The cost of climate change on households and families in the EU

STUDY

European Economic
and Social Committee

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Study

This study is based on data from Eurostat, Household Budget Survey, 2010 and 2015. The responsibility for all conclusions drawn from the data lies entirely with the authors.

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Foreword

By Séamus Boland

President of the Civil Society Organisations' Group
European Economic and Social Committee

I am pleased to present this study on "*The cost of climate change on households and families in the EU*" carried out by the Euro-Mediterranean Centre on Climate Change (CMCC). I believe its findings will act as an important aid to the formulation of climate change policy, particularly policy which speeds up the achievement of international targets to reduce carbon emissions set by the EU along with its partners.

One of the main frustrations for the implementation of climate change directives was and continues to be the perceived resistance among electorates, coupled with a reluctance by governments to develop imaginative measures, which are attractive and feasible to householders in terms of implementation. Change of behaviour is extremely difficult in any circumstance and requires strong communication between stakeholders. It will be necessary for people to 'own' the change and to become leaders in their own community, so that others can have the confidence to follow them. Fortunately, many individuals, through their membership of civil society organisations, are intensely involved with communities stricken by fires and floods, which have resulted in homelessness, dislocation and loss of life. It is their experience that needs to be listened to, and even more importantly, their advice.

However, behaviour will undoubtedly be influenced by the cost of change to households. For many households, be they families, single- or multiple-person households, the cost of climate change could be prohibitive and an added source of pre-existing anxiety towards change. As the impact of climate change becomes more and more visible (fires, flooding and extreme weather events), it has become clear that the budgets of all Member States must include a contingency to deal with the consequences of such change. It is equally clear that continuous demand on these budgets will become unsustainable, unless we change radically the behaviour of all people. For people already affected by poverty, this request to change behaviour will be extremely difficult in terms of having the resources to support them. The danger is that if people do not change or worse, become resistance enablers, then we will have to accept that valuable time will be lost.

Therefore, the design and even the distribution of social transfer systems need to be prioritised with urgency. Most of the Member states are already planning such systems. However, time is running out and if we are to take seriously the statement of António Guterres, Secretary-General of the United Nations, that the planet is boiling, then we also know that time has run out.

It is our contention that this study will be extremely informative to the agencies tasked with bringing about change. I am sure that it will stimulate the discussion on the distributional implications of climate change and it is in itself a call for further research.

Séamus Boland
September 2023

Abstract

This study investigates the major climate-related risks for households in the EU by quantifying the relationship between a set of selected climate-hazards metrics, households' income by source, and sector-specific expenditures, capturing both the climate induced cost of impacts and adaptation measures. This analysis is complemented with the assessment of mitigation policy costs for households using a mixed modelling approach.

The report highlights the distribution of climate change costs by type (income source- and selected good/service expenditure-related) across regions (NUTS1 level) and socioeconomic characteristics of households (poor, medium income and rich households). In addition, the implications of climate change costs on income distribution and risk of poverty are analysed. The vulnerabilities of EU households highlighted in this study call for risk-specific policy measures at national and EU level and the transversality of climate change costs, especially in Southern EU, will require horizontal policy integration.

Executive Summary

This report provides a comprehensive assessment of the **economic costs of climate change impacts, adaptation, and mitigation for EU27 households**. It examines three major channels through which the climate cost can affect households, i) changes in **expenditure** patterns, ii) reductions or increases in **labour productivity**, iii) reductions or increases in the availability and value of **assets**.

A review of the recent literature on the costs of climate change impacts and adaptation in Europe reveals important gaps.

1. Most **economic impact assessments have focused on the economy-wide costs of selected climate change impacts or adaptation actions or mitigation policies**. There are no studies quantifying all three dimensions jointly. Adaptation costs are usually the least analysed dimension.
2. In the **economy-wide impact assessments,** the costs of climate change are measured in terms of GDP or sectoral output changes; the overall impact on household is in general disregarded and so is the distribution of this impact across households.
3. Other **modelling literature** have focused on the **direct impacts** of climate change on key production factors and assets (labour, land, and capital), and commodities/services (energy, health, food).
4. The **empirical literature** has mainly analysed the climate change economic implications for specific sectors, commodities, and services in selected regions/countries.

The **study statistically assesses the empirical relations between climate-related hazards** (mean temperature, Cooling Degree Days -CDDs-, Heating Degree Days -HDDs-, Standard Precipitation Index -SPI-, and burnt area), **various expenditure types** (health, food, energy, insurance, total expenditure), **and income sources** (sectoral labour income, total labour income, imputed rent which approximate housing value, and monetary income, which includes labour income, imputed rent, profits, investments and transfers) in EU27[1]. The study sets off from historical data recorded in two waves (2010 and 2015) of the European Household Budget Surveys (HBSs) by Eurostat and from ERA5 meteorological data, which provides the most complete currently possible picture of past weather and climate[2]. The estimated

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[1] The analysis covers all EU28 Member States for 2010 and 2015 (Eurostat Household Budget), excluding Austria (all years) and the Netherlands for 2010. We focused our analysis on EU27, i.e. we excluded the UK that is no longer part of the EU since 2020.

[2] ECMWF Reanalysis v5 (ERA5): https://www.ecmwf.int/en/about/media-centre/focus/2023/fact-sheet-reanalysis

empirical relationships are used to develop **two scenarios describing the future potential costs of climate change impacts and adaptation for households** when considering future climate projections from CMIP6[3] and socioeconomic pathways from SSP[4].

In addition, the study assesses **the implications for EU households of two mitigation scenarios** through modelling and microsimulation analysis.

The outcome of the analysis is a characterization of the costs of climate change impacts and adaptation in 2050 for EU households living in different **NUTS1 regions** under moderate and severe climate change scenarios[5]. The climate change cost definition includes changes in **income sources** as well as variations in **expenditure patterns** that may be related to specific poverty issues. The results are detailed for **three socio-economic groups** (terciles) defined in terms of the equivalised annual average expenditure of households (poor, medium income, and rich households). Poverty and inequality metrics at country level give a synthesis of climate change cost for EU households.

The assessment of economic costs of climate change impacts and adaptation **reveals a North-South gradient.** Health, food, and electricity expenditure increase mostly in Southern EU and fall or remains constant in Northern (and Eastern) EU. The contraction in labour income prevails in the South of the EU and the negative impact on monetary income (labour income, asset/investment remuneration and social transfers) affects nearly all EU countries, with the exception of the Eastern regions.

Climate-induced health expenditure of EU households marks the highest increase among all expenditure types, rising by 0.3% and 6.2% under moderate and severe warming, respectively. **The highest increase** in health expenditure is projected to take place in **Cyprus and Greece,** followed by **Spain, Croatia, Italy, and Portugal** (Figure S1, Panel A). In the severe warming scenario, rising health expenditure also characterises regions in North and East Europe**. In Southern regions, the effect will be regressive**, meaning that the poorest households would face the largest increase in health expenditure compared to the richer socio-economic groups.

Climate change will also cause an increase in average household **food expenditure** in most EU countries, between 0.81% and 0.74% across climate change scenarios. **The highest increase in food expenditure is expected in Cyprus, Greece, Spain, Italy, and Portugal** (Figure S1, Panel B). The climate related increase in food expenditure is regressive in Eastern EU, i.e. the poorest households would face a significantly larger increase in food expenditure.

Energy expenditure will slightly drop in the EU, between 0.5% and 1% across climate change scenarios. The drop characterises most of the EU Member States excluding the very North of Europe, namely Denmark, Estonia, Finland, Ireland, and Sweden (Figure S1, Panel C). This is mainly due to a **contraction of gas expenditure** by 14% (19%) observed across all EU under the moderate (severe) climate change scenario (Figure S1, Panel E). This result masks a **moderate increase in electricity expenditures** by 3.3% (4.2%) under the moderate (severe) climate change scenario (Figure S1, Panel D). Poor households would need to increase electricity expenditure relatively more than rich ones in Northern and Southern EU[6].

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[3] Specifically, we consider the NEX-GDDP-CMIP6 global daily downscaled bias-corrected projections (DOI: 10.7917/OFSG3345) using the median value of 14 global climate models (ACCESS-ESM1-5, BCC-CSM2-MR, CMCC-CM2-SR5, CMCC-ESM2, FGOALS-g3, GFDL-CM4, GFDL-ESM4, GISS-E2-1-G, MIROC-ES2L, MIROC6, MPI-ESM1-2-HR, MPI-ESM1-2-LR, MRI-ESM2-0, orESM2-LM), using the air temperature and precipitation variables.

[4] O'Neill et al. (2014)

[5] Severe impacts are associated with an end-of-the-century temperature increase by 4.8°C compared to pre-industrial levels whereas moderate impacts with an end-of-the-century temperature increase by 2.9°C. Technically, these two scenarios correspond to SSP245 and SSP585.

[6] These results do not take into account the recently observed prices spikes.

Only half EU households in the sample relies on **insurance to protect their dwellings** from multiple hazards, and this kind of private adaptation would be intensified mainly under severe climate change impacts. At the EU level, insurance expenditure is projected to increase due to severe climate change impacts (+10.4 % on average), driven by very large increases in Lithuania and Greece (Figure S1, Panel F).

At the EU level, the **total expenditure** of households decreases by 1.2% (1.5%) under the moderate (severe) climate change scenario (Figure S1, Panel G) compared to a no climate change scenario (no temperature increase compared to the historical period, 1995-2014). The reduction of expenditure, mainly concentrated in the South of EU and in Greece (-11% and 10.4%), is probably related to budget constraints namely a concomitant contraction of labour income due to climate change that can be observed in Figure S1 (Panel H and M). Households living in the South of EU will experience a rise of their spending on health, electricity, food due to climate change, but the overall contraction in income would limit households' ability to cope with the residual costs of climate change and to adapt, without increasing their risk of falling below the poverty line.

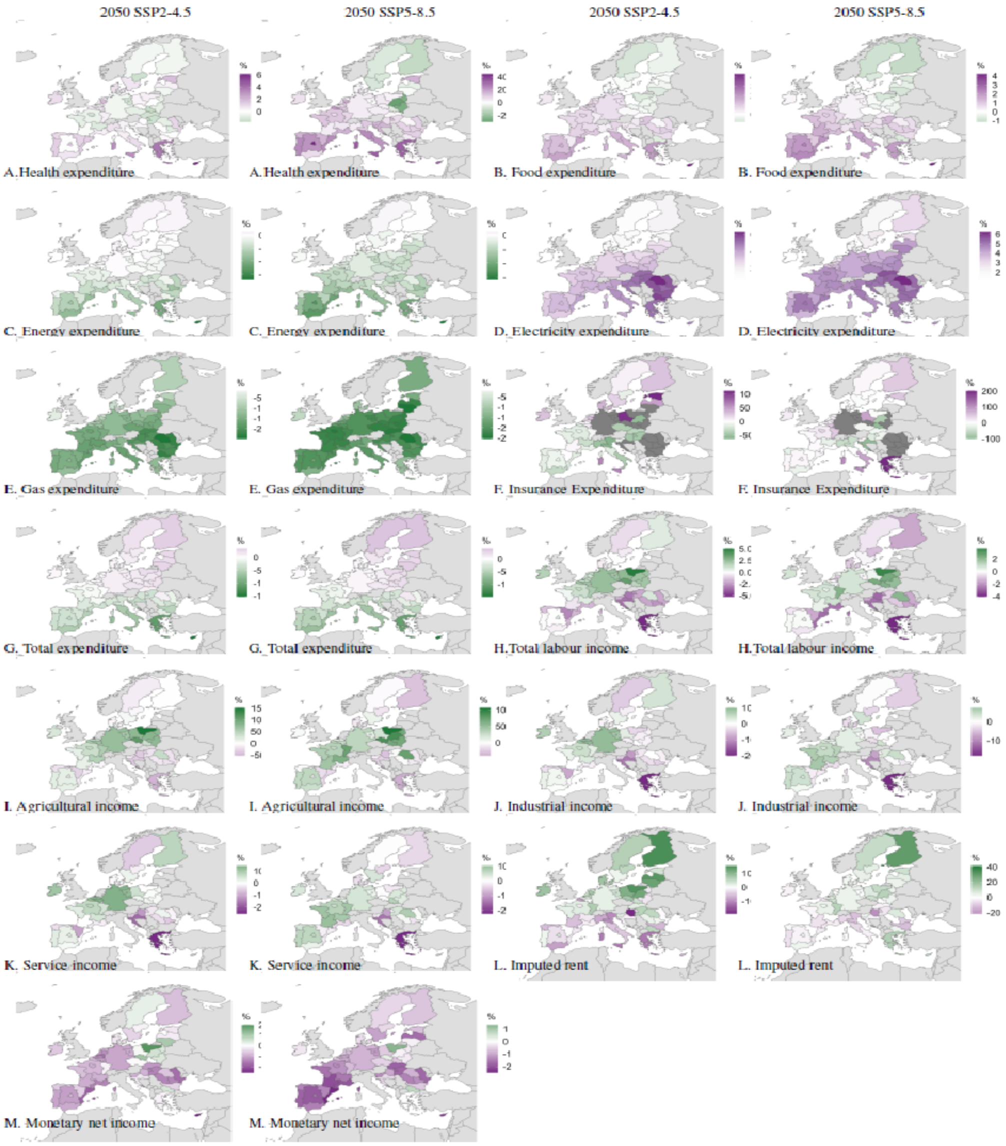


Figure S1– Percentage changes in climate change impact and adaptation *costs for* EU *households in 2050* under moderate and severe climate change scenarios with respect to *a future without* climate change.

Climate change will also influence income sources. Overall impacts on **labour income** are small (0.73% and -0.02% under the moderate and severe climate impacts). **The highest reduction in labour income is registered in Greece**, -5.2% (-4%), followed by France, Croatia, and Hungary (Figure S1, Panel H). The regional distribution of impacts reflects the different economic structure of regions. At the EU level, moderate (severe) impacts increase **agricultural income** by 5.5% (8.6%), **industrial income** by 2.4% (0.8%), and **service income** by 4.3% (1.7%). The magnitude of impacts is very different across sectors and ranges between -50% and 150% in agriculture, and -20% and 10% in industry and services. Regarding **agriculture, the areas at greatest risk are in Greece, Hungary, and Eastern Spain.** The economic impacts of climate change scenarios for households receiving their income from the industry and service sectors reveals the same North-South divide found for agriculture. The projected loss across all sectors in Greece highlights a structural fragility of this country towards future climate scenarios. The income loss in the South of EU affects poor households more than rich ones and impact, lower in magnitude but similarly regressive, emerges also in the Northern EU under severe climate change scenario.

