governments and insurance systems. While investments in climate adaptation can effectively reduce damages, residual risks remain inevitable, making effective flood risk financing an increasingly important component of climate adaptation strategies. Beyond ensuring recovery after disasters, the design of flood risk financing mechanisms has important implications for within country equity and justice. As government budgets become increasingly constrained and discussions on mandatory natural hazard insurance gain momentum across Europe, understanding who ultimately bears the costs of climate-related disasters has become a key policy question.

Recent research provides evidence that climate change may exacerbate within-country inequality, with low-income households often being disproportionately affected by climate-related risks and necessary responses to them (Paglialunga et al., 2022, Campagnolo et al., 2023). Evidence from the 2021 floods in Germany further shows that flood exposure itself is unevenly distributed, with poorer neighbourhoods facing substantially higher flood risk than wealthier areas (Odersky & Löffler, 2024). At the same time, risk-based insurance schemes can create affordability challenges for vulnerable households, potentially limiting uptake (Kousky & Kunreuther, 2014; Tesselaar et al., 2020) and increasing reliance on the government as insurer of last resort. Despite growing recognition of these distributional issues, relatively little is known about how alternative flood risk financing arrangements affect welfare and inequality once both direct and economy-wide indirect effects are taken into account.

ACCREU addresses this gap by analysing the distributional implications of alternative flood risk financing schemes for Austria. The analysis combines spatially explicit flood risk projections with a recursive-dynamic computable general equilibrium (CGE) model that distinguishes households by income, location and flood exposure (the detailed model setup is explained in milestone 4.2). Flood damages from GLOFRIS are allocated to household groups based on their spatial exposure and represented as reconstruction expenditures that reduce welfare-relevant consumption. Three alternative financing schemes are considered: i) a risk-based scheme in which exposed households bear recovery costs, ii) a government co-financing scheme in which part of the reconstruction costs is covered by the public sector, and iii) an income-based solidarity scheme that distributes recovery costs across all households according to their ability to pay. By comparing these financing arrangements, the analysis evaluates how the allocation of disaster recovery costs influences household welfare, inequality and broader macroeconomic and fiscal dynamics.

3.2 Method

The analysis combines spatially explicit flood risk projections with a recursive-dynamic CGE model of the Austrian economy to assess the distributional implications of alternative flood risk financing schemes (Figure 12).

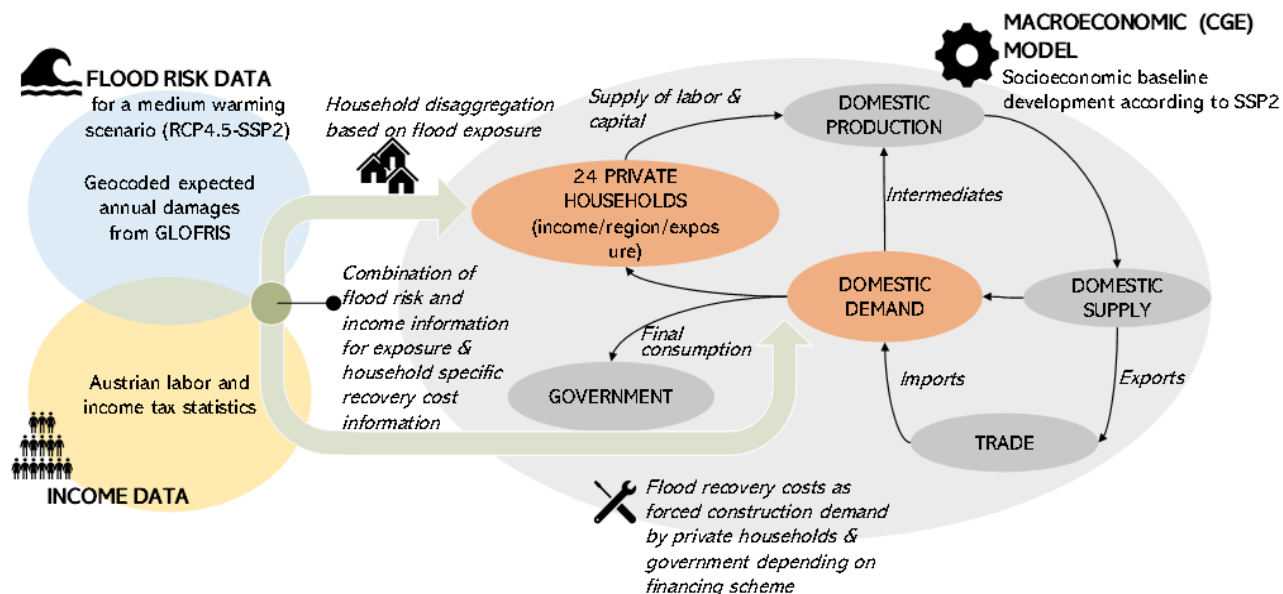


Figure 12: Overview of the integrated modelling framework. Flood risk projections from GLOFRIS are combined with spatial income data to allocate expected annual flood damages to representative household groups. Household-specific recovery costs are introduced into a recursive-dynamic CGE model as compulsory reconstruction demand, enabling the analysis of direct and indirect impacts under alternative flood risk financing schemes.

Flood risk information is obtained from GLOFRIS (WP2), which provides expected annual damages (EAD) from riverine flooding at 1km spatial resolution under different climate and socioeconomic scenarios. In this study, the medium warming pathway (SSP2-4.5) is used. Relative grid-level damage shares are combined with the CGE model baseline, ensuring that absolute flood damages evolve consistently with the socioeconomic assumptions used throughout the economic analysis.

To spatially link recovery cost estimates with the Austrian population, we use high resolution microdata derived from the Austrian labour and income tax statistics (Statistics Austria, 2022). Combining these data with the GLOFRIS flood maps allows annual recovery costs to be assigned to households according to both their income level and flood exposure.

The resulting household-specific recovery costs are introduced into the CGE model as compulsory reconstruction expenditures. While reconstruction stimulates economic activity through additional demand for the construction sector, it reduces households' welfare-relevant consumption by diverting resources from other consumption activities. This framework allows us to capture both the direct impacts on affected households and the indirect economy-wide effects transmitted through prices, production, labor markets and public finances.

To analyze distributional impacts, the model distinguishes 24 representative household groups based on three dimensions: income quartile, settlement type (urban, suburban, rural) and flood exposure (exposed versus non-exposed). Spatially matching flood risk information with geocoded income and population statistics makes it possible to identify both households directly exposed to flooding and those affected only through indirect economic adjustments. This representation enables the analysis of how flood damages and recovery costs propagate across different income groups and regions.

We distinguish three alternative flood risk financing arrangements:

1. A **risk-based financing scheme**, where exposed households bear the full cost of reconstruction.
2. A **government-supported financing scheme**, where 25% of recovery costs are covered by the public sector, reflecting the Austrian Katastrophenfonds.
3. A **solidarity-based financing scheme**, which distributes recovery costs across all households according to their income, irrespective of flood exposure.

3.3 Results

3.3.1 Incidence of flood recovery across risk financing schemes

Figure 13 illustrates the evolution of the welfare effects resulting from direct flood exposure and indirect effects caused thereof under socioeconomic development and climate change (SSP2-4.5). It represents the risk-based financing scenario, in which households located in flood-exposed areas bear their recovery costs entirely, without any public compensation or redistribution. As expected annual flood damages (EAD) increase over time, welfare losses become larger across all household groups. Directly exposed households experience substantially larger effects than non-exposed households, although among Q1-Q3 of the latter also incur welfare losses through indirect economy-wide effects transmitted via relative price changes, production and factor markets. Non-exposed highest income households (Q4) gain from relative factor price changes. Welfare losses are generally largest in rural areas, reflecting higher absolute flood damages associated with lower protection levels. Rural low income (Q1) households in flood zones lose up to almost 7% of welfare due to flood recovery payments by 2080. This effect reduces along income quartiles, and reduces to around 3% for Q4 households. Within each region, the strongest welfare losses occur for the lowest-income households, indicating that flood impacts are regressive.

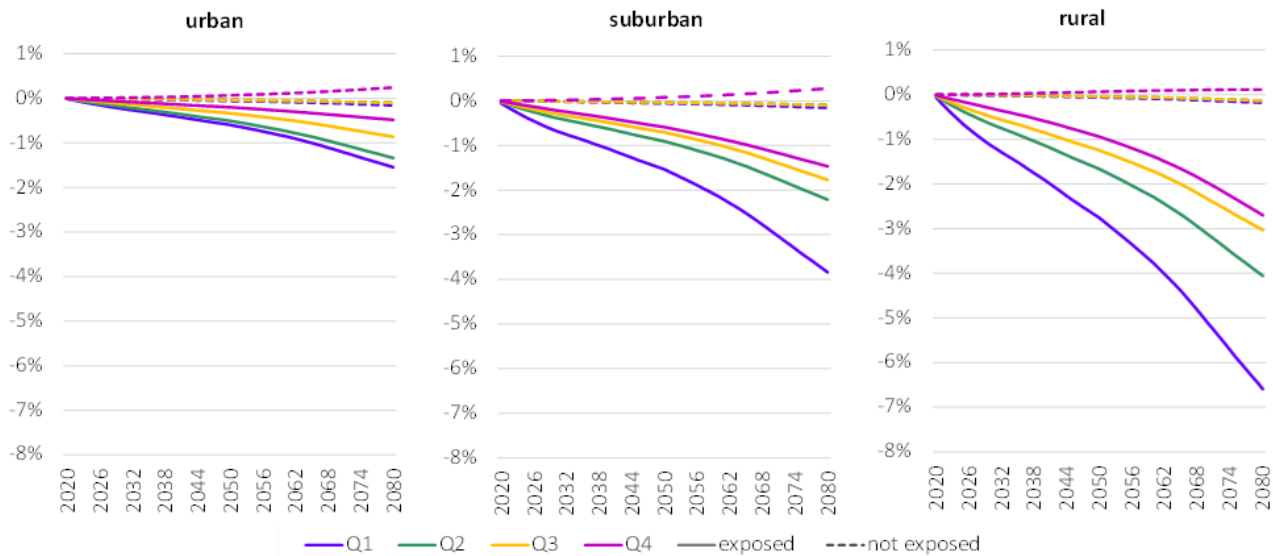


Figure 13: Welfare effect of flood risk under the risk-based financing scenario for urban, suburban and rural Austrian households (SSP2-4.5). Solid lines denote households directly exposed to flood risk, while dashed lines represent non-exposed households affected only through indirect economy-wide effects. Colours indicate income quartiles (Q1-Q4). Welfare changes are expressed relative to the baseline without climate change.

While regional differences are primarily explained by variations in direct flood exposure, the persistent differences across (not) exposed income quartiles motivate the comparison of alternative risk financing schemes across income groups, considering alternative distributions of recovery costs across households.

Figure 14 decomposes the welfare effects in 2080 into their main income components for exposed and non-exposed households under the three flood risk financing schemes. Bars show absolute per-capita changes in household income from transfers, labour and capital income and flood recovery expenditures, while the dashed line shows the resulting relative welfare change. The figure summarizes results across regions and therefore focuses on differences between income quartiles and direct versus indirect flood exposure.

In the **risk-based financing scheme**, directly exposed households experience welfare losses primarily due to flood recovery expenditures, which divert resources away from welfare-enhancing consumption towards reconstruction to recover the pre-flood status. In addition, labour incomes decline as reconstruction increases the demand for the relatively capital-intensive construction sector, reducing the return to labour. Although capital becomes relatively more valuable, exposed households are unable to fully benefit from higher capital returns because repeated reconstruction reduces their savings and therefore their capital accumulation over time. Transfer income also declines slightly, reflecting lower public revenues in the model. Consequently, the welfare effects are regressive, with lower-income households experiencing larger relative welfare losses than higher-income households. As a result, by 2080, annual welfare losses from flood recovery amount to approximately EUR 400 per capita in Q1 households and almost EUR 600 EUR per capita for those in the highest income quartile (Q4). Despite these higher absolute costs for wealthier households, the welfare effects are strongly regressive because recovery expenditures represent a much larger share of available resources for low-income households. Consequently, relative welfare losses amount to around 3% for Q1, compared with only 1% for Q4.

For non-exposed households, no direct reconstruction costs arise. Instead, welfare changes are entirely driven by indirect economy-wide effects. Higher capital returns benefit high income households with greater capital ownership, while lower labour income predominantly affects lower-income households. As a result, the indirect impacts are likewise regressive, with Q4 households experiencing a net welfare gain of EUR 120 per capita by 2080, whereas Q1 households face losses of EUR 25 per capita, compared to a scenario without flood damages.

Under the **government supported financing scheme** the underlying economic mechanisms remain largely unchanged, but the partial public compensation reduces the burden on directly exposed households. Assuming that the government covers one-quarter of recovery costs, absolute welfare losses decline to approximately EUR 300 per capita for Q1 households and EUR 400 per capita for Q4 households by 2080. Although public compensation lowers the overall welfare losses across all exposed households, the relative burden remains concentrated among the lower income quartiles. Government support therefore alleviates the welfare impacts of flooding but does not reduce their regressive distribution.

For non-exposed households, welfare effects remain largely unchanged compared with the risk-based financing scheme. As these households are affected only through indirect economy-wide adjustments, the underlying mechanisms remain the same. Reconstruction demand is unchanged, but part of its financing is shifted from exposed households to the government sector, resulting in only minor changes in the indirect welfare effects.

In the **solidarity-based financing scheme**, flood recovery costs are shared across all households according to their income, irrespective of whether they are directly exposed to flooding. As a result, the recovery burden is redistributed from exposed to non-exposed households and increases with income. Consequently, the regressive pattern observed under the previous financing schemes largely disappears. By 2080, directly exposed households in the lowest income quartile incur annual welfare losses of about EUR 60 per capita, while the corresponding burden increases to EUR 240 per capita in the highest income quartile. In contrast to the risk-based and government-supported financing schemes, higher-income households therefore bear a larger share of the recovery costs in both absolute and relative terms, substantially reducing the welfare losses experienced by low-income households.

For non-exposed households, recovery costs are no longer limited to indirect economy-wide effects but also include direct financial contributions to flood reconstruction through the solidarity scheme. Consequently, welfare declines across all income quartiles compared with the previous financing schemes. However, as additional contributions are distributed according to households' ability to pay, the resulting burden is progressive. Overall, the solidarity-based financing scheme substantially reduces the welfare losses of directly affected households, particularly in the lower income quartiles, by spreading reconstruction costs across the society as a whole.