The overall impact on **the value of EU dwellings** (approximated by **imputed rent)** under climate change ranges between -0.2% and -0.4% (Figure S1, Panel L). The temperature change (cold and hot extremes) as well as exposure to flood risk are the main drivers. At the regional level, this joint effect leads to an appreciation of the value of dwellings in the North, (e.g., in Finland, Lithuania and Latvia) and to a reduction in the South (e.g., Cyprus, Greece, and Italy).

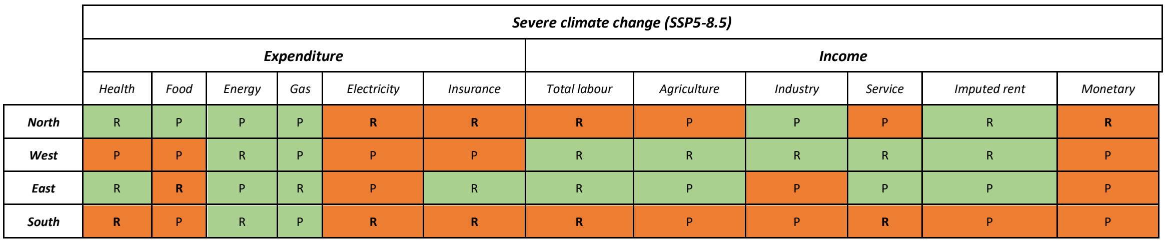
The overall climate change impact on income sources (**monetary net income** including labour income, asset value and social transfers, net of taxes) is negative in the EU reducing by 0.8 % (1.1%) under the moderate (severe) climate change scenario. Monetary net income shrinks across almost all terciles and macro-regions, probably due to the negative effect on investments and rent revenues, despite the redistributive effect of social transfers. **The highest losses are observed in the Southern EU.** The impact is progressive in all macro-regions excluding the North EU region under severe warming.

Table S1 highlights in which regions households are negatively (orange) or positively (green) affected by climate change and whether poor households bear the higher (regressivity, R) or lower (progressive, P) burden than the rich households. The areas towards which corrective national and EU policies should focus are those highlighted in orange. However, the **priority should be given to areas characterised at the same time by negative impacts on households and regressivity**. In the case of severe climate change scenario, these are:

- Electricity expenditure, insurance expenditure, labour and monetary income in the Northern EU;
- Food expenditure in the Eastern EU;
- Health expenditure, electricity expenditure, insurance expenditure and total labour (service) income in the Southern EU.

Table S1: Cost of climate change impacts and adaptation by type and macro-region across scenarios. Green cells highlight a reduction of costs (reduction of expenditure or increase in income), orange cells highlight an increase in costs. The distribution of cost across terciles can be progressive (P) or regressive (R)

	Moderate climate change (SSP2-4.5)											
	Expenditure						***Income***					
	Health	*Food*	*Energy*	*Gas*	*Electricity*	*Insurance*	*Total labour*	*Agriculture*	*Industry*	*Service*	*Imputed rent*	*Monetary*
North	🟧 P	🟩 P	🟧 P	🟩 P	🟧 **R**	🟧 P	🟩 R	🟩 P	🟩 P	🟩 R	🟩 P	🟧 P
West	🟩 R	🟧 P	🟩 R	🟩 P	🟧 P	🟩 P	🟩 P	🟩 R	🟩 P	🟩 P	🟩 R	🟧 P
East	🟩 R	🟧 **R**	🟩 P	🟩 R	🟧 **R**	🟩 P	🟩 R	🟩 R	🟧 **R**	🟧 **R**	🟩 R	🟧 P
South	🟧 P	🟧 P	🟩 R	🟩 P	🟧 **R**	🟩 R	🟧 **R**	🟧 P	🟧 P	🟧 P	🟧 P	🟧 P



	Severe climate change (SSP5-8.5)											
	Expenditure						***Income***					
	Health	*Food*	*Energy*	*Gas*	*Electricity*	*Insurance*	*Total labour*	*Agriculture*	*Industry*	*Service*	*Imputed rent*	*Monetary*
North	R	P	P	P	**R**	**R**	**R**	P	P	P	R	**R**
West	P	P	R	P	P	P	R	R	R	R	R	P
East	R	**R**	P	R	P	R	R	P	P	P	P	P
South	**R**	P	R	P	**R**	**R**	**R**	P	P	**R**	P	P

The report then focuses on the implications of climate change impacts, adaptation and mitigation on income inequality and **population at-risk-poverty.** The climate-induced poverty prevalence computed with monetary net income increases for almost all analysed countries suggesting that **social transfers are not sufficient to compensate for the climate-induced losses in the asset and labour revenues**. The climate impact hitting poor households through assets can be inferred also by looking at the lower magnitude and heterogeneity of change in the population at-risk-poverty measured on the labour income. The mitigation polices seem beneficial to reduce poverty prevalence (computed on the labour income) in all analysed EU countries.

To conclude, the report highlights that:

- EU subnational regions and socio-economic groups will bear differentiated impacts from climate change.
- The analysis covers major types of expenditures and various sources of income that are impacted by climate change or used to adapt to it. Losses affecting income sources are the common measures of climate costs, we complement them with climate-induced expenditures that are a direct consequence of impacts or that are used to adapt to climate change.
- The increased household expenditure on specific goods/services such as health, food and energy can put a heavy burden on poor households, who would face a reduction in the capability to diversify their consumption and limitations in their ability to adapt, both of which would increase their likelihood of experiencing multidimensional poverty.
- Negative and regressive (worsening the wellbeing of the poor households) impacts on a wide set of expenditure goods/services and income sources will be observed in Southern Europe (Greece in particular), marginally in the Northern and Eastern EU (food expenditure).
- Poor households living in the South of Europe will increase their spending on health, electricity, food; their condition is further worsened by the overall contraction in income.
- Climate change impacts increase the population at risk of poverty across EU; mitigation scenarios will likely reduce it, favouring a faster growth of low-skilled labour remuneration compared to high-skilled one.
- Income support measures for low-income households, as currently planned in Greece and Romania, should be strengthen and tailored to the most vulnerable segments of a given population. The potential role of social transfers in compensating for the impacts of climate change on poverty and inequality calls for more research on the role of compensatory measures related to this specific risk.
- Horizontal policy integration is expected to lead to more effective policy making compared to a silo-thinking approach considering the nexus between agriculture, energy, and health, which will face major disparities and could contribute to the risk of compounded adverse outcomes for households.

1. Introduction

The impacts of climate change are already perceivable in Europe and they are expected to intensify over the coming decades (Bednar-Friedl et al. 2022). **Major impacts** have been already observed in five domains that will continue to face growing risk also in the future. These areas include **human morbidity and mortality** due to heatwaves and temperature increase, **losses in crop production, water scarcity, river and coastal flooding** and their impacts on **cultural heritage** and **long-living infrastructure**.

While the median estimated economic loss, in terms of Gross Domestic Product (GDP), would be 2.2% between 2020 and 2070, one fourth of EU regions in the South and in the East could experience GDP losses larger than 5% and individual countries could reach 10%, e.g. in Latvia (Bosello et al., 2020). Recent literature has highlighted the distributional consequences of climate change across regions or households; the economic damages caused by climate change vary across populations essentially because of differences in socio-economic conditions and differences in the initial climate conditions (Hsiang, Oliva, and Walker 2019). Yet, systematic assessments crossing the two dimensions over large geographic areas, such as Europe, are scarce.

Understanding the characteristics of households that are likely to determine exposure to the highest costs due to climate change impacts, mitigation, and adaptation measures at mid-century is a key piece of information for policymakers to better target current and future policies and alleviate disparities. This study will shed light on the actual adequacy of the welfare support and fiscal measures included in the Fit-for-55 package to enable a just transition for the economically disadvantaged households in the EU, and on the magnitude and direction of the changes needed to close the gap between the current provisions and a true just transition.

This study combines different methodological approaches including literature review, multivariate regression analysis, economic modelling and downscaling methods applied to scenarios of future differentiated mitigation efforts. Multivariate regression analysis is used to quantify the costs of climate change impacts and adaptation building on a novel database purposedly developed for this study. This database combines socioeconomic and demographic information about households with subregional historical data on climate conditions including extreme temperatures, flood, drought, and fire risk. The statistical evidence resulting from historical data is used for inference about future possible impacts in 2050 under different levels of warming. Modelling and downscaling approaches are then used to quantify the indirect impacts on EU households belonging to different income classes induced by differentiated mitigation efforts through their effect on energy prices and on the expenditure devoted to these services.

We find that literature on the economic costs of climate change impacts has mostly focused on the economy-wide or sector-wide economic costs, whereas an important gap exists relatively to the economic implications for individual households. We fill this gap with a newly developed empirical analysis that quantifies the households' costs of climate change impacts and adaptation. Patterns in the historical data already point out significant impacts of climate change on European households through the expenditure, asset, and productivity channels. European households increase their expenditure on health and food in response to increased temperatures, and to a greater exposure to fire and flood risks. The value of assets such as dwellings and labour productivity are also affected by temperature, fire, and flood risks. Impacts on households are highly differentiated depending on income level, on average climate conditions, as well as on the sectoral composition of the economy and sectors of employment. Some results might also implicitly factor in the role of public adaptation measures acting as substitute for autonomous private adaptation. European households adapt to changes in temperature by altering their domestic energy consumption, and to the perceived risk of flood and fire by purchasing dwelling insurance. The literature on the distributional implications of mitigation costs is more developed. Mitigation policies directly affect the consumption of fuels, as well as of other goods, proportionally to the use of energy in their production. Mitigation policies, by altering energy prices, production costs, and the relative remuneration of production factors, can determine a shift in household expenditure patterns and in the relative importance of income sources.

The quantitative approach adopted in the analysis makes not relevant the distinction between the term household and families. The survey data from Eurostat, at the core of our analysis, has the EU households as main statistical unit of analysis. A household is defined as "a housekeeping unit or, operationally, as a social unit: i) having common arrangements; ii) sharing household expenses or daily needs; iii) in a shared common residence. It includes either one person living alone or a group of people, not necessarily related, living at the same address with common housekeeping"[7] Our analyses account for the heterogeneity of socio-economic and demographic characteristics of households' members (e.g., numerosity, age, education, individual income, sector of occupation). We think the socioeconomic characteristics are key in identifying the distributional impacts of climate change. The relationships among household members, which characterise the concept of families, seems to be less relevant to our research question.

Furthermore, the size and the age of households' members enter directly in the computation of equivalised income and expenditure to build distributional metrics (Gini index, population at-risk-of-poverty and energy poverty prevalence); the equivalised income is discounted for the number of individuals in the household it supports and the equivalised expenditure is discounted for the economies of scale in consumption and for the age of household members, expecting a lower consumption by children. The equivalence scale allows making all households comparable and assessing their ranking in the income/expenditure distribution, i.e. their economic wellbeing.

The remainder of the study is organized as follows. Section 2 introduces the conceptual framework that will guide our novel empirical assessment, followed by a short review of the most recent literature on the economics of climate change impacts and adaptation with a household-level focus. Section 3 will describe the empirical methods and data used to estimate the economic costs of climate change on European households that will be discussed in the same Section. Section 4 will reflect on the households' implications of mitigation costs. Section 5 concludes the report with a critical discussion of the EU policies that can address the distributional implications of climate change impacts, adaptation, and mitigation.

2. Economic costs of climate change in Europe

2.1 A simple framework

The present report focuses on households' vulnerability to climate change and analyses the cost and reduced wellbeing related to climate change impact, adaptation to climate change and mitigation policies. Following Hallegatte (2014) and Kahn (2016), we further disentangles the channels though which climate change influences households' wellbeing; these considers not only the impact of climate change on income generation (occupation and labour productivity) and wealth (real estate and financial assets), but also on the purchase of primary good and service, e.g. health, food and energy, that can

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[7] Eurostat glossary at:

https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Household_-_social_statistics#:~:text=A%20household%20includes%20either%20one,a%20living%20or%20sitting%20room.

dominate the budget making the households more fragile to shocks and uncapable to differentiate their purchases.

There are at least three channels through which climate change impacts can affect households’ wellbeing: 1) by altering health, food, energy, and other good prices and therefore consumption (expenditure channel); 2) by destroying assets or reducing their value, but also by slowing down the accumulation of capital (asset channel); 3) by modifying household’s labour productivity and remuneration (productivity channel).

In addition to climate change impacts, also adaptation to climate change entails some costs for households. Adaptation can take place in a myriad of different ways, and it consists in diversified actions undertaken at local and sectoral level by private and public actors. Adaptation actions are usually classified as proactive (taking place before the impacts of climate change such as dam construction) and reactive (taking place after the occurrence of climate change impact such as reconstruction works). In this category, we also include autonomous market-driven adaptation i.e. the adaptation that is triggered by market or welfare changes in human systems. In this report, we will focus on planned and reactive adaptation of households. **The main channels through which climate change adaptation can affect households’ wellbeing are**: 1) by modifying energy and other goods’ demand in response to price changes or new needs induced by climate shock (expenditure channel – autonomous adaptation); 2) by protecting households’ assets (e.g. insurance) or by maintaining their productivity (e.g. improving dwelling characteristics, asset channel - planned adaption); 3) by changing sector of employment (job channel); 4) by expanding the individual set of opportunities, for example through migration (opportunity channel, not covered in this report).

The main channels through which mitigation policy affects households’ costs are: 1) the price change of goods directly targeted by the policy (energy goods) and all other goods produced using energy (expenditure channel); 2) the variation in labour income remuneration in the sector interested by the policy (income channel); 3) the chosen recycling scheme of mitigation policy revenues (transfer channel, not covered in this report).