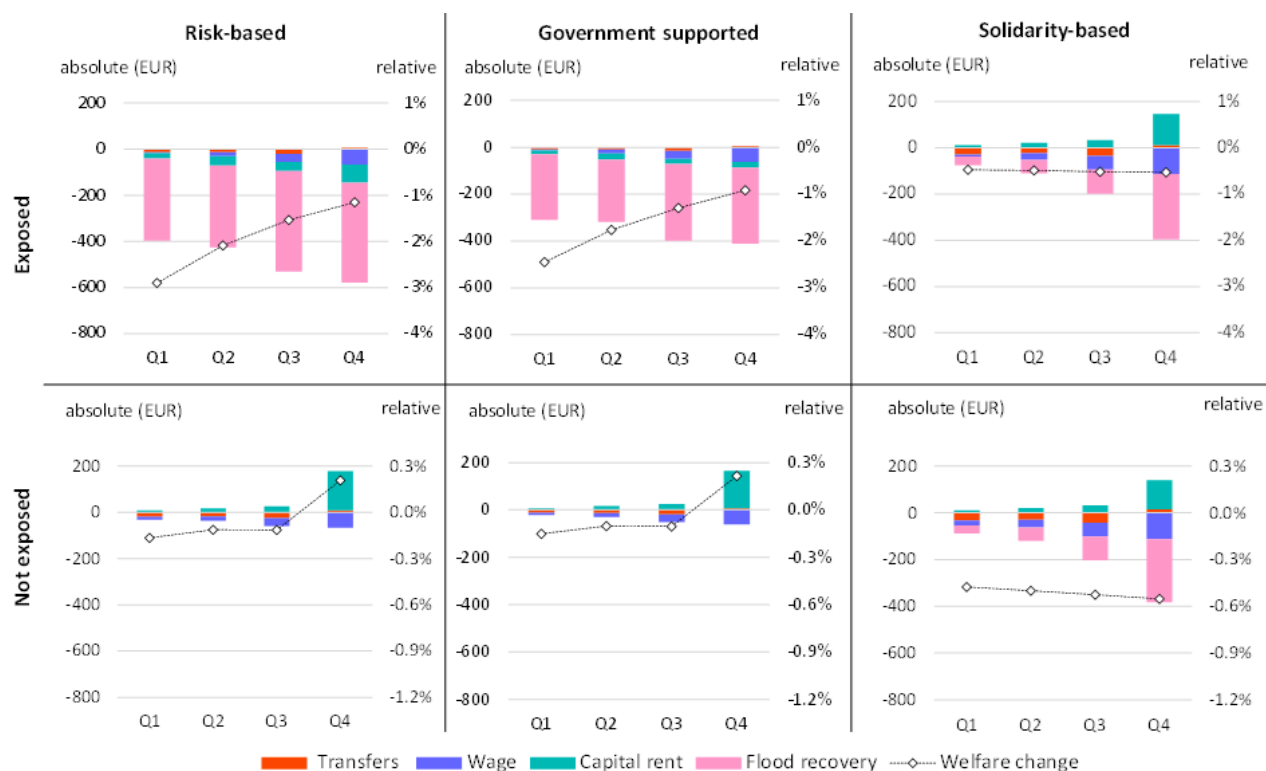


Figure 14: Decomposition of Austrian household welfare effects by income source and flood recovery costs in 2080 under alternative flood risk financing schemes for SSP2-4.5. Bars show absolute per-capita changes (EUR) in transfers, labour income (wage), capital income (capital rents) and flood recovery expenditures, relative to the baseline. The dashed line indicates the resulting relative welfare change. Upper panels show households directly exposed to flooding, while lower panels show non-exposed households affected only through indirect economy-wide effects.

3.3.2 Private welfare and within-country inequality

While Figure 14 presented the household level welfare effect for an understanding of how effects are composed across financing schemes, Figure 15 illustrates how these effects evolve through 2080 with socioeconomic and climate change according to SSP2-4.5. The figure 16 illustrates the effects on aggregate household welfare and within-country inequality under the three alternative risk financing schemes. Aggregate welfare losses reflect changes in overall household consumption opportunities, while equal-weighted welfare losses assign the same importance to each income quartile. The difference between the two measures (shaded in light yellow) therefore captures the extent to which flood impacts are distributed unequally across income groups. The grey line shows the corresponding change in the GINI coefficient, illustrating how alternative financing mechanisms influence the evolution of within-country welfare inequality over time.

Under the risk-based financing scheme, aggregate welfare losses gradually increase over time, reaching 0.48% by 2080. Equal-weighted welfare losses are 0.1 percentage points higher, reflecting the disproportionate welfare burden borne by lower-income households. The growing gap between aggregate and equal-weighted welfare losses therefore confirms that flood impacts are distributed regressively, with lower-income households experiencing substantially larger welfare losses in relative terms. This is also reflected in the evolution of the GINI coefficient which increases by approximately 0.04% relative to the flood impact baseline, indicating a deterioration in within-country welfare inequality.

Under the government-supported financing scheme, aggregate welfare losses are lower than under risk-based financing, as part of the recovery costs is absorbed by the government, reducing the disruption to private consumption. By 2080, aggregate welfare losses amount to 0.35% compared to 0.43% on an equal-weighted basis. Similar to the risk-based scenario, the persistent gap between the two welfare metrics indicates that the remaining burden continues to fall disproportionately on lower-income households. This is also reflected in the GINI coefficient, which increases by around 0.04% relative to the no-flood baseline. Government support therefore reduces the overall welfare costs of flooding but has only a limited effect on the distributional inequality of these impacts, as the relative welfare burden remains concentrated among lower-income households.

Under the solidarity-based financing scheme, aggregate welfare losses reach 0.52% by 2080. In contrast to the risk-based and government-supported schemes, however, aggregate and equal-weighted welfare losses almost coincide throughout the simulation period. This indicates that welfare losses are distributed more evenly across income quartiles, as recovery costs are shared across the entire population according to households' ability to pay rather than flood exposure. Consequently, the increase in within-country inequality is eliminated, with the GINI coefficient remaining close to its baseline level. The results therefore suggest that the solidarity-based financing does not reduce the overall welfare costs of increasing flood risk, but it substantially changes the distribution preventing flood recovery costs from disproportionately burdening lower-income households.

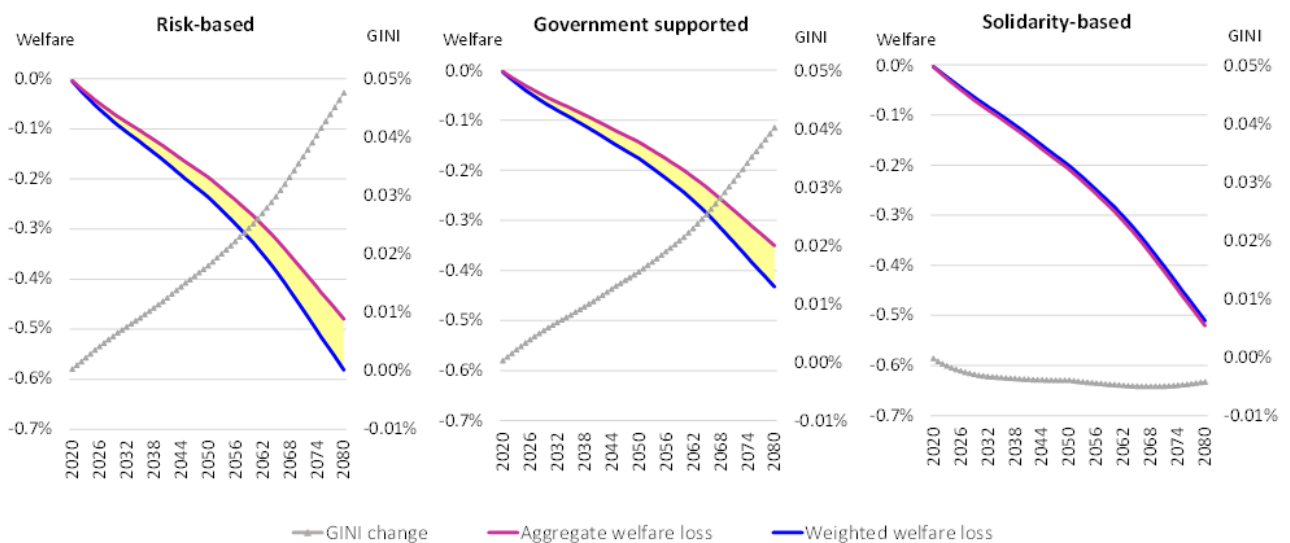


Figure 15: Changes in Austrian household welfare and within-country inequality under alternative flood risk financing schemes. Changes in the GINI coefficient measures changes in the welfare distribution across the four income quartiles relative to the baseline trajectory. Aggregate welfare loss represents changes in private consumption levels relative to the baseline. Weighted welfare loss assigns equal weight to the relative welfare losses of each income quartile. The shaded area (light yellow) between the two welfare measures indicates the distributional component of aggregate welfare loss.