The remainder of Section 2 summarizes the most recent studies on the economic costs of climate change impact, adaptation and mitigation.

2.2 Literature review

The literature review is shaped following the channels of propagation of climate change costs described in Section 2.1. Section 2.2.1 describes the costs related to climate change impacts, Section 2.2.2 focuses on adaptation costs and Section 2.2.3 on mitigation costs.

2.2.1 Climate change impact costs on European households

2.2.1.1 Expenditure channel

The expenditure channel looks at the variations in households’ expenditure on specific goods and services due to the occurrence of a climate-hazard event. Here we focus on health expenditure and food expenditure that are directly impacted by climate change; these two expenditure categories are essential material requirements for social and physical wellbeing of individuals (Rao & Min, 2018). Moreover, health and food expenditure are two important budget items that absorb at least 20% of an average

European household[8]. Therefore, the impacts of climate change on households through the expenditure channel related to these two items can be significant. Ideally, the expenditure channel would account for the rise of health service demand and of food price, before the occurrence of other autonomous adaptation actions of the household, such as the reallocation of consumption towards a less expensive bundle of goods. Unfortunately disentangling these two components is not possible and therefore the observed change in health and food expenditure combine the direct expenditure effect as well as the expenditure reallocation due to budget constraint. The literature on the climate change adaptation through the food and health expenditure channel is very scarce.

Physical health impacts and costs of the health sector

The literature has mostly focused on the direct, **physical health impacts**, or on the **economy-wide economic costs, or the costs of the healthcare sector.** Recent meta-analyses summarise the **health impacts** of exposure to heat on mortality (Sheridan and Allen 2018) and morbidity (K. Wu et al. 2022). Significant associations have been found between temperatures and respiratory, cardiovascular, neurological (mainly due to heat strokes) and infectious diseases. New findings also regard diabetes, cataracts, impaired sleep, kidney diseases, and some negative birth outcomes such as low birth weight, preterm birth, hypertension, eclampsia and preeclampsia. Temperature and humidity are associated with skin diseases (including skin cancer) and allergies, and the evidence on temperature's effects on health outcomes is consistent across countries, and infants and the elderly are found to be more vulnerable. For example, a temperature increase scenario of +1.5°C could result in 30,000 annual deaths due to extreme heat, with up to threefold the number under +3°C. At +2.5°C (Bednar-Friedl et al. 2022).

A macroeconomic assessment has been provided by the PESETA[9] initiative at the JRC. The first rounds of the assessments found that, across Europe, winter benefits from reduced cold-related mortality more than compensate higher heat-related mortality in summer. Also significant are the expected disaster-induced mental health impacts: annual costs to treat depression caused by coastal flood events, could reach, 1.0 to 1.4 billion/year by 2071-2100 under high sea level rise (+4°C scenario) and 0.8 to 1.1 billion/year under the +3°C scenario. In both PESETA III (Ciscar; et al. 2018a) and IV (Szewczyk et al. 2020), heat-related mortality based on value of statistical life [10](VSL) dominates by far all other economic impacts. **Welfare losses from these health impacts**, aggregated for the EU plus the UK are estimated at **36 billion euro for the 1.5° C scenario, compared to today, 65 billion euro in the 2° C scenario and over 122 billion euro in the 3° C scenario**. More than 80% of the losses are in Southern Europe.

Ščasný et al. (2020) estimates a VSL for fatal events due to heatwaves equal to € 1.5 million in Spain and € 1.6 million in the UK. Adjusting values for income in nominal Euro, the VSL for the heat wave context for the EU 28 is between 2.33 million Euro (2015 values) and 2.15 million Euro. Applying these estimates to projected excess mortality due to heat waves in the EU, the effect of heat waves in Europe on premature mortality grows over time and is more severe with less strict mitigation targets. While in the 2030 the impacts are comparable across scenarios (between 180 and 200 billion PPS[11] 2015 Euro), the impacts on premature mortality in 2050 grow up to 285 million, and 390 million PPS Euro for +2.4

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[8] Authors' calculations based on the EU HBS survey 2010 and 2015.

[9] The PESETA initiative has issued for assessments between 2009 and 2020.

[10] The value of statistical life (VSL) a summary measure of the willingness to pay (WTP) for reductions in the risk of dying.

[11] PPS is the technical term used by Eurostat for the common currency in which national accounts aggregates are expressed when adjusted for price level differences using Purchasing power parities (PPPs). Thus, PPPs can be interpreted as the exchange rate of the PPS against the euro.

°C scenario, and +4.3 °C scenario, respectively. In 2100, the impacts consistently increase up to 700 billion only for +4.3 °C scenario.

Roldán et al. 2015 concludes that 107 deaths could be attributed to heat during the 2002-2006 in Zaragoza, Spain, with an **in-hospital estimated cost** of € 426,087. Heat is also found to be associated with increased hospital admissions due to mental illness (depression, bipolar disorder and schizophrenia) and with an increased frequency in suicide attempts (Thompson et al. 2018). Hübler et al. 2008 show that the reduction in cold stress only partially counteracts heat-related deaths, which could increase by a factor of 3.7 by 2070-2100 compared to current levels. By the same year, **hospitalization costs** could reach 300 to 700 million € (2015 value) per year, a 6-fold cost increase compared to current levels in Germany. Karlsson and Ziebarth 2018 assesses the short and medium-term impact of extreme temperatures on population health and health-related costs in Germany. Under both approaches, they find that extreme heat significantly and immediately increases hospitalizations and death. They find economic costs can reach €5 million every 10 million population per hot day with maximum temperatures above 30 °C. The study by (Adélaïde, Chanel, and Pascal 2022) estimate excess visits to emergency rooms and outpatient clinics and hospitalizations for heat-related causes using health indicators collected by the French national heat wave plan, and then derived the related impacts in terms of total excess mortality and years of life loss, as well as the share of the population whose activity was restricted activity. By applying a cost-of-illness and willingness-to-pay approach they estimated economic impact of heat waves between 2015 and 2019, to have reached €25.5 billion, in terms of excess mortality (€23.2 billion), restricted activity days (€2.3 billion), and morbidity (€0.031 billion).

Impacts on the availability and price of food

Climate change will affect the **food** availability and prices for European households either through the occurrence of climate change impacts on EU agricultural production or through the impacts on major producers outside the EU that export food products to Europe. To our knowledge, there are no assessments looking at the implications for household budget of climate -related shocks in agriculture inside and outside the EU and therefore there are no reviews the literature on the climate change impacts for the EU agricultural sector, including the impacts related to wildfire. The literature has mostly focus on the direct, **physical impacts on agricultural production** and on the **economy-wide economic costs**.

Southern Europe will face higher damages to the **agricultural system** with lower harvestable yields and a reduction in suitable areas for traditional crops. These regional patterns have been confirmed by more recent studies as well. **Reductions in agricultural yields** will be higher in the south at +4°C, with lower losses or gains in the north. Net yield losses will reduce economic output from agriculture in the EU, reaching a reduction of 7% for the EU and the UK combined, and 10% in Southern Europe at +4°C. Regarding Aquatic Food Production, projections suggest a reduced abundance of most commercial fish stocks in European waters of 35% between 1.5°C and +4.0°C (Bednar-Friedl et al. 2022). Crops like grain **maize** are projected to be the most affected in Southern Europe where for a +2 °C warming mean yield losses will range from -4% to -22% compared to a loss of -1% to -14% for Northern Europe. If problems related to water availability for irrigation were to arise, it is projected that European maize output will collapse around 2050, with yield drops of at least 23% across the board and upwards of 80% in some Member States, including Portugal, Bulgaria, Greece, and Spain (Hristov et al. 2020). Wheat production losses are foreseen to be worst in Southern Europe with yield reductions for 2050 up to -49% compared to a yield increase in northern Europe for 2050 from 5% to 16% (Hristov et al. 2020). Increased climate related stress will cause the abandonment of farmland in Southern Europe with farmland values projected to decrease by 5–9% per degree of warming (Bednar-Friedl et al. 2022). By the middle of the century, climate change effects on agriculture in the EU will begin to be noticeable in terms of **GDP losses or gains**, with a higher vulnerability for southern regions such as Spain and Italy showing losses ranging from 2.5 to 5% of GDP for 2050, and possible net GDP gains for central and northern regions (Bosello et al. 2020). In case of low and medium impacts (SSP245 and SSP585) from climate change on agriculture reaching +2-2.6°C around 2050, effects on GDP are mildly positive until 2050, in 2070 they will range between -4 and + 4%. For high impact case, GDP is impacted mostly negatively since 2030. In 2070 many regions will experience a GDP loss between 5% and 10%. At +2°C, agro-climatic zones are expected to shift northwards by 25-135 Km per decade (Bednar-Friedl et al. 2022) causing crops such as maize, sunflower, and soybeans, which are presently grown in southern EU, to turn better suited for Northern EU regions (Bindi & Olesen 2011). Northern Europe will experience the best seasonal weather for growing crops with warmer, drier autumns and springs, and cooler, wetter summers and winters, which will increase farm values, whereas a marginal temperature increase for southern countries would be detrimental. The largest marginal advantage will occur in Sweden and Finland, where land value increases by about 16%, while the largest marginal loss will occur in Greece and Portugal, where land value decreases by 9% (Passel, Massetti, and Mendelsohn 2017).

A second risk that has been affecting more drastically southern Europe compared to the Northern regions is **fire hazard.** Nearly one million hectares of land was burned in Europe in 2017, compared to an average of around 213,000 hectares between 2008 and 2016, and the number of days with high-to-extreme wildfire risk is projected to increase as temperatures rise to 2 °C and 3 °C, with fires worsening in severity and size (Costa et al. 2020). Turkey and Italy were the nations most impacted in 2021, with respectively 206,013 ha and 159,537 ha of burned area; Spain was close by with 901 fires that burned a total of 91,295 ha. 45% of all fires in protected regions happened in these last two nations putting at risk endangered plants and animals; in the end a total of 1 113,464 hectares were scorched by fires in 2021 in 43 European countries and about 25% of the total burned area belonged to crop lands while forests accounted for 28% (San-Miguel-Ayanz et al. 2022). A recent study by Meier et al. (2023) estimated the economic impacts of wildfires in terms of **GDP losses or gains and employment** in European regions. Using annual regional economic data on employment and GDP growth from 2010 to 2018 together with satellite imagery of burned areas, the research focused on the regions more at risk of fire hazards in Europe such as Portugal, Spain, Italy, and Greece. What emerged is that an additional fire reduces the region's yearly GDP growth rate by 0.026% on average; for instance, the ‘‘worst’’ observed year in the sample period the annual GDP growth rate than decreased of 3.3%. Overall, for Southern Europe, wildfires have a persistent negative modern impact on the annual regional GDP growth rate, which ranges from 0.11 to 0.18%. In monetary terms, the study shows that, between 2010 and 2018, Southern Europe suffered losses between 12.8 and 20.9 billion euros per year. It is anticipated that a sizable portion of Mediterranean Europe will experience drier extremes in the deep fuel[12] and Spain, Portugal, Turkey, Greece, a portion of central and Southern Italy, and Mediterranean France are the nations facing the greatest risks (Ciscar; et al. 2018; De Rigo et al. 2017).

2.2.1.2 Asset channel

The asset channel refers to the impacts of climate change in terms of physical destruction or value loss of the resources (with an economic value) owned by the households, that yield them a periodic monetary flow or are an investment made in view of future needs/profits, such as buildings, land, and equipment. Here we focus on the **loss of assets** due to extreme weather events like floods.

Flood-related phenomena are among the costliest natural disasters in Europe (Leiter et al. 2009, EEA, 2017). During the period 1980-2009 only, above 80 % of European economic losses caused by natural

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[12] The potential fuel constituted by the deep layers of wood, leaves, soil and other organic matter on the ground. This entail that drier deep fuel may exert on fire danger.

disasters were related to hydrometeorological events (EEA, 2010). Hydrological events alone (i.e., floods and wetland mass movements) accounted for 25 percent of the total losses in the member states. European Environment Agency (EEA), estimated at 455 billion euros during 1980-2009 (in 2015 values) (EEA, 2010), while losses for the period 1990/2016 have been estimated around 210 billion euros (in 2015 values) (Paprotny et al. 2018). Over the period 1870 to 2016, on average, flood hazard in Europe increased due to climate change, but economic losses and fatalities have in general decreased. In total, flooding generated losses equal 0.08 / 0.09% of GDP (in 2015 euros) between 1963 and 2017. The biggest shift in financial losses occurs for the period between 1950 and 2016 where the trend is −2.6% per year. River flood events are very unevenly distributed. While overall exposure to floods has declined in most countries, especially in central and northern Europe, it has increased in several western and southern European states including France, Germany, Italy, and the Netherlands (Paprotny et al. 2018). In Southern Europe, flash floods accounted for most flood events, while in Central and Western Europe, river floods were more frequent than flash floods (Paprotny et al. 2018). In most countries in Western and Central Europe, models consistently predict a relevant increase in future flood impacts (Rojas et al. 2013, Alfieri et al. 2018, Dottori et al. 2018), while projections agree on up to a 30% reduction of precipitation per year in Southern European countries (Alfieri et al. 2015), potentially leading to recurrent drought phenomena. Overall, significant increase is projected in the frequency of extreme events larger than 100% in 21 out of 37 European countries up to 2035, and a further deterioration in the subsequent future (Alfieri et al. 2015).

While direct impact losses can be derived by the physical damage to the stock, that is actual damages to buildings (residential, commercial, and public assets), flood events produce **indirect losses** in the national economic system, which can amount to a significant share of the **direct losses** (Carrera et all. 2015), or even become double the direct damage (Koks et al. 2015; 2019; Dottori et al. 2018). Indirect losses are more difficult to be captured, especially in future projections scenarios, and when accounting for indirect effects disaster losses on a continental scale via regional economic interdependencies (Koks et al. 2019).