3.3.3 Macro-fiscal trade-offs

Figure 17 highlights that the choice of the flood risk financing scheme also involves important macroeconomic and fiscal trade-offs. Although all financing mechanisms generate

similar aggregate welfare losses, they differ considerably in their macroeconomic and fiscal effects.

The government-supported scheme performs most favourably in terms of GDP, reducing GDP by 0.09% by 2080 relative to the no flood impact baseline. By partially compensating households for flood recovery costs, it reduces the disruption of private consumption and investment decisions, thereby supporting capital accumulation and long-term economic activity. However, this comes at the expense of public finances. As government resources are redirected towards flood recovery, government consumption declines over time by 0.47%, making this the least favourable option from a fiscal perspective.

In contrast, the risk-based financing scheme places the full burden of reconstruction on directly affected households. While this leads to stronger distributional inequalities, it preserves government consumption because no public resources are required for compensation. Thus, losses in government consumption stem from second round effects only, amounting to 0.15%. With 0.13% of relative loss, GDP outcomes are less favourable than under government support

Solidarity based financing performs least favourably in terms of GDP, with losses accruing to 0.17%. By distributing reconstruction costs across all households, it reduces aggregate savings and investment throughout the economy, leading to lower capital accumulation and consequently lower economic productivity. This also affects government revenue and consequently limits the scope for government consumption, by 0.25%.

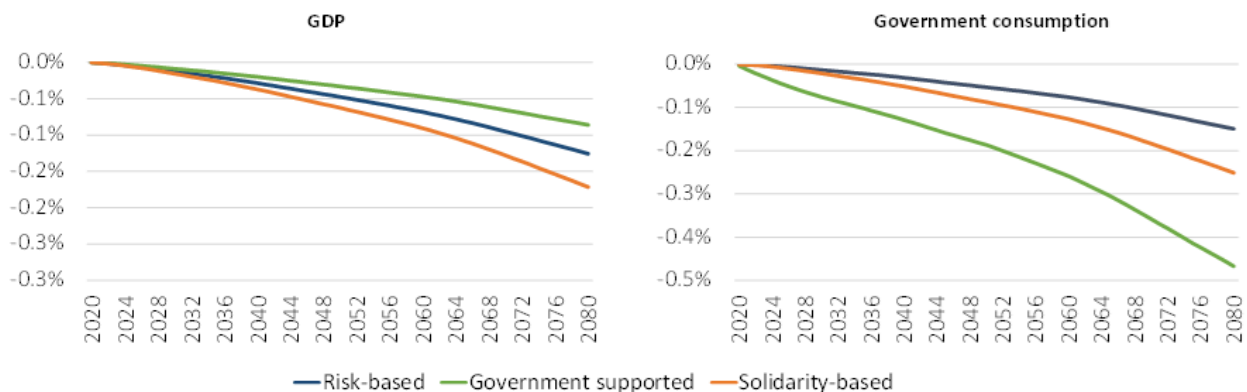


Figure 17: Relative changes in Austrian GDP and government consumption across risk financing schemes until 2080. Changes in GDP and government consumption are indicated relative to the baseline without flood impacts.

3.4 Conclusion

This analysis demonstrates that increasing flood risk affects households not only through direct flood damages but also through indirect economy-wide adjustments. While in a risk-based financing scheme, directly exposed households experience the largest welfare losses, non-exposed households are affected through changes in prices, labour incomes and capital returns. Across all regions, these effects are distributed regressively, with lower-income households experiencing substantially larger relative welfare losses than higher-income households. Without risk redistribution, this would lead to rising within-country welfare inequality by 2080.

The results further show that while risk-based financing reinforces the regressive nature of flood exposure, alternative financing arrangements can substantially alter this distribution. Income independent government-supported financing reduces the welfare burden on exposed households but only partly mitigates the increase in inequality. In contrast, solidarity-based financing largely prevents the increase in within-country inequality by allocating recovery costs according to households' ability to pay rather than their exposure to flood risk.

At the same time, improving distributional outcomes is associated with broader macroeconomic and fiscal trade-offs. While solidarity-based financing is most effective in limiting welfare inequality, it also results in the largest reduction in long-run GDP through lower savings and capital accumulation. Conversely, risk-based financing performs best from a fiscal perspective but produces the strongest increase in inequality. The government-supported financing scheme, which resembles the Austrian compensation system ("Katastrophenfonds"), reduces private welfare losses and supports economic performance more effectively than a fully solidarity-based system, but only partially addresses the risk of growing within-country inequality of flood impacts.

Overall, the findings presented in this study suggest that flood risk financing should be considered an integral component of climate adaptation policy, rather than merely a mechanism for funding disaster recovery. While investments in structural flood protection and other adaptation measures can reduce physical damages, residual risks will remain and are expected to increase under climate change. How these remaining losses are financed determines whether climate impacts reinforce or mitigate existing socioeconomic inequalities. Rather than viewing risk-based, public and solidarity-based financing as mutually exclusive approaches, the results point towards the potential of targeted public support that focuses limited public resources on low income households. Such an approach could reduce the distributional consequences of climate change while limiting adverse effects on economic production and public finances. Although demonstrated for Austria, these findings are relevant for many European countries currently reconsidering the role of public compensation, private insurance and solidarity mechanisms as part of broader climate adaptation strategies.

4 General conclusions

This deliverable assesses the distributional effects of climate change in Europe at three levels: between EU regions, within countries across income groups, and within one country across households with different location and flood exposure. Taken together, the three studies point in the same direction. Climate change is regressive at every level examined, and the way losses are shared depends on the economic channel through which impacts are transmitted and on how policy responds, not only on the size of the physical damage. At the regional level, the NUTS-2 analysis with ICES-REG shows that southern and eastern regions lose most, that poorer regions lose proportionally more, and that the gap widens as warming intensifies, driven mainly by labour impacts, riverine floods and sea-level rise. Within countries, the multi-household model ICES-MH shows that under severe warming (RCP7) losses weigh most on the middle of the income distribution through the labour channel, and that Central-Eastern and Southern Europe are the most exposed. The Austrian case study shows that flood losses are regressive for directly exposed households and, through prices and factor incomes, also for non-exposed households.

The analysis also shows that policy choices change who bears the cost. Adaptation reduces losses for every income group but does not reduce overall inequality: it removes the regressive effect of flooding and sea-level rise, but raises that of the labour and health channels. Mitigation lowers mean income but is progressive, since the carbon tax mainly reduces capital returns and resource rents at the top of the distribution. Under a moderate warming scenario (RCP4.5), the net effect on inequality therefore depends on adaptation: slightly regressive with low adaptation and slightly progressive with high adaptation. In Austria, how recovery costs are financed determines the distribution: risk-based financing and government co-financing leave the regressive pattern largely in place, while solidarity-based financing largely removes it, at the cost of lower GDP and government consumption through reduced savings and investment. In both cases the distributional outcome is a matter of design, and improving it can involve economic and fiscal trade-offs.

Several implications follow for policy. Support schemes should look beyond the poorest households, because the largest losses in the within-country analysis fall on the middle of the distribution. Adaptation needs to be designed so that its benefits reach lower-income households and workers, rather than relying on market-driven adjustment alone. Compensation and financing mechanisms, such as revenue-recycling schemes like the EU Social Climate Fund or public flood compensation, may need to be differentiated by region and by exposure, and should be treated as part of adaptation policy. Finally, the regional and within-country results are complementary: regional analysis identifies where vulnerability concentrates, and household-level analysis identifies who within those places bears the cost.