The literature has emphasised the economic costs of floods for the overall economy and for the producing sectors. For example, by using a multi-model framework, human losses, **direct economic damage**, and subsequent **indirect impacts (welfare losses)** are estimated on a global scale by Dottori et al. 2018, under a range of temperature (+1.5 °C, +2 °C and +3 °C warming) and socio-economic scenarios, assuming current vulnerability levels and in the absence of future adaptation. Alfieri et al. 2018 estimate that global warming is linked to substantial increase in river flood risk over most countries in Central and Western Europe (already accounting for 22% of present global direct losses due to river flood events) at all warming levels, while in Eastern Europe damages are not expected to increase. Economic estimates of flood impacts at the European level for the baseline period (2007-2015) are 11.5 billion €/year of losses (in 2015 values). Average relative changes in flood impacts of the three ensembles rise with the temperature projections from +113% expected damage (17.2 billion €/year) at 1.5 °C, up to +145% (19.5 billion€/year) at 3 °C. Economic damages were calculated for five relevant economic sectors (residential, commercial, industrial, infrastructure, and agriculture). Koks et al. 2019 show that indirect economic implications of river flooding in Europe go beyond the direct damages typically considered. Future increases in losses are found to be highest for **commercial services** (+980%) and **public utilities** (+580%), with respect to 2010. Increases in economic flood losses (up to 350%) can be expected for all global warming scenarios, but indirect losses rise by 65% more if compared to direct asset damages, due to the increasing size of future flood events. Results show that **flooding can have widespread economic effects across Europe**. Carrera et al. 2015, in assessing the economic impacts for Northern Italy’s flood of the Po River in October 2000, highlight that the flood event produces high indirect losses in the national economic system, which are a significant share of the direct losses, playing an important role in the full social costs of floods. By the end of this century, relative economic impacts are projected to increase for almost all EU countries. Eastern European countries will still be most severely affected by flooding (damage above 0,5% of GDP), especially Hungary (1.36%), but also Slovakia (0.87%), the Czech Republic (0.81%), and Romania (0.79%).

2.2.1.3 Productivity channel

Climate change can affect households' wellbeing by modifying household's labour productivity and, consequently, their remuneration. Although effects on labour is one of the most tangible and attributable climate impact (Dasgupta et al., 2021, Gosling et al., 2018). Europe is expected to have an average decrease in effective labour productivity by 0.3 % under +2.0 °C and 1.0 % under +3.0 °C warming. However, these effects greatly vary across the continent, with a decline of up to 28.5% in southern Europe.

Economic structures play a significant role in determining the overall economic impact of climate change. For high-exposure work conditions, such as for in agriculture, Europe is expected to have a decline of 5.8 % in effective labour under a global warming scenario of 3.0°C (Dasgupta et al., 2021). Under a moderate scenario of +2.4 °C (RCP4.5), industry and construction sectors' productivity will decline by 2.7% and 3.1%, respectively. Under an unmitigated warming scenario of +4.3 °C (RCP8.5), productivity will decline by 4.3% and by 6.6%, respectively. According to Gosling et al., 2018 (PESETA III report), if climate change remains unmitigated and no adaptation occurs, labour productivity in outdoor labour could decline by 10-15% by the end of the century compared to present-day in southern European countries such as Bulgaria, Greece, Italy, Macedonia, Portugal, Spain, and Turkey, while the northern countries such as Denmark, Estonia, Finland, Norway, and Sweden will have an estimated 2-4% decline.

The **economy-wide impacts** of decreasing labour productivity are assessed by Bosello et al. 2020, who estimated an average potential GDP loss in 2030 between 0.15% in a medium case scenario of +2.9°C and 0.23% in the worst scenario of +4.8°C. In 2050, these projections increase up to -0.38% and -0.71%, respectively. In 2070 the highest losses are experienced under +4.8°C scenario in 2070 (-0,94%), where southern and central-eastern European regions are hit more adversely showing potential GDP contractions in the order of -1.5 / - 2%. Cooler areas like northern Europe, but also Austria, or Italian Alpine regions, can gain roughly a 1% improvement in the economic performance. On average, the lowest losses are expected under the moderate +2°C scenario, with all the EU regions experiencing a GDP contraction of the 0.5% or lower.

2.2.1.4 Gaps

The literature review on the climate change impacts on European households shows that most economic impact assessments have focused on the economy-wide or sector-wide economic costs, measured in terms of GDP changes (Bosello et al., 2020; Standardi et al 2023), and often connected to labour productivity-related impacts. Direct economic impact assessments on key production factors and assets, such crop yields, infrastructures, or on specific services such as healthcare, do not often account for household's direct implications in terms of expenditures or welfare. For example, many studies underline the increasing mortality (Vicedo-Cabrera et al, 2021; Sheridan and Allen 2018, Ščasný et al, 2020) and morbidity (K. Wu et al. 2022) due to temperature, and the consequent GDP impact on society as a whole (Szewczyk et al. 2020; Kovats et al. 2015), but there are generally no data regarding the related increased households expenditure. The same applies for agriculture impact and related increase in food cost for households. Consistent gaps seems therefore to exists in the assessment of impact and costs at household dimension in all the impact channels analysed (i.e. health, agriculture, energy, floods).

2.2.2 Climate change adaptation of European households

2.2.2.1 Expenditure channel

Adaptation actions that might be taken by households to protect their assets related to the stock of human health and capital include changes in the use of **energy** to ensure a comfortable environment~~.~~ While studies assessing the impacts on health expenditure in Europe are not available, recent studies show that adaptation measures such as heat alert systems[13] can be very effective, although they do not completely reduce all heat-related impacts (Hunt et al, 2016: Sanderson et al, 2018). Numerous studies exist on the assessment of climate change on energy demand, though only a few explicitly focus on household energy expenditure (Randazzo, De Cian, and Mistry 2020) or household energy investments (De Cian et al. 2019) in European regions. The study by (De Cian et al. 2019) estimated the propensity of households to invest in housing conditions that can improve households' resilience to weather shocks, such as air-conditioning and thermal insulation. Households in hotter places in Europe have a lower probability of improving walls and roof insulation, but the effect is reversed when the number of hot and cold days, measured in terms of Cooling and Heating Degree Days, is sufficiently large. Exposure to a warmer climate raises the probability that a household installs air conditioning. The impact of air-conditioning on electricity expenditure is quantified in (Randazzo, De Cian, and Mistry 2020). Households who adapt to high temperature through air-conditioning spend, on average, 42% more on electricity compared to households who do not choose this solution. The analysis by (Campagnolo and De Cian 2022) combines a computable general equilibrium model with a downscaling module based on household survey data to evaluate the impacts of mitigation policies and climate impacts on households' expenditure and energy poverty. In Italy, the share of budget spent on electricity varies from 1.8% in colder regions to 3.5% in hotter regions. Both mitigation policies and climate change impacts increase households' expenditure on electricity, whereas spending on other fuels is reduced. The net effect varies in sign depending on the regions, but some Italian regions (e.g., Sicily) could experience an increase in electricity poverty.

2.2.2.2 Asset channel

When accounting for economic impacts of climate change, adaptation possibilities can be either the **prevention and limitation** of the impact itself, through implementation of defense strategies against extreme events (i.e., dike upgrade and beach nourishment), but also through **transferring the climate risk and its costs** to a third party. **Households, but also communities, can thus decide to protect their assets through risk insurance arrangements.** Climate insurance increases resilience by providing financial support to those affected, helping them to adopt measures to limit the impact (losses) of a catastrophic event (i.e. providing incentives through premium discounts to policyholders who protect their property against natural catastrophes damages). The risk reduction measures that can be included in insurance products include: incentivizing risk reduction measures in property insurance, promoting proactive business interruption risk management (i.e., by covering an insured for losses arising from interruption to their business as a result of damage to insured property), improving creditworthiness of

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[13] The heat alert systems analyzed in the paper issue a heat-wave weather warning when there is an expectation of significantly higher-than-average temperatures in one or more regions of the country. It comprises four levels of response based upon threshold maximum daytime and minimum night-time temperatures, these thresholds vary by English region, with an average threshold temperature between 30°C and 15°C overnight.

insured adopting adaptation measures (Scholer, M., Schuermans, P. 2022). Incentivizing autonomous risk mitigation can be supported by creating a risk price signal that encourages households to avoid risk or take risk-reducing measures (Tesselar et al. 2020). In purely market-based insurance systems, insurance premiums are set according to risk. As a result of climate change, the increase in flood risk may cause substantially higher risk-based insurance premiums, making commercial insurance markets unappealing when it comes to climate change (Will M. et al. 2022). Because of this, the uptake of flood insurance in voluntary markets may decline when flood risk increases, because of climate change (Tesselar et al. 2020).

While disaster insurance coverage can enhance financial resilience of households to changing flood and other risks caused by climate change, income inequalities imply that not all households can afford flood insurance, and residual damage arises. The actual extent of residual impacts though also depends on the extent of adaptation implemented at the regional or community level. Hudson et al. 2019 evaluate the ability of flood insurance arrangements in Europe to cope with trends in flood risk. Results show that the average risk-based flood insurance premium could double between 2015 and 2055 in the absence of risk reduction behaviours by households and if no flood insurance market reforms are undertaken. Average household insurance premium is lowest in the solidarity public structure (€5–€125 per year in 2015) and highest in the private voluntary markets (€30–€2000 per year in 2015). These differences in premiums translate into different rates of unaffordability due to the differing degrees of cross-subsidization between high- and low-risk households. For instance, the voluntary private insurance premiums are unaffordable for about 21% of the regional population in high-risk areas (on average), whilst this is only 16% in the public private partnership market. Households with insurance coverage will be exposed to a potential premium discount if the household employs damage mitigation measures (i.e., precautionary measures such as long-lasting infrastructure or specifically aimed at preventing climate change, such as better insulation of dwelling against rising summer temperatures or as protective measures against extreme events such as flooding). Part of the expected future increase in flood risk could be hedged by flood insurance mechanisms that better incentivize risk reduction by policyholders, which lowers vulnerability. The affordability of flood insurance can be improved by introducing the key features of public-private partnerships, which include public reinsurance, limited premium cross-subsidization between low- and high-risk households, and incentives for policyholder-level risk reduction (Hudson et al. 2019, Tesselar et al. 2020).

By using an adaptation of the “Dynamic Integrated Flood and Insurance” (DIFI) model, Tesselar et al. 2020 show rising unaffordability and declining demand for flood insurance across scenarios towards 2080. A progressively rising flood insurance premiums is observed over time from the climate change scenario of +2,81°C to +4,31°C, for countries that maintain risk-based insurance premiums. Under a high climate change scenario, insurance uptake almost disappears. As a result, regional inequalities arise in the ability to use flood insurance as an instrument for adapting to increasing flood risk, particularly in regions with below average income per capita. The collapse of private flood insurance calls for a shift of flood damage compensation from pre-funded, formal insurance, towards less formal means of financing, such as ex post government compensation or self-insurance. (Surminski et al. 2015) reflect on how to use insurance as a lever for risk reduction and prevention efforts. The wide variety of existing insurance schemes, as well as different supply and demand patterns, shows that there is no ‘one-size-fits-all’ solution, and so there is wide agreement that a complete harmonization of flood insurance offering across the EU is unlikely to be effective (Hung 2009, EC 2013; EP 2014; Surminski et al. 2015). Insurance, or risk transfer in general, can boost resilience to natural hazards more effectively than ex-post disaster aid, but significant challenges for financial compensation mechanisms are expected, unless more risk-reducing measures are applied, such as flood defences, stricter building codes and/or land-use (zoning) policies.

Flood insurance still has low average penetration in Europe. People in recurrently affected areas seek insurance, while those who live some distance from a river are not interested in buying cover. For private homes and small businesses and their contents the annual premium can be relatively low. In Germany, premium starts at an affordable level of roughly €50 (in May 2019) in low-risk areas. Transferring to insurance the residual risk is highly recommended for areas with recurrent river flooding, while it is not known with sufficient lead time where and when a flash flood resulting from intense rainfall will hit. At the same time, the probability of being hit is so small that expensive structural flood protection measures are not reasonable compared to loss expectation.

In order to maintain the productivity of **land asset**, many adaptation actions are taken in the **agricultural sector**. Adaptation strategies in this sector can include altering sowing and harvest dates, switching to climate -resistant cultivars, irrigation changes, water reallocation among crops, increased land use efficiency, and soil water saving techniques (Bednar-Friedl et al. 2022). Adaptation strategies to prevent, or at least reduce detrimental effects of climate change bring about some costs. For the agricultural sector the increased need for crop protection entails, for instance, changes in farming practices such as the introduction of organic farming, which may have a higher resilience to climate change, but such a change may result in greater operating expenses and imply premium charges or subsidies. Moreover, addition costs for farmers will arise from an increased demand for pesticide control, the need for new agricultural systems with lower GHGs emissions and for new irrigation systems (Bindi & Olesen 2011). With higher warming levels due to climate change, financing needs are likely to increase, individuals might need to ask for more financial tools to speed up private adaption efforts, such as loans, subsidies, direct investments, and governments will have to decide how to act, for instance whether to reduce some expenses or raise taxes (Bednar-Friedl et al. 2022).

Balkovic et al. (2015) estimated the difference in **welfare** (the sum of producer and consumer surplus) with and without climate-induced yield shocks using the partial-equilibrium model GLOBIOM for a 2°C scenario (mid-century). They found that when adaptation was included, climate change had an overall positive monetary aggregated impact on land-use-related sectors in Europe of USD $ +0.56 billion/year but found a loss of USD$ 1.96 to 6.95 billion/year without adaptation. Some studies quantified the **effectiveness of adaptation**. With adaptation the predicted 22% decline in barley yields could be reduced to 15%, for maize yields losses would be reduced from 9% to less than 1% and overall average agricultural profits in Europe with adaptation would slightly rise (1.5%) but without it they might fall by 2.3% (Moore & Lobell 2014).