The studies differ in model structure, time horizons and outcome measures. ICES-REG is a standard computable general equilibrium model with a representative household per region and a subnational detail suited to between-region equity, while ICES-MH splits households into five income quintiles per country to capture differences within countries. The Austrian model distinguishes 24 household groups by income, settlement type and flood exposure. The models also differ in how public finances and capital are treated. In the Austrian model, public adaptation spending is paid for either by cutting government consumption, which is partly offset as adaptation reduces damages and restores fiscal space, or by issuing bonds, and capital moves across sectors but not across countries. In ICES-MH, which builds on

ICES-XPS, capital moves freely across countries, which spreads climate impacts across borders, and the explicit government budget allows public debt to accumulate over time, which amplifies the cost of climate change.

Highlights

- Climate change is regressive at all three levels examined: between EU regions, within countries across income groups, and within Austria across households with different flood exposure.
- Southern and eastern EU regions and poorer regions lose most, and the regional gap widens with warming, mainly through labour impacts, riverine floods and sea-level rise.
- Within countries under RCP7, the EU27+UK loses 5.8%, 2.6% and 1.5% of mean real income in 2070 under low, reference and high adaptation, with the largest losses for the middle quintiles.
- Adaptation reduces losses for every income group but does not make them less regressive; it removes the regressive effect of flooding and sea-level rise, but raises that of the labour and health channels. .
- Mitigation costs the EU27+UK 1.3% of mean income by 2070 but is progressive.
- Under RCP4.5, the EU27+UK loses 4.3%, 1.9% and 1.2% of mean income under low, reference and high adaptation, and the effect on inequality turns from slightly regressive to slightly progressive as adaptation rises.
- In Austria, the financing of flood recovery decides the distribution: solidarity-based financing largely removes the rise in inequality but lowers GDP and government consumption most.

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Annex I



Figure A1: Climate change regional impacts on GDP per capita in 2070 by scenario and impact level

Table A1: Linear regression estimates of climate change impacts on GDP per capita as a function of GDP per capita by year, climate scenario and impact level

year	Scenario	level	Intercept	Slope	R2	Obs
Y2025	SSP2-RCP2.6	Low	-2.24	0.2	0.16	276
Y2025	SSP2-RCP2.6	Medium	-3.04	0.27	0.18	276
Y2025	SSP2-RCP2.6	High	-3.93	0.34	0.18	276
Y2025	SSP2-RCP2.6	all	-3.07	0.27	0.15	828
Y2025	SSP2-RCP4.5	Low	-2.06	0.19	0.11	276
Y2025	SSP2-RCP4.5	Medium	-2.88	0.26	0.15	276
Y2025	SSP2-RCP4.5	High	-3.81	0.33	0.17	276
Y2025	SSP2-RCP4.5	all	-2.92	0.26	0.13	828
Y2025	SSP2-RCP7.0	Low	-3.05	0.27	0.11	276
Y2025	SSP2-RCP7.0	Medium	-4.03	0.36	0.15	276
Y2025	SSP2-RCP7.0	High	-4.8	0.42	0.16	276
Y2025	SSP2-RCP7.0	all	-3.96	0.35	0.14	828
Y2025	all	Low	-2.45	0.22	0.12	828
Y2025	all	Medium	-3.31	0.3	0.15	828
Y2025	all	High	-4.18	0.36	0.17	828
Y2025	all	all	-3.31	0.29	0.14	2484
Y2030	SSP2-RCP2.6	Low	-5.18	0.48	0.17	276
Y2030	SSP2-RCP2.6	Medium	-7.17	0.64	0.2	276
Y2030	SSP2-RCP2.6	High	-9.08	0.8	0.2	276
Y2030	SSP2-RCP2.6	all	-7.15	0.64	0.17	828
Y2030	SSP2-RCP4.5	Low	-4.78	0.44	0.12	276
Y2030	SSP2-RCP4.5	Medium	-6.78	0.61	0.16	276
Y2030	SSP2-RCP4.5	High	-8.67	0.76	0.18	276
Y2030	SSP2-RCP4.5	all	-6.74	0.6	0.15	828
Y2030	SSP2-RCP7.0	Low	-7.06	0.64	0.12	276
Y2030	SSP2-RCP7.0	Medium	-9.42	0.85	0.16	276
Y2030	SSP2-RCP7.0	High	-11	0.98	0.17	276
Y2030	SSP2-RCP7.0	all	-9.16	0.82	0.15	828
Y2030	all	Low	-5.67	0.52	0.13	828
Y2030	all	Medium	-7.79	0.7	0.17	828
Y2030	all	High	-9.58	0.84	0.18	828
Y2030	all	all	-7.68	0.69	0.15	2484
Y2035	SSP2-RCP7.0	Low	-9.47	0.86	0.11	276
Y2035	SSP2-RCP7.0	Medium	-13.29	1.19	0.17	276
Y2035	SSP2-RCP7.0	High	-15.5	1.36	0.18	276
Y2035	SSP2-RCP7.0	all	-12.75	1.13	0.15	828
Y2035	all	Low	-7.84	0.71	0.13	828
Y2035	all	Medium	-11.46	1.03	0.19	828
Y2035	all	High	-13.8	1.21	0.19	828
Y2035	all	all	-11.03	0.98	0.16	2484
Y2040	SSP2-RCP2.6	Low	-9.28	0.84	0.18	276
Y2040	SSP2-RCP2.6	Medium	-14.86	1.32	0.26	276
Y2040	SSP2-RCP2.6	High	-17.77	1.54	0.23	276
Y2040	SSP2-RCP2.6	all	-13.97	1.23	0.19	828
Y2040	SSP2-RCP4.5	Low	-8.78	0.8	0.13	276
Y2040	SSP2-RCP4.5	Medium	-14.34	1.28	0.21	276
Y2040	SSP2-RCP4.5	High	-17.17	1.49	0.2	276
Y2040	SSP2-RCP4.5	all	-13.43	1.19	0.16	828
Y2040	SSP2-RCP7.0	Low	-12.28	1.1	0.11	276
Y2040	SSP2-RCP7.0	Medium	-17.58	1.56	0.17	276
Y2040	SSP2-RCP7.0	High	-20.34	1.76	0.18	276
Y2040	SSP2-RCP7.0	all	-16.73	1.47	0.15	828
Y2040	all	Low	-10.11	0.91	0.13	828
Y2040	all	Medium	-15.59	1.39	0.2	828
Y2040	all	High	-18.42	1.6	0.2	828
Y2040	all	all	-14.71	1.3	0.16	2484
Y2045	SSP2-RCP2.6	Low	-10.86	0.97	0.16	276
Y2045	SSP2-RCP2.6	Medium	-18.43	1.63	0.26	276
Y2045	SSP2-RCP2.6	High	-21.76	1.86	0.21	276
Y2045	SSP2-RCP2.6	all	-17.01	1.49	0.18	828
Y2045	SSP2-RCP4.5	Low	-10.4	0.94	0.12	276
Y2045	SSP2-RCP4.5	Medium	-17.71	1.57	0.21	276
Y2045	SSP2-RCP4.5	High	-20.55	1.76	0.18	276
Y2045	SSP2-RCP4.5	all	-16.22	1.42	0.15	828

Y203 5	SSP2-RCP2.6	Low	-7.23	0.66	0.1 7	276
Y203 5	SSP2-RCP2.6	Medium	-10.76	0.97	0.2 3	276
Y203 5	SSP2-RCP2.6	High	-13.26	1.16	0.2 2	276
Y203 5	SSP2-RCP2.6	all	-10.42	0.93	0.1 8	828
Y203 5	SSP2-RCP4.5	Low	-6.81	0.62	0.1 3	276
Y203 5	SSP2-RCP4.5	Medium	-10.31	0.93	0.1 9	276
Y203 5	SSP2-RCP4.5	High	-12.66	1.11	0.1 9	276
Y203 5	SSP2-RCP4.5	all	-9.93	0.88	0.1 5	828

Table 4 (continued...)