For **fire hazards,** regional policy makers will need to evaluate strategies of adaptation and prevention mechanisms (Meier et al. 2023), that might entail **additional costs for a region (public expenditure).** Adaptation actions to reduce fire propagation and ignitions include **mechanical clearing, prescribed burning, land management activities,** better vegetation management, and human intervention to help the recovering of valuable ecosystems after a fire (Costa et al. 2020). Additional costs might be related to **education for trainings on safety and health impacts and to** increasing citizen's awareness and preparedness (de Rigo et al. 2017), together with **psychological support** for more vulnerable citizens. (Costa et al. 2020). Southern regions in Europe are the ones most affected by climate change and most of the time these are the most vulnerable regions with reduced adaptive capacities, therefore if no local adaptation strategies are put into place, the disparities between Southern Europe and Northern Europe will risk growing even more.

2.2.2.3 Gaps

Even though the literature review shows a good coverage of adaptation at household level through insurance sector and increased energy demand (autonomous adaptation), it is important to note that only rarely there are estimates of adaptation costs at household level, while in most cases analyses estimate the overall cost for the economy in terms of GDP. Additionally, individuals may decide to increase their expenditure boosting dwelling energy efficiency and risk protection; this research question is currently scarcely explored, mainly for the lack of data on these investments and their explicit link to adaptation concerns.

2.2.3 Climate change cost of mitigation for European households

2.2.3.1 Expenditure and income channel

The costs of the mitigation actions are likely to have uneven impacts across the European population, leaving disadvantaged people more exposed and vulnerable (Watkiss et al. 2016; Temursho et al. 2020; Rao et al. 2017).

Overall, there are three main mechanisms that determine how mitigation policies affect households. First, the **direct or forward cost-shifting component**, which refers to the direct increase in energy prices faced by consumers, leading to higher expenditure (also known as **use-side effect**). Second, the **indirect component leading to changes in the production costs of all commodities**. Third, the **behavioural changes in consumption and production**. On the consumption side, budget-constrained households adjust their consumption mix responding to changes in relative prices. On the production side, firms substitute the more expensive energy-intensive inputs with other inputs, including imported ones, a channel leading to carbon leakage. Behavioural responses on the production side can also affect the sectoral returns to the primary factors of production labour and capital, and so household income (source income effect).

Indirect and behavioural responses are second-order effects that can be evaluated by general equilibrium analyses, such as those based on computable general equilibrium models. **The indirect impacts of a consumer tax across income levels (vertical equity) can differ significantly from the direct impacts on energy**. However, the direct component can be expected to be the main driver of distributional implications.

A broad country-specific literature has investigated the distributional implications and the welfare incidence of policies such as fuel and carbon taxes, as reviewed by Fullerton & Muehlegger (2019) and Pizer & Sexton (2019). Empirical approaches have highlighted that the regressivity of these policies depends on the fuel that is targeted (Pizer and Sexton, 2019), on the time horizon that is considered (Bovenberg and Goulder, 2002; Paltsev et al., 2007; Rausch et al., 2011), and on the chosen measure of household welfare (Grainger and Kolstad, 2010).

Temursho et al. (2020) proposes an alternative approach (a macro-micro framework) and provides an EU-wide assessment of the distributional implications of a 55% cut of emission in 2030 with respect to 1990. The distributional effects of environmental and climate policies have been reviewed taking into account ex-post empirical evidence (Vona, 2021), and from the ex-ante modeling methods to include household heterogeneity (van Ruijven et al., 2015). A systematic review of models used in climate research analyzes the different methods for assessing distributional impacts of climate change impacts and policies providing insights to improve them (Rao et al., 2017).

The Energy Modelling Forum 36 (EMF36) (Böhringer, Peterson, and Weyant 2022) coordinated a study to provide insights on the **Post-Paris climate policy** designs up to 2030, considering impacts and costs not only at the national level but also their distributional implications for selected case studies. They estimate a welfare median cost of 0.6% for Europe in the National Determined Contribution (NDC) scenario where regions attain the mitigation targets by means of domestic action, with carbon prices in the range of 25–250 \$/TCO2 (2001\$) by 2030 (Böhringer et al., 2021). Results confirm the regressive effect of mitigation policies that could be compensated with uniform lump-sum transfers to households. Free allocation of abatement permits, despite safeguarding the competitive position of selected industries, could lead to regressive effects for households. This behaviour is explained by three reasons (Vandyck et al. 2021): i) with a cap on emissions higher output levels brings a higher carbon price that place and additional burden on households as well, ii) grandfathering[14] emission permits limit revenues which could be recycled to offset welfare losses in particular of low-income households, and iii) grandfathering permits increase capital income, which is higher among high-income groups.

2.2.3.2 Recycling scheme

The recycling schemes of the carbon revenues can be used to reverse the regressive implications of mitigation policies (Böhringer et al., 2021). The revenues from carbon price auction could be redistributed with a progressive offsetting effect, suggesting that there is room for reconciling competitiveness and equity concerns in a partial permit auctioning scenario. Another study from EMF36 analyses distributional impacts between and within 21 European Union countries considering fully auctioning permit policy scenarios with different revenue recycling schemes confirming the progressivity of revenue redistribution alternatives with more progressive outcomes with a per-capita basis redistribution (Landis, Fredriksson, and Rausch 2021). Gancheva et al. (2023) confirms in another literature review the regressivity of carbon taxes unless a revenue recycling mechanism is in place to offset it. Similarly, Temursho et al. (2020) suggest, tax revenues can also be recycled to pursue equitable climate policies.

2.2.3.3 Gaps

Despite a broad country-specific literature has investigated the distributional implications of mitigation policies such as fuel and carbon taxes, cross-county comparative analyses are still sporadic. The (economy-wide and sectoral) modelling cost assessments of mitigation policies provide a multi-country picture of policy implications but mostly disregarding the household dimension.
Individual behavioural shifts that may represent key-elements into GHG emission reduction e.g., the consumption of zero km food, circular economy and private mobility, are scarcely analysed due to the lack of data and quantification issues.

3. A new empirical study on the costs of climate change impacts and adaptation on households

3.1 Methodology

This section presents **a new empirical assessment of the cost of climate change impacts on households’** sector-specific **expenditures and** different **income** sources at the EU level. To the best of our knowledge, this is the first systematic, quantitative assessment of the costs of climate change with a

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[14] "Grandfathering" refers to the practice of allocating or distributing a certain amount of emissions allowances for free to existing participants or entities based on their historical emissions.

high coverage of EU Member States and focusing specifically on households[15]. In addition, the study considers climate-induced changes in income sources as well as in expenditure. Climate change can affect households' income by altering the availability and the productivity of their income sources such as labour, capital, and land. Climate change can also induce unanticipated variations in sector-specific expenditure of households, such as health expenditure after injuries and distress associated with extreme flood events, but also energy and food expenditure (autonomous reactive adaptation), or in the form of autonomous proactive adaptation (e.g., insurance). In this report, we focus on these specific sectoral expenditure (health, food, energy, insurance) because they are essential material requirements for social and physical wellbeing of individuals, and they can be used to assess multi-dimensional poverty risk other than the income-related ones (Rao & Min, 2018). The assessment of climate change costs related to mitigation policies are described in Section 4 because they stem from a different methodological approach.

The methodology to evaluate the economic costs of impacts and adaptation consists of three steps:

1. A **statistical relationship** is established between the magnitudes of a range of climate-related hazards and expenditure types and income sources.
2. **Future climate and socio-economic scenarios** are collected to project the future climatic and socio-economic characteristics of households.
3. The statistical relationships from (1) are combined with the scenarios from (2) to develop our own **projections of climate change impacts and adaptation for European households** around mid-century (year 2050).

The study combines socioeconomic data, i.e., the European Household Budget Surveys (HBSs) from Eurostat and climate/hazard data mainly form ERA-5 dataset. The datasets are described in Section 3.2.1 and 3.2.2. Starting from the statistical specifications categorized in the literature, we identified simple linear and non-linear[16] statistical relationships between socioeconomic and climate-hazard variables of interest. All specifications control for sociodemographic characteristics (total expenditure, presence of elders in the household, number of members, gender, employment status, age and education level of the household's head), country, and wave fixed effects. For some expenditure types, we adopt an empirical strategy (tobit model) that performs well with censored variables, i.e. those variables with many zero values.

Households' choices and their wellbeing strongly depend on public adaptation investments that countries and regions in which they reside might adopt, unfortunately the microdata (HBSs) do not provide any information on the implemented policies. We do not observe regional/country enforced policies, but we account for their potential implications through country- and time-related fixed effects[17].

All regression results are reported in Appendix D-II. In Section 3.3, we provide a graphical and intuitive description of the historical correlation between expenditure/income variables and climate/hazard ones. These estimated coefficients together with future climate and socio-economic scenarios allow defining

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[15] Our unit of analysis is the household, the same of our main data source (Eurostat HBS) and on specific demographic characteristics such as households' size, age, gender and occupation of their members that seem key in quantifying future cost of climate change for the households.

[16] Non-linear statistical relationships capture how the impact of a climate stressor varies depending on the initial level of the climate variable

[17] Introducing a country fixed effect is a statistical method allowing to isolate the effect on the estimation results of (omitted) variables that differ across entities (e.g., country), but are constant over time. For example, it singles out the peculiarities of each analyzed country. The time fixed effect works similarly accounting for the effect of (omitted) variables that differ over time, but are constant across entities (e.g., country). For example, it isolates particular shocks characterizing a specific year.

the future pathways of the expenditure/income variables (Section 3.2.1 and 3.2.2 describe climate and socio-economic scenarios used in creating these projections). Section 3.4 provides the assessment of 2050 climate change impact and adaptation costs by NUTS1 regions and population terciles, drawing some conclusions in terms of poverty and inequality. All these metrics are computed weighting the household income and expenditure (equivalised scale) by the size and age of household components as is common practice in the literature.

3.2 Data and projections

The present section describes the set of data used to estimate the statistical relationships between climate variables and household impact and adaptation costs and to derive future cost projections in 2050. Section 3.2.1 describes historical climate/hazard metrics used in the study and their future evolution under a moderate climate change scenarios and a severe one. Section 3.2.2 gives an overview of the socioeconomic data used in the empirical estimates (Eurostats’ HBS), of the metrics computed to analyse distributional and poverty implications of climate change, and of the future evolution of socioeconomic variables under a business as usual and a high-growth scenario.

3.2.1 Climate-related hazards metrics and their projections

The **historical dataset of climate/hazard metrics**[18] is developed starting from meteorological variables available at sub-daily or daily timescales (e.g., temperature, precipitation, wind, humidity). Using ERA-5 dataset[19] and geospatial data analysis techniques (see Appendix A), we extract historical climate data at the NUTS-3 level and subsequently aggregate them at the NUTS-1 or NUTS-2 level considering the urban-rural stratification to match the spatial granularity of the Eurostat HBS in each EU Member State. We compute the following historical climate/hazard metrics:

- **Mean temperature**
- **Cooling Degree and Heating Degree Days** (**CDDs, HDDs**), a measure of how much (in Celsius degrees), and for how long (in days), air temperature was higher/lower than a specific base temperature (set at 18° C in our analysis);
- **Standard Precipitation Index (SPI)** for determining the onset, duration and magnitude of drought or flood conditions with a reference scale (deficit/surplus accumulation period) of 12 months;
- relatedly, **count variables of moderate and severe dry and wet spells,** defined as the count of months with a SPI index value < -1.5 (or >1.5) and < -2 (or >2), respectively;
- **burnt area** based on a burn-sensitive vegetation index[20].

The selected metrics are computed for the available HBS survey years (2010 and 2015), and for the long run (average or cumulative count, depending on the metric) starting from 1980 (and from 2000 for the MODIS burnt area variable, as data are not available previously to this date.

To assess the future implications of climate change on EU households, we combine the information form the regression analysis with the **future projections of selected climate/hazard metrics up to 2050**.

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[18] We use the climate/hazard metric to describe both a descriptive statistic of a climate variable (e.g. historical mean temperature) and an index (e.g. Standard Precipitation Index - SPI).

[19] ECMWF Reanalysis v5 (ERA5) dataset (DOI: 10.24381/cds.adbb2d47)

[20] The burnt are is extracted from NASA’s MODIS satellite dataset.

Using CMIP6 projections data (for more details see Appendix A), we compute the future projections of climate hazards metrics for two alternative futures: a **moderate climate change scenario** (SSP2-RCP4.5, thereafter **SSP2-4.5**) and a **severe climate change scenario** (SSP5-RCP8.5, thereafter **SSP5-8.5**). See Box 2 and Appendix B for the extended explanation.

BOX 2: Shared Socio-Economic Pathways (SSPs) and Representative Concentrations Pathways (RCPs)

Within the Sixth Assessment Report of the IPCC(2021), each SSP (socioeconomic scenario) has been associated with one Representative Concentration Pathway (RCPs) describing the mean global surface temperature changes at the end of the 21st century.The **SSP2- RCP4.5** and foresees the mean rise of mean global temperature by 2.9°C by 2100, which almost aligns with the extension of current mitigation policies to the end of the century (UNDP, 2022); while the full implementation of Paris Agreement's NDCs (Nationally Determined Contributions) will limit warming to 2.4°C in 2100. The **SSP5-RCP8.5** (+4.8 °C) is considered by the scientific community less likely unlikely, but it provides a useful worst-case counterfactual.

Figure 1 gives a snapshot of the level assumed by the selected climate/hazard metrics in the historical period (1980-2015) across NUTS1 regions in the left column and displays the projected changes in 2050 under SSP2-4.5 (moderate) and SSP5-8.5 (severe) climate change scenarios (central and right column). **Mean temperature** and **CDDs**, representing cooling requirements, show a strong North-South divide in the historical period (A and B panels). **HDD** (C panel), representing heating requirements, which are high in North Europe, are less unequally distributed, as considerable winter heating requirements exist also in Western and Eastern Europe. Mean annual temperature increases everywhere, with a spatial mean difference value of around 1.1-1.3° C in the two scenarios (compared to the reference 1980-2015 period average), but several NUTS regions experience significantly higher (Eastern EU) and lower (Northern EU) values (A panel). The spread of higher temperature intensifies in the severe climate change scenario. The rise of mean temperatures goes along with an increase in CDDs and a decrease in HDDs. CDDs grow in all NUTS regions of Europe, with the strongest increase observed in the already relatively hotter southern and Mediterranean areas, such as the Iberian Peninsula, Southern Italy, Greece and the Balkans, and the Anatolian peninsula. Increases are also observed in central and continental Europe, and over Eastern Europe. SSP5-8.5 shows a significantly stronger intensification of CDDs (B panel). HDDs decrease in all NUTS regions, and most prominently in the Alpine region and over parts of Eastern Europe and the Anatolian peninsula, whilst they shrink to a lesser extent in Northern Europe or in regions with already currently low HDD values, such as Andalucía and Portugal (C panel).

The incidence of **drought events** shows a rapid growth, especially in the 2009-2015 period (Figure 1 - panel D). An intensification of moderate dry events is observed in several areas of Europe, with hotspots in Northern Europe (e.g., Scandinavia, Great Britain) and in Southern, Mediterranean countries. Conversely, when looking at severe drought events, this intensification is most prominent in Western Europe (e.g., France, Germany, Northern Italy). Severe drought events will intensify mostly in Western and Eastern Europe as well as in specific regions of Southern Europe, while they are projected to significantly decrease in Northern Europe. Severe floods have increased particularly in Eastern Europe, while moderate flood events surged mostly in Western and Northern Europe between 2009-2016 (Figure 1 – panel E). Projections foresee severe floods to become more frequent – depending on the scenario considered – in Western Europe, Central and Southern Italy, as well as parts on the United Kingdom and the Baltic countries, and over Greece. On the other hand, severe floods seem to be declining in the Alpine region, the Iberian Peninsula, and Eastern Europe. However, when looking at the total flood indicator (including also milder flood events), the situation is that of a generalised drying of Europe, with most regions showing a decrease in wet events.

Annual average burnt area shows a clear and expected pattern with hotter and drier areas in Southern Europe (and most prevalently in the Iberian Peninsula, in Southern Italy, in the Balkans and Hellenic region, and in Anatolia) showing recurrently higher burnt areas than Western and Northern European NUTS regions. While yearly-variability is expected, the maps seem to reveal that – compared to 2009-2010 – the 2014-2015 period showed a higher incidence of burnt area in Western European regions, with a persisting high-incidence in Southern Europe. This metric, although correlated to high temperature and dry weather, depends on other socioeconomic and institutional factors that prevent us from computing future projections.

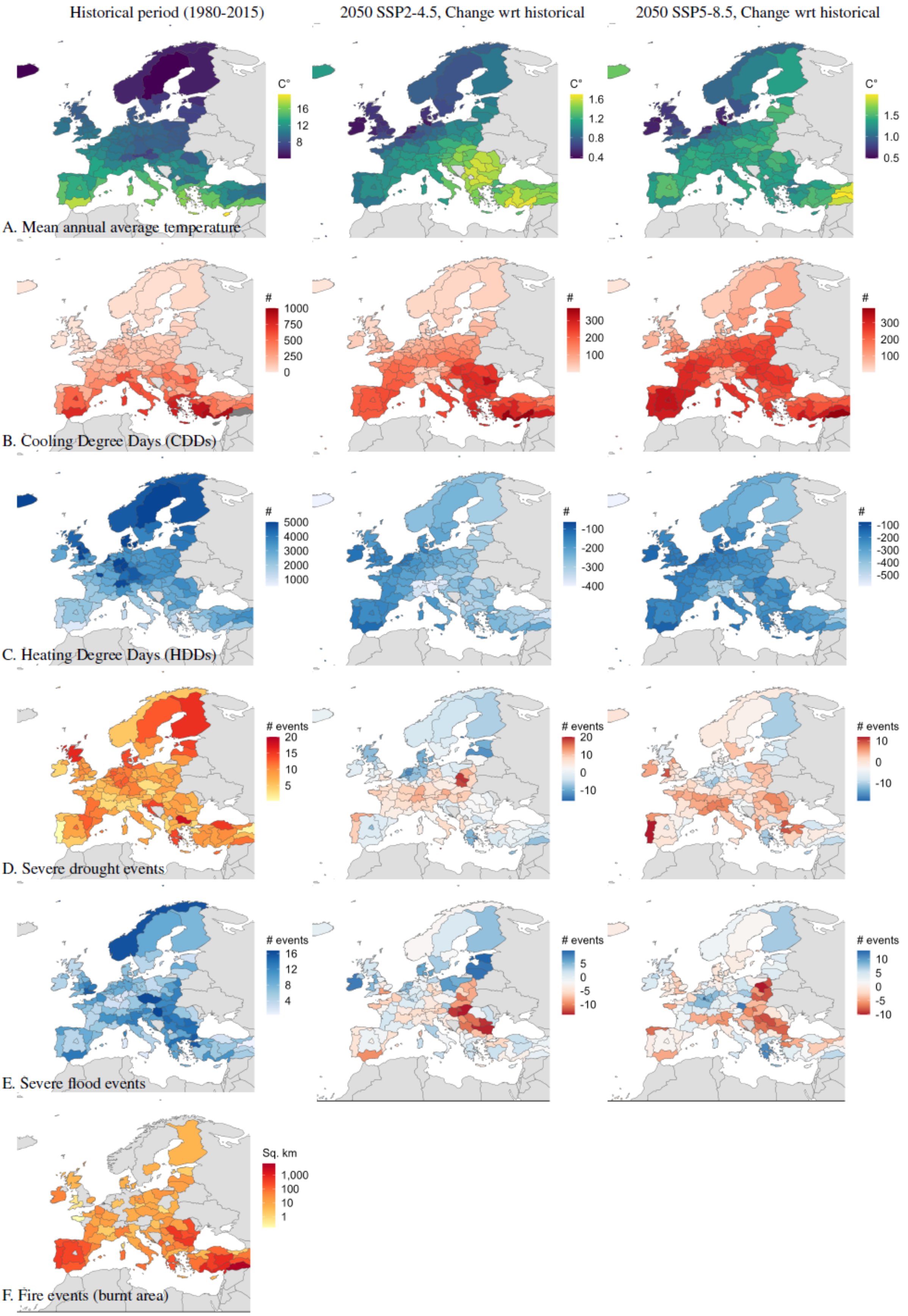

Figure 1: Climate/hazard metrics at the NUTS-1 level in historical period (left column) and projected changes in SSP2-4.5 (central column) and SSP5-8.5 (right column) with respect to the historical period

3.2.2 Socioeconomic data, metrics and projections

3.2.2.1 Historical socioeconomic data

The European Household Budget Surveys (HBSs) by Eurostat collect information on households' expenditures and income sources in EU[21]. According to HBS 2010 and 2015, the average EU equivalised expenditure in the EU27 is 13,699 euro/yr[22]. Figure 2 (left) shows two main groups of Member States' expenditure patterns, those spending more than the EU average, such as Denmark, Luxembourg and Netherlands, and those spending less, such as Bulgaria and Romania. The countries with the lowest equivalised expenditure levels are mainly in Eastern Europe. A low average expenditure/income level is already an indicator of potentially greater vulnerability to climate-related shocks, as bounded spending opportunities limit the possibility to undertake adaptation actions.

The distribution of **expenditure** across sectors in Figure 2 (right) helps identify country-specific vulnerabilities. For example, food expenditure share, on average 21.2% in the EU, is much bigger in Bulgaria (34.9%) and Romania (40.2%). High budget shares devoted to food expenditure are often connected to food-related poverty and overall poverty because they imply that most of the expenditure is used to purchase necessary goods. Energy expenditure as well, which in Figure 2 (right) falls in the aggregate “Rent/Utilities”, absorbs a higher share of income in the same countries spending a large fraction of household budget on food (see the Appendix D-I for Tables with country-level descriptives).

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[21] HBSs cover all EU28 Member States excluding Austria and the Netherlands only for the 2010. We focused our analysis on EU27, i.e. we excluded UK that is no longer part of EU since 2020.

[22] We use here the OECD-modified equivalence scale to rescale household flows depending on household size and the age of household members. This scale assigns a value of 1 to the household head, of 0.5 to each additional adult member and of 0.3 to each child. See https://www.oecd.org/els/soc/OECD-Note-EquivalenceScales.pdf

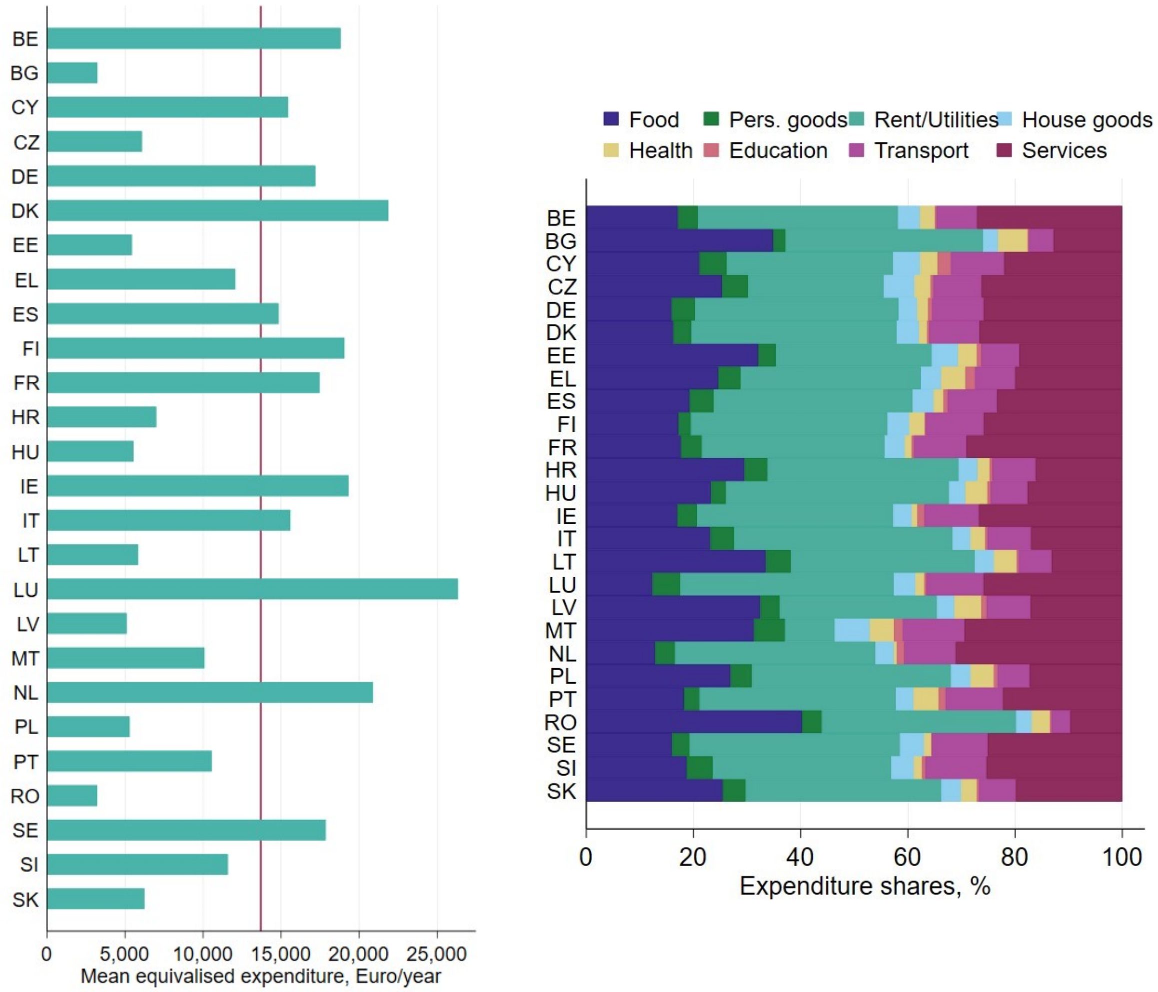

Figure 2: Total equivalized expenditure across Member States and EU27 average -red line- (left) and expenditure shares across Member States (right). 2010 and 2015 HBS value average.

HBS gives a thorough description of household **income** in several EU Member States[23] and its main sources. The distribution of income sources across regions can be important to understand country-specific vulnerabilities. Figure 3 (left) partially summarises the income components, their relative weights within each country and their positioning with respect to the EU average. We see that labour income is the most important component of net income for most countries (with available data). This is not true on average in Greece, Romania, and Spain, probably due to the high contribution of the profit and investment components[24]. As previously observed, the Eastern-Europe is characterised by income and labour income strongly below the EU average.

Despite the missing data in the HBS labour income statistics[25], we observe that on average 3% of labour income in EU comes from the agricultural sector, 13% form the industrial and 31% from services. Figure 3 (right) highlights that some countries rely more than the average to the agricultural income (Romania

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[23] Some countries do not report almost any information on income (Italy and Luxembourg) and Bulgaria, Cyprus, Czech Republic, Estonia, Ireland, and Lithuania do report information on the job income.

[24] This is an average result at county level, disregarding the within country distribution of different income types.

[25] Labor income statistics are available only for Belgium, Germany, Denmark, Greece, Spain, Finland, France, Croatia, Hungary, Ireland, Latvia, Netherlands, Poland, Portugal, Romania, Sweden and Slovenia. Furthermore, a big portion of income (around 50%) is not classified by source sector; in the Netherlands this happens in 100% of the sectors.

and Portugal); this sector is expected to be the most exposed to climate change risks and household relying on income from this sector will be likely to be adversely affected.