year	Scenario	level	Intercept	Slope	R2	Obs
Y205 0	SSP2-RCP2.6	Low	-12.06	1.07	0.1 4	276
Y205 0	SSP2-RCP2.6	Medium	-21.44	1.87	0.2 4	276
Y205 0	SSP2-RCP2.6	High	-25.12	2.11	0.1 8	276
Y205 0	SSP2-RCP2.6	all	-19.54	1.68	0.1 5	828
Y205 0	SSP2-RCP4.5	Low	-11.75	1.05	0.1 1	276
Y205 0	SSP2-RCP4.5	Medium	-20.52	1.8	0.2 4	276
Y205 0	SSP2-RCP4.5	High	-22.95	1.93	0.1 4	276
Y205 0	SSP2-RCP4.5	all	-18.41	1.59	0.1 3	828
Y205 0	SSP2-RCP7.0	Low	-15.36	1.33	0.0 8	276
Y205 0	SSP2-RCP7.0	Medium	-23.24	2	0.1 4	276
Y205 0	SSP2-RCP7.0	High	-25.77	2.14	0.1 3	276
Y205 0	SSP2-RCP7.0	all	-21.45	1.82	0.1 1	828
Y205 0	all	Low	-13.06	1.15	0.1 8	828
Y205 0	all	Medium	-21.73	1.89	0.1 8	828
Y205 0	all	High	-24.61	2.06	0.1 5	828
Y205 0	all	all	-19.8	1.7	0.1 2	248 4
Y205 5	SSP2-RCP2.6	Low	-12	1.04	0.1 1	276
Y205 5	SSP2-RCP2.6	Medium	-22.86	1.96	0.2 1	276
Y205 5	SSP2-RCP2.6	High	-26.66	2.19	0.1 4	276
Y205 5	SSP2-RCP2.6	all	-20.51	1.73	0.1 2	828
Y205 5	SSP2-RCP4.5	Low	-12.85	1.12	0.0 9	276
Y205 5	SSP2-RCP4.5	Medium	-22.86	1.96	0.1 8	276
Y205 5	SSP2-RCP4.5	High	-25.04	2.04	0.1 1	276
Y205 5	SSP2-RCP4.5	all	-20.25	1.7	0.1 8	828
Y205 5	SSP2-RCP7.0	Low	-19.39	1.63	0.0 8	276

Y204 5	SSP2-RCP7.0	Low	-14.18	1.25	0.1 7	276
Y204 5	SSP2-RCP7.0	Medium	-20.86	1.82	0.1 6	276
Y204 5	SSP2-RCP7.0	High	-23.73	2.02	0.1 6	276
Y204 5	SSP2-RCP7.0	all	-19.59	1.7	0.1 3	828
Y204 5	all	Low	-11.81	1.05	0.1 1	828
Y204 5	all	Medium	-19	1.67	0.2 8	828
Y204 5	all	High	-22.01	1.88	0.1 8	828
Y204 5	all	all	-17.61	1.54	0.1 5	248 4

year	Scenario	level	Intercept	Slope	R2	Obs
Y206 0	SSP2-RCP7.0	Low	-23.74	1.96	0.0 8	276
Y206 0	SSP2-RCP7.0	Medium	-33.62	2.77	0.1 4	276
Y206 0	SSP2-RCP7.0	High	-35.82	2.82	0.1 4	276
Y206 0	SSP2-RCP7.0	all	-31.06	2.52	0.1 0.0	828
Y206 0	all	Low	-16.43	1.37	0.0 7	828
Y206 0	all	Medium	-27.44	2.28	0.1 4	828
Y206 0	all	High	-29.95	2.36	0.0 9	828
Y206 0	all	all	-24.61	2.01	0.0 9	248 4
Y206 5	SSP2-RCP2.6	Low	-11.3	0.92	0.0 6	276
Y206 5	SSP2-RCP2.6	Medium	-24.42	2	0.1 5	276
Y206 5	SSP2-RCP2.6	High	-27.86	2.13	0.0 7	276
Y206 5	SSP2-RCP2.6	all	-21.2	1.68	0.0 7	828
Y206 5	SSP2-RCP4.5	Low	-14.97	1.22	0.0 7	276
Y206 5	SSP2-RCP4.5	Medium	-26.65	2.17	0.1 3	276
Y206 5	SSP2-RCP4.5	High	-27.81	2.1	0.0 6	276
Y206 5	SSP2-RCP4.5	all	-23.14	1.83	0.0 7	828
Y206 5	SSP2-RCP7.0	Low	-28.49	2.31	0.0 9	276
Y206 5	SSP2-RCP7.0	Medium	-38.92	3.15	0.1 3	276
Y206 5	SSP2-RCP7.0	High	-40.68	3.12	0.0 9	276
Y206 5	SSP2-RCP7.0	all	-36.03	2.86	0.0 9	828
Y206 5	all	Low	-18.25	1.48	0.0 6	828
Y206 5	all	Medium	-30	2.44	0.1 2	828
Y206 5	all	High	-32.12	2.45	0.0 7	828
Y206 5	all	all	-26.79	2.12	0.0 7	248 4
Y207 0	SSP2-RCP2.6	Low	-11.1	0.87	0.0 5	276

Y2055	SSP2-RCP7.0	Medium	-28.4	2.39	0.14	276
Y2055	SSP2-RCP7.0	High	-30.75	2.48	0.11	276
Y2055	SSP2-RCP7.0	all	-26.18	2.17	0.1	828
Y2055	all	Low	-14.75	1.26	0.08	828
Y2055	all	Medium	-24.71	2.1	0.16	828
Y2055	all	High	-27.48	2.23	0.12	828
Y2055	all	all	-22.31	1.87	0.1	2484
Y2060	SSP2-RCP2.6	Low	-11.63	0.98	0.08	276
Y2060	SSP2-RCP2.6	Medium	-23.76	1.99	0.18	276
Y2060	SSP2-RCP2.6	High	-27.37	2.17	0.1	276
Y2060	SSP2-RCP2.6	all	-20.92	1.71	0.09	828
Y2060	SSP2-RCP4.5	Low	-13.92	1.17	0.08	276
Y2060	SSP2-RCP4.5	Medium	-24.93	2.09	0.15	276
Y2060	SSP2-RCP4.5	High	-26.65	2.1	0.08	276
Y2060	SSP2-RCP4.5	all	-21.84	1.79	0.08	828

Y2070	SSP2-RCP2.6	Medium	-24.99	2	0.13	276
Y2070	SSP2-RCP2.6	High	-28.3	2.08	0.05	276
Y2070	SSP2-RCP2.6	all	-21.46	1.65	0.05	828
Y2070	SSP2-RCP4.5	Low	-16.06	1.27	0.06	276
Y2070	SSP2-RCP4.5	Medium	-28.05	2.21	0.11	276
Y2070	SSP2-RCP4.5	High	-28.27	2.03	0.04	276
Y2070	SSP2-RCP4.5	all	-24.13	1.84	0.05	828
Y2070	SSP2-RCP7.0	Low	-33.53	2.68	0.09	276
Y2070	SSP2-RCP7.0	Medium	-44.12	3.51	0.13	276
Y2070	SSP2-RCP7.0	High	-45.15	3.38	0.08	276
Y2070	SSP2-RCP7.0	all	-40.93	3.19	0.09	828
Y2070	all	Low	-20.23	1.6	0.05	828
Y2070	all	Medium	-32.39	2.57	0.1	828
Y2070	all	High	-33.91	2.5	0.05	828
Y2070	all	all	-28.84	2.22	0.06	2484