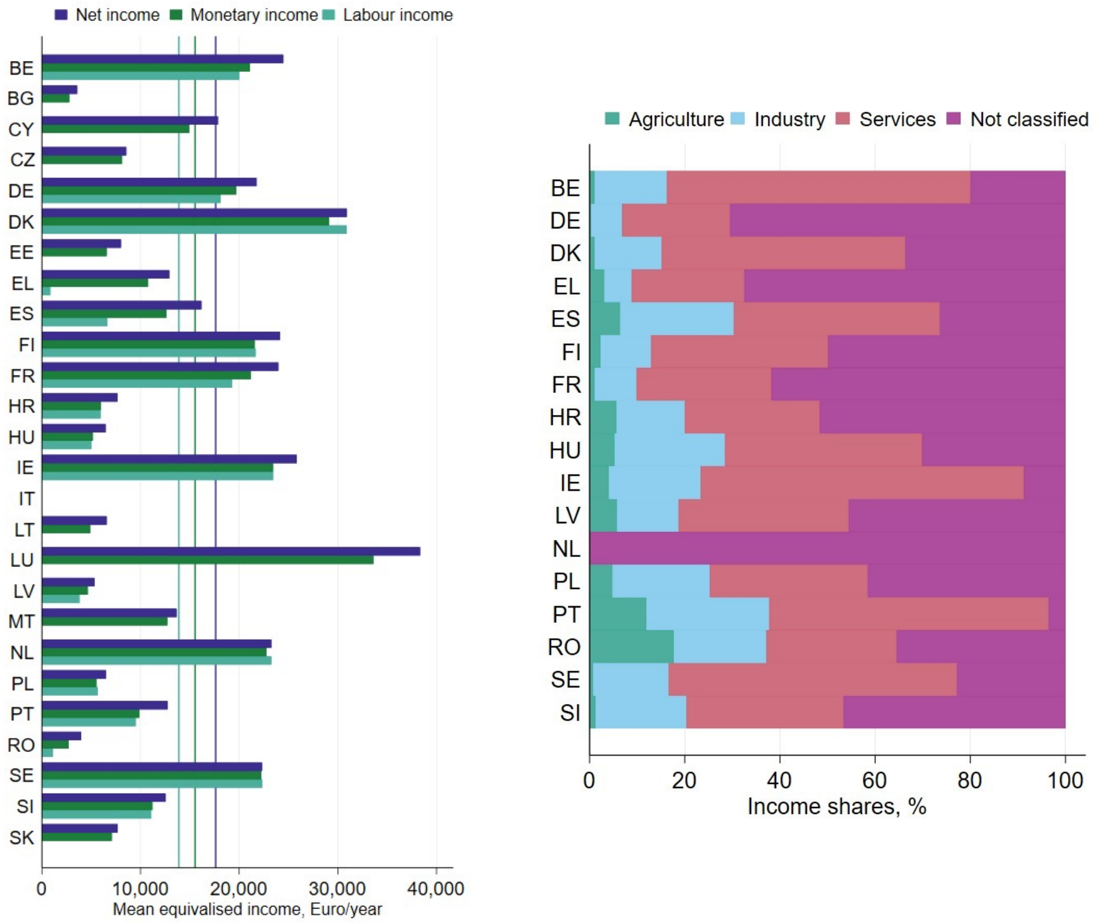

Figure 3: Mean equivalised income sources across Member States and EU averages -lines- (left), and mean labour income source shares across Member States (right). 2010 and 2015 HBS value average.
Monetary net income= labour income + profits + investments + transfers – taxes; Imputed rent = owners' imputed rent and that of tenants living free of charge. Countries not shown in the right panel do not report information on the different income sources.

3.2.2.2 Distributional and poverty metrics

We analyse three widely used indicators to characterise the income distribution, the risk of poverty and of energy poverty within EU27 counties. The **Gini index** is a synthetic measure of income distribution, taking high values (up to 100) in presence of high levels of inequality, i.e., rich individuals receive a high percentage of country income, and low values (up to 0) when the distribution converges to equality. We computed the Gini index using both the net monetary income (income from all sources i.e., labour income, profits, investments and transfers, net of taxes) and labour income in order to account for inequality due to the remuneration of labour and inequality due to asset remuneration and social transfers[26]. Figure 19 (left) in Appendix C highlights the labour income is slightly more unequally distributed with respect to the monetary income, due to the equalising effect of social transfers in the latter aggregate.

The **at-risk-of-poverty indicator** (Figure 19 – right, Appendix C) highlights a stronger discrepancy in results depending on the income category considered. It is much higher if it is measured on the labour

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[26] The country coverage is limited especially in the case of labour income. However, we are particularly interested on the labour income because it is a more homogenous aggregate with respect to monetary income in which we are not able to distinguish the effect of social transfers and of investment/profits.

income and lower if we account for investment and transfer components included in the monetary net income[27].

We complement this set of indicators which focus on income dimension with the **energy (fuel) poverty prevalence indicator** that is computed using energy expenditure shares. Energy (produced from different fuels) contribute to a comfortable and healthy living environment, but it is only one good/service, among many that increase individual wellbeing, When a significant portion of a household's income is spent on energy bills, it may leave inadequate funds for other essential needs such as food, clothing, and healthcare. Therefore, we define as energy (fuelv) poor those household whose energy expenditure budget share is higher than that of households under the poverty line.

3.2.2.3 Future socioeconomic pathways.

The information contained in the HBS dataset are essential for defining the relationship between climate-related hazards measured in the past and household wellbeing, but envisioning the future evolution of this relationship requires the definition of some broad socio-economic scenarios. Scenarios provide a description of how the future may develop, based on a coherent and internally consistent set of assumptions about key drivers e.g., demography, economy, technological innovation, and governance (IPCC, 2021; Rounsevell and Metzger, 2010; O’Neill et al., 2014).

BOX 1: Shared Socio-Economic Pathways (SSPs)

The SSPs (O’Neill et al., 2017a) describe five pathways representing plausible trends in the evolution of society over the 21st century. The SSP1 *‘sustainability’* describes a world converging toward lower inequality and resource/energy intensity and increased human wellbeing. The SSP2 is the *‘middle-of the-road’* scenario displaying a similar socio, economic and technological pattern to the historical one. The SSP3 describes a *‘regional rivalry’* scenario where countries focus on regional competitiveness and security with no concerns on the global development, slow economic development, high resources intensity and persistent inequalities. The SSP4 is an *‘inequality’* scenario across and between countries characterized by a widening gap between connected and capital-intensive regions and poor and labour intensive ones. The SSP5 describes a *‘fossil-fuelled development’* characterised by high technological progress, strong integration, high economic and population growth, but not abandoning high energy intensity and resource exploitation.

The most widely used scenarios in climate change literature are the Shared Socio-Economic Pathways (SSPs) that spans the range of challenges ahead for climate change mitigation and adaptation (Rothman et al., 2014; Schweizer and O’Neill, 2014). In this report, we focus on **SSP2**, the ***‘middle-of the-road’*** scenario, which can be considered a business-as-usual scenario, and **SSP5**, the ***‘fossil-fuelled development’*** scenario, which is a high growth scenario regardless of the environmental aspects. Figure 4 describes the how GDP and population distributes in 2015 across NUTS1 regions and the expected change in 2050 according SSP2 and SSP5. We can observe that both population and GDP growth are stronger under SSP5. The GDP will grow more in the Eastern EU than in the Western, with very low growth expected in the Western EU. Population is expected to grow more it the Eastern EU, less in the Western and will be negative in some Eastern NUTS1.

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[27] The different magnitude of results when comparing Gini index and at-risk-of-poverty indicator is not surprising considering the low sensitivity of the Gini index to the tails of the income distribution (Cobham and Sumner, 2014) and the fact that instead poverty indicators focus on the left tail of the distribution.

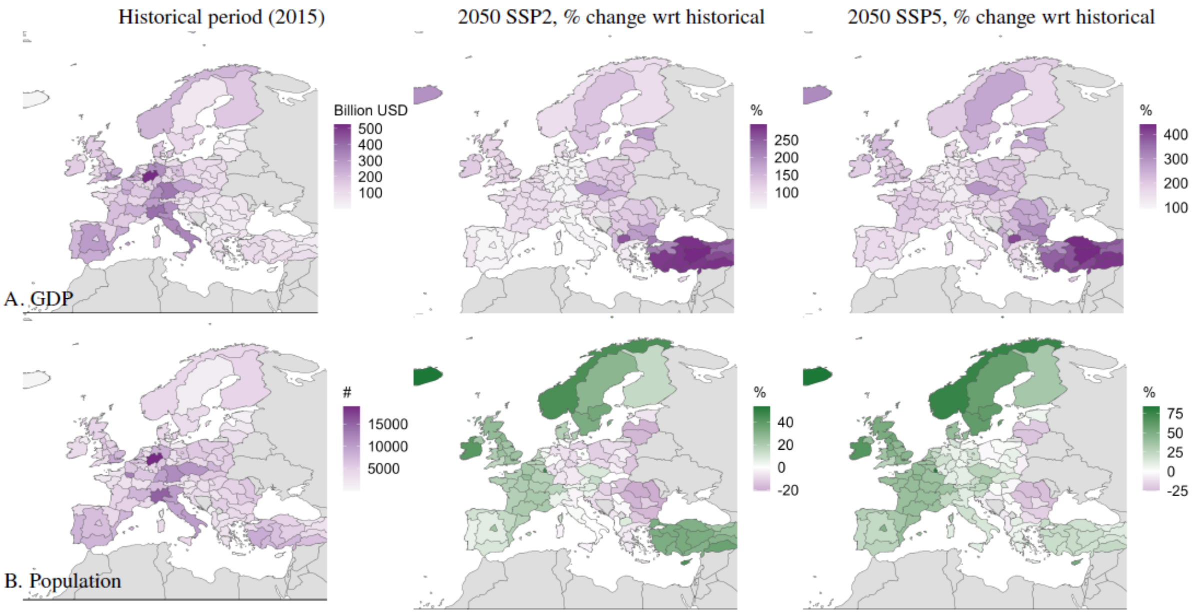

Figure 4: GDP and population at the NUTS-1 level in historical period (left column) and projected % changes in SSP2 (central column) and SSP5 (right column) with respect to the historical period

3.3 The relationship between climate/hazard metrics and the cost of climate change

In this section, we provide a graphical and intuitive description of the estimated relationship between climate/hazard metrics and the cost of climate change. The complete set of results is reported in Appendix D-II.

3.3.1 Costs of climate change impacts through the health and food expenditure channel

We analyse the relationship between **health expenditure** and climate hazards, specifically average historical temperature, the total (moderate plus severe) flood episodes over a year (SPI)[28] and the burnt area (km^2). In Figure 5 (A panel-left), we see that health expenditure has a U-shaped relationship with average temperature; below 10°C, an increase in temperatures reduces health expenditure, probably due to the reduced cold-related health issues, whereas the sign changes when temperature is above this threshold. According to our analysis, the effect of a one-degree Celsius rise in temperature increases average households' health expenditure in EU by 2.8%. As expected, more affluent households show a stronger reaction to a marginal temperature increase, and the increase in health expenditure are 4.7% and 3.7% respectively for the medium- and high-expenditure terciles (Table 9, Appendix D-II). By comparing different income groups, we observe that rich households start purchasing health services at a lower temperature compared to the poor ones.

The relationship is inversely U-shaped with the total SPI flood episode (Figure 5, A panel-centre) indicating that, up to 27 floods episodes, one additional flood episode increases health expenditure. After crossing the threshold of 27 flood events on average per year, one additional flood episode reduces households' health expenditure (a possible saturation effect that can be related to the governments' interventions - public adaptation - backing up private health expenditure). We do not observe public adaptation actions, but they can include proactive (e.g., a government undertakes preventive investments to reduce the impacts of floods) or reactive (e.g., a government supports health expenditure of the

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[28] The Standardized Precipitation Index (SPI) classifies SPI values between 1 and 2 as moderate floods and above 2 as severe floods.

households negatively affected) measures. The effect of an additional flood event on health expenditure is heterogeneous depending on a household wealth. For medium-income and rich households, the correlation between health expenditure and flood events is positive, while for poor households is almost null. The poor tercile increases health expenditure up to 20 flood episodes, above such threshold one additional flood event reduces the health expenditure. This result suggests the lack of resources of poor families to be invested in health expenditure when the count of extreme events increases or the effectiveness of government safety net for poor households rises. On average, health expenditure increases by 1.9% for each additional flood event. Among rich and medium-income households, health expenditures increase, respectively, by 1.8 and 2.7%.

Increased exposure to fire risk could also induce more spending on health, but our empirical evidence (1% increase in burnt area implies a 0.4% increase in health expenditures) is only indicative and it is not statistically significant, meaning that we cannot exclude a null impact (Figure 5, A panel-right).

The relationship between **food expenditure** and multiple hazards considers the following set of hazards: average historical temperature, moderate floods ($1.5<SPI < 2$), severe floods ($SPI > 2$), moderate drought ($-2 < SPI < -1.5$), severe drought ($SPI < -2$), and the bunt area (km^2). In Figure 5 (B panel-left), we can observe a U-shaped relationship, characterising the average historical temperature and the food expenditure; the relationship is instead inversely U-shaped for the SPI indicator. One additional degree of temperature determines a rise in food expenditure by 0.3%, one point increase in SPI indicator (fewer floods or more droughts) lead to a 0.5% rise of food expenditure, and a 1% increase in burnt area implies a 0.01% surge of food expenditure (Table 9, Appendix D-II). Analysing the effect of temperature on food expenditure at tercile level, heterogenous responses emerge. On average, one degree increase in temperature determines a drop of food expenditure for poor household by 2.9%, a rise for medium-expenditure households by 1% and a rise for rich households by 0.3%. The negative impact of temperature on the food expenditure of poor households is likely attributable to a rearrangement of consumption choices following the increase in food prices given the limited resources of a poor household or to a diet shift towards lighter and cheaper food (autonomous adaptation). This intuition is confirmed when analysing the results of a parallel regression on food quantity (Appendix D-II); the temperature increase in one degree determines a contraction of 3.4% of food consumption, higher than the expenditure reduction to compensate the warming-related rise of prices of food as well as of other goods (e.g. energy). The contraction of food consumption characterises mainly the poor and the medium households. A one-point increase in SPI indicator (fewer floods or more droughts) induces a rise in food expenditure more pronounced for the poor and medium terciles (respectively 1.8 and 7.7 %).