Annex II

A. Reconciled factor income and consumption distribution in 2017

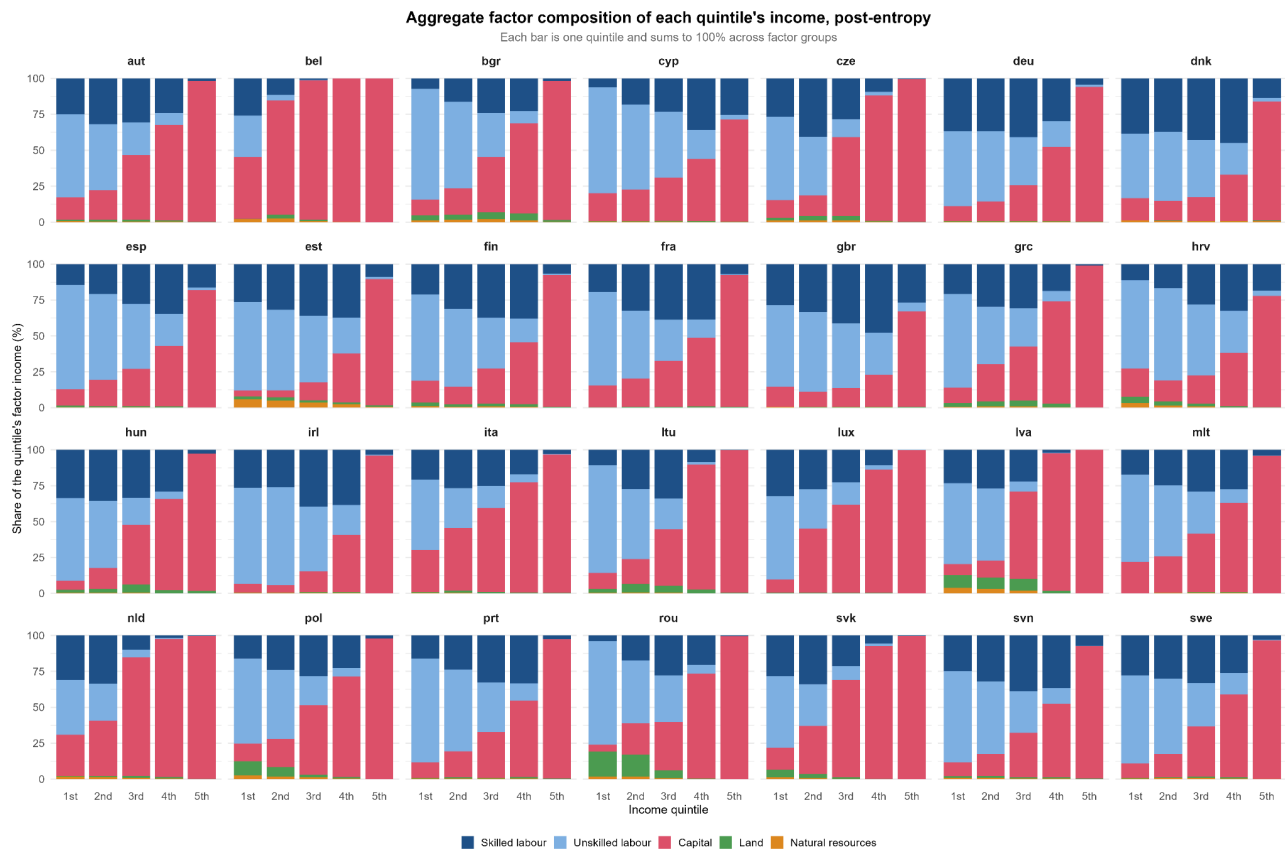


Figure A1 Factor income distribution in 2017 by quintile, post entropy result



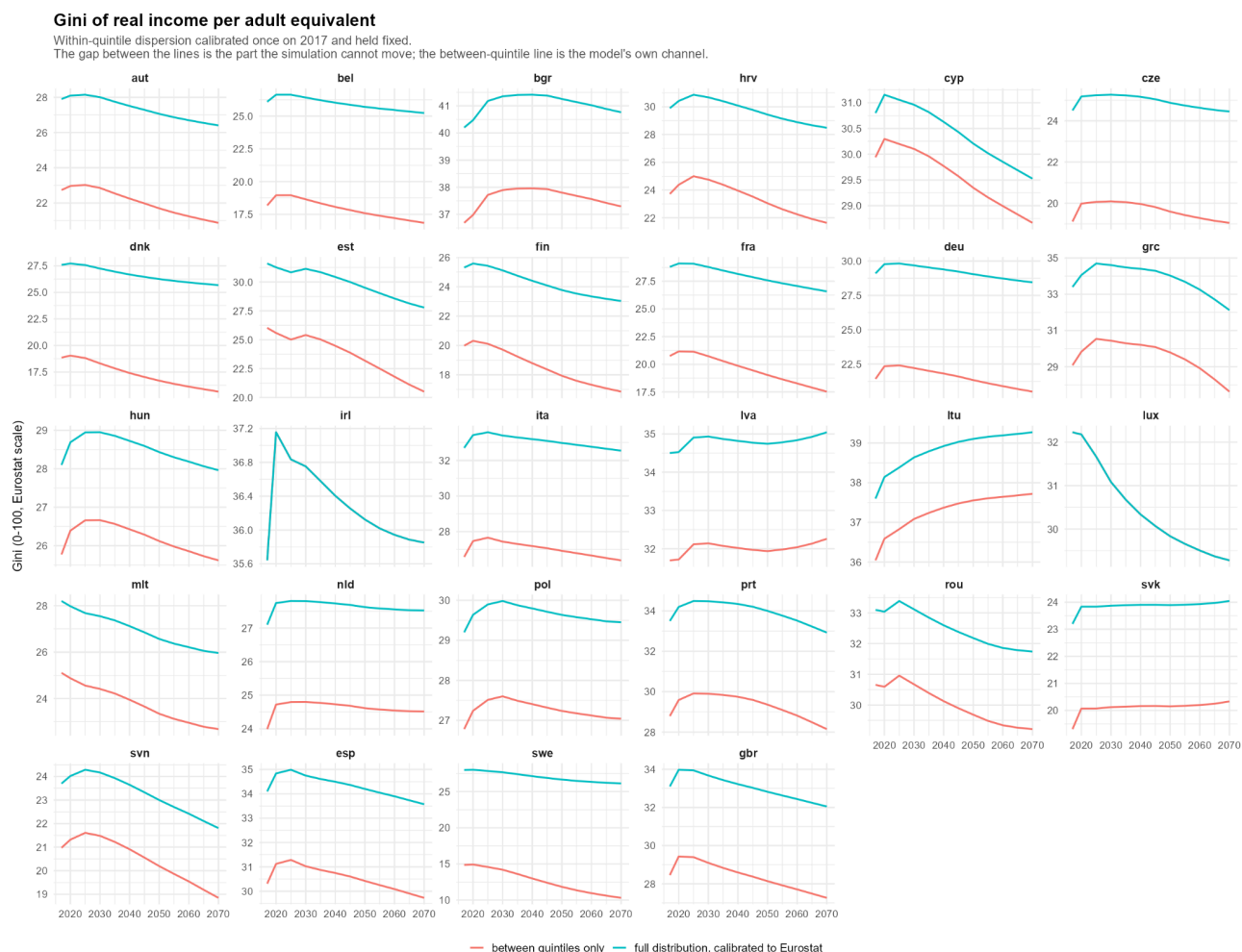
Figure A2 Sectoral income distribution in 2017 by quintile, post entropy result



Figure A3 Consumption distribution in 2017 by quintile, post entropy result

B. Gini coefficient in 2017

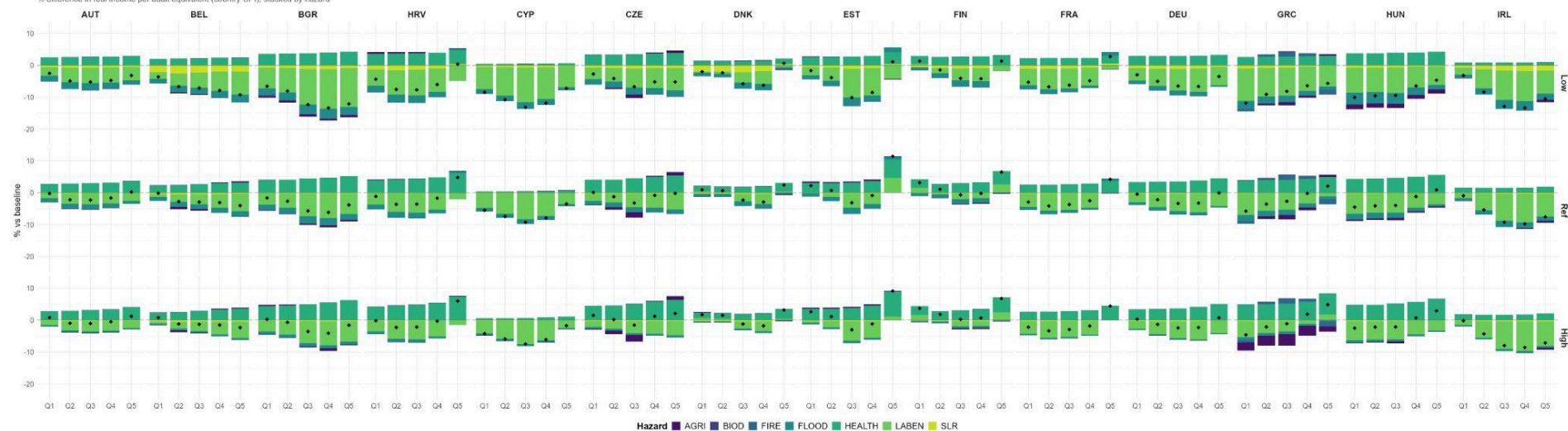
This figure shows how the Gini coefficient of real income per adult equivalent evolves between 2017 and 2070 in each of the 28 countries. Two lines are plotted per country: the full-distribution Gini, calibrated to the Eurostat value in 2017, and a between-quintile Gini built only from the five quintile means that the model simulates. Because the within-quintile dispersion is calibrated once on the base year and held fixed, the two lines move together, and the gap between them is the share of inequality the simulation cannot change. In the case of Ireland and Malta, the quintile-based Gini coefficient overlaps with the Eurostat value in 2017. In most countries (for example Austria, Belgium, Finland, France, Germany, Slovenia and the United Kingdom) the Gini rises slightly in the first model steps and then falls steadily until 2070, with the largest declines in Luxembourg, Estonia, Slovenia and Cyprus. Lithuania and Slovakia move in the opposite direction, with the Gini rising throughout, and Latvia rises slightly after about 2050. Greece shows a hump, with the Gini rising until about 2030, staying high until about 2050 and falling afterwards.



C. Severe climate change (RCP7) scenario impact across quintiles by EU27+UK country

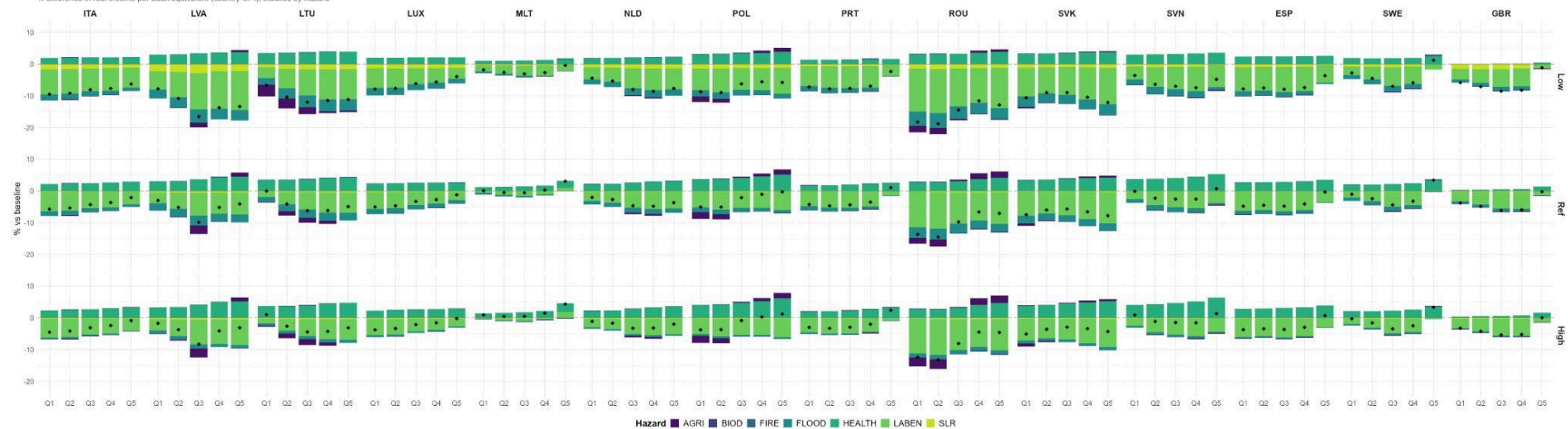
Distance from the baseline by quintile, 2070 - RCP7, country level (1/2)

% difference in real income per adult equivalent (country CPI), stacked by hazard



Distance from the baseline by quintile, 2070 - RCP7, country level (2/2)

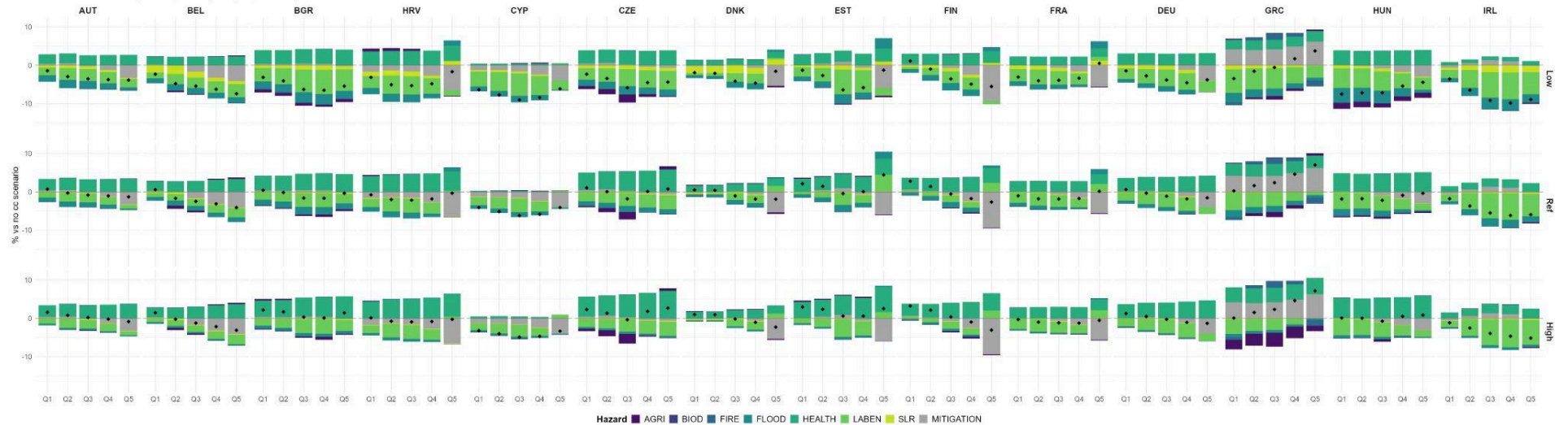
% difference in real income per adult equivalent (country CPI), stacked by hazard



D. Moderate climate change (RCP4.5) scenario impact across quintiles by EU27+UK country

Distance from baseline by quintile, 2070 - country level (1/2)

% difference in real income per adult equivalent (country CPI), stacked by hazard



Distance from baseline by quintile, 2070 - country level (2/2)

% difference in real income per adult equivalent (country CPI), stacked by hazard