3.3.2 Costs of climate change adaptation through the energy expenditure channel

Households' adaptation to climate change entails a variation in **energy expenditure** (**expenditure channel**). Figure 5 (C panel), describes the relationship between energy expenditure, CDDs, and HDDs. The overall impact of CDDs on aggregate energy expenditure combines two opposite effects on fuels used for different purposes, electricity for cooling, and gas for heating. A higher need of energy for cooling (usually electricity) is related to an increase in CDDs and more energy for heating (usually gas) is linked to a rise of HDDs. The fitted relationship between degree day and electricity expenditure shows a positive relationship with CDDs and a negative relationship with HDDs (Figure 10, C panel). The opposite occurs for gas expenditure (Figure 5 D panel). In the EU, a 100-unit increase in CDDs (HDDs) reduces the total energy expenditure by 0.5% (0.2%). A 100-unit increase in CDDs increases electricity expenditure by 1.1% and reduces gas expenditure by 9.1% (Figure 5 E panel, Table 9, Appendix D-II). A 100-unit increase in HDDs reduces electricity expenditure by 0.5% and rises gas expenditure by 0.6%.

All in all, the reduced gas expenditure due to milder temperature prevails, leading to a positive effect on a household aggregate energy expenditure.

Comparing responses of electricity and gas expenditure across terciles, we observe a magnitude change but no change in the sign of the semi-elasticities’ relationship for the entire sample. The increase in electricity expenditure following a 100-unit increase in CDDs (hotter temperature) is virtually the same for poor households and for rich ones (0.1% in both cases). A 100-unit rise in CDDs reduces the gas expenditure for poor households (-10%) more than for rich ones (-8.3%). The overall effect of CDDs on energy expenditure is regressive, i.e., the energy expenditure rises (in percentage terms) for poor households (0.6%) and drops for the medium and rich ones (-2.2% and -1.7%). The increase in electricity expenditure for cooling more than compensate the drop of gas expenditure for heating. The overall effect of HDDs (cooler temperature) on energy expenditure is instead slightly progressive with poor households decreasing energy expenditure by 0.05% with respect to 0.01% of rich households.

3.3.3 Overall costs of climate change impacts and adaptation through the expenditure channel

To summarise the overall effect on household expenditure, we analysed the relationship between the household total **expenditure** and climate hazards (average historical temperature the SPI[29] and the burnt area. Figure 5 (F panel) highlights an inversely U-shaped relationship with temperature, on average a one-degree Celsius rise in temperature decreases total expenditure in EU by 0.4%. Up to 10 degree Celsius the total expenditure rises, afterwards it starts dropping due to the conflicting effect of different expenditure types (expenditure in food and good rises under high temperature, while energy expenditure drops) and due to the impacts affecting the income sources (lower income as the temperature increases may imply lower total expenditure). Conversely, the relationship is instead almost linear and slightly increasing for the SPI metric: one point increase in SPI (fewer floods or more droughts) lead on average to a 0.7% rise in total expenditure (Table 9, Appendix D-II). The extension of the burnt area seems to be negatively correlated with the total expenditure probably due the negative effect of this variable on the income available for household expenditures.

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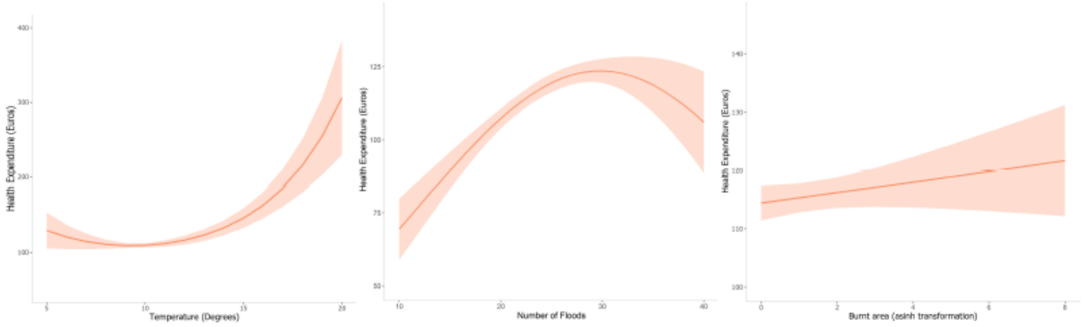
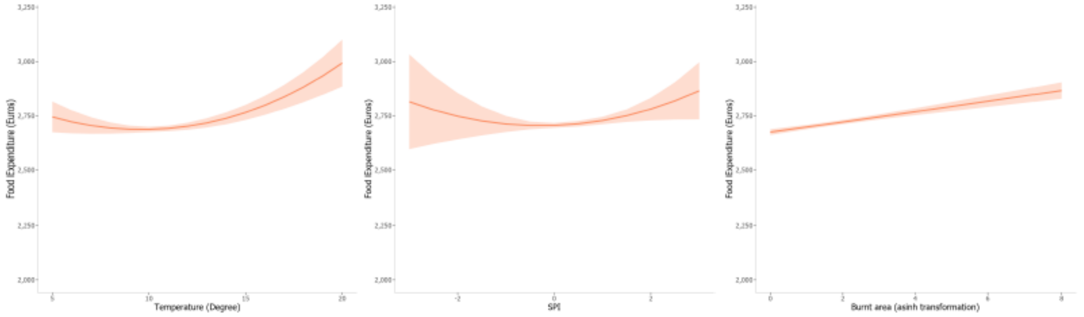
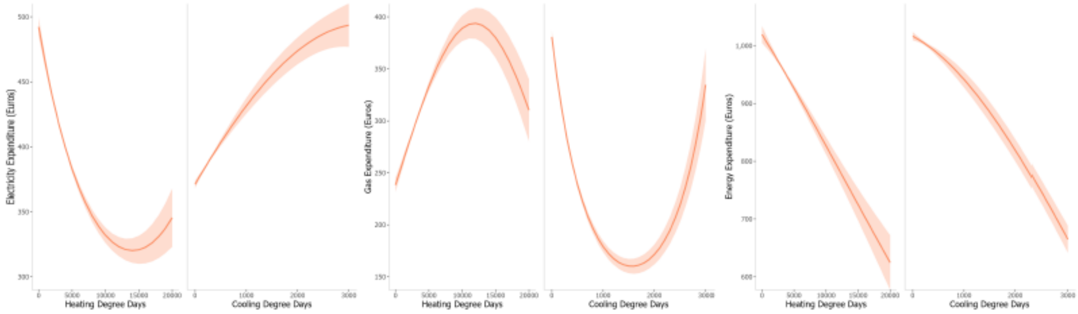
[29] The Standardized Precipitation Index (SPI) classifies SPI values between 1 and 2 as moderate floods and above 2 as severe floods.



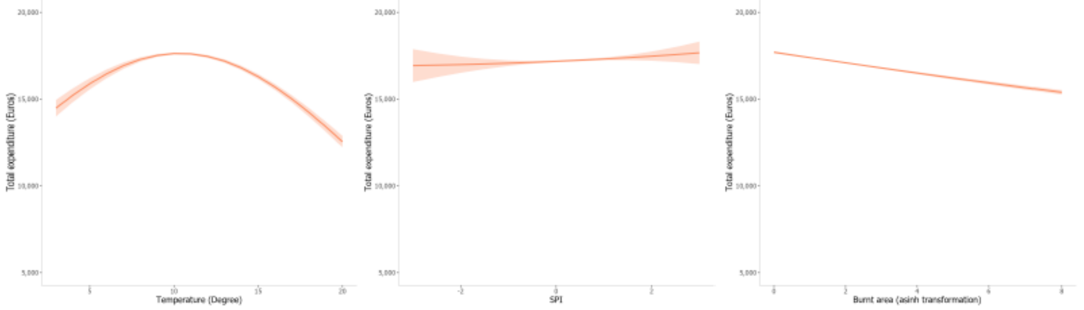
A. Health expenditure



B. Food expenditure



C. Electricity expenditure D. Gas expenditure E. Energy expenditure



F. Total expenditure

Figure 5: The cost of climate change through the expenditure channel, average response function in EU

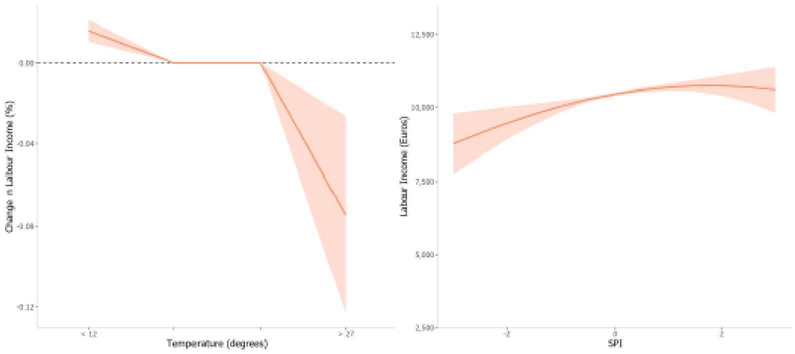
3.3.4 Costs of climate change impacts through productivity channels

Climate change impacts can also have a direct bearing on the sources of households' income, for example through individuals' labour productivity and remuneration (**productivity channel**). The impact of climate change on labour is differentiated across sectors and regions and for this reason it is intertwined with autonomous adaptive actions such as switching from more to less impacted sector of employment (job channel) or relocation/migration (opportunity channel). Unfortunately, it is not possible to disentangle these three effects given the information provided by the HBS.

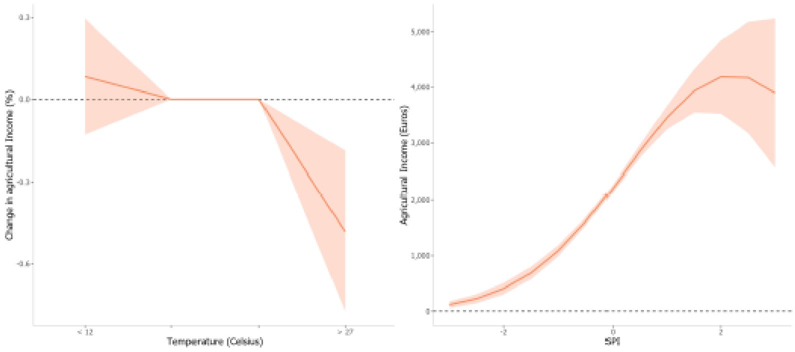
The correlation between **labour income** and temperature is analysed by using the temperature bins indicators that report the count of days whose daily average temperature fall within a specific range. We focus on the coldest and warmest bins, namely the count of days with average temperature below 12°C and with average temperature higher than 27°C and on the SPI indicator accounting moderate drought ($-2 < SPI < -1.5$), severe drought ($SPI < -2$), and moderate floods ($1.5<SPI < 2$), severe floods ($SPI > 2$). We excluded from this list of hazards the burnt area because this regressor is capturing a big portion of labour income response to above 27°C temperatures (regressions including burnt are reported in Appendix D-II).

If we consider the total labour income, we observe that an additional day with temperature below 12°C increases marginally labour income by 0.02%, while one additional day with temperature above 27°C brings about a 0.1% drop in income. Looking at the drought/flood implications on total labour income, we find a positive relationship between labour income and SPI, indicating an increasing positive effect of moving from severe to moderate flood events and of moderate drought events up to a certain threshold where the relationship reverses and income starts dropping (Figure 6 A panel-right).

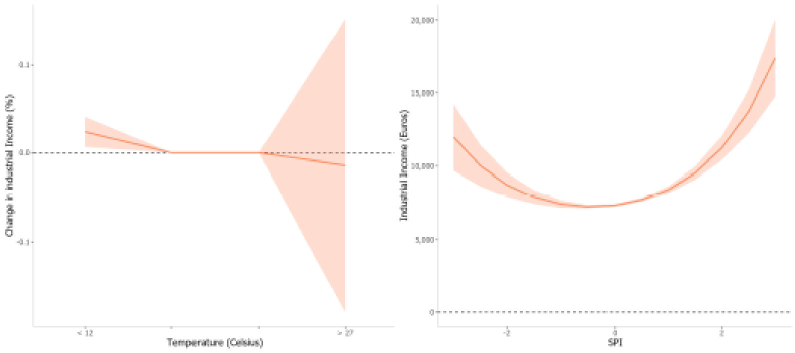
The positive relationship between more cold days and job income comes from the performance of industrial and service sectors (Figure 6 C and D panel), although these coefficients are not significant. The negative relationship between income and warm days is mainly due to the loss of income in agriculture, i.e., 0.5% for each additional day with temperature above 27°C (Figure 6 B panel). The relationship between income and SPI is positive but inversely U-shaped if we consider total labour income (Figure 6 A panel-right) and U-shaped for industry and service income (Figure 6 C and D panel-right). The response of agricultural income to the increase in SPI from a severe to moderate drought, and to no drought/flood events is positive and increasing (Figure 6 B panel-right).



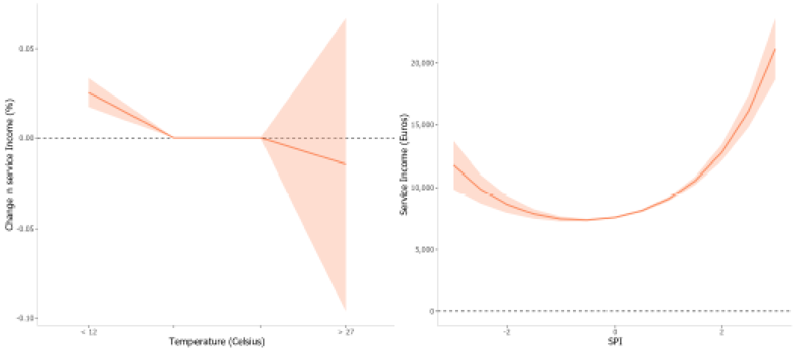
A. Total labour income



B. Agricultural income



C. Industrial income



D. Service income

Figure 6: The cost of climate change impacts through the productivity channel, average margins, and response functions in EU

3.3.5 Costs of climate change impact through the asset channel

Statistical offices estimate the value of housing assets (imputed rent) by using the market rents for equivalent properties (rental equivalence approach) or the housing operational costs plus the returns from alternative investments (the capital market approach)[30]. We analyse the implications of multiple hazards (temperature, floods, and wildfire) on households’ **imputed rent[31]**. Imputed rents increase on average by 1.9% following a 1° increase in mean temperature. The effect of a marginal increase inmoderate and severe floods is not significant and on average very small, but with positive sign in the case of moderate floods and negative for severe floods. An additional squared kilometre of burnt area in the region reduces the imputed rent by 0.0003%. The fitted relationships displayed in Figure 7 (A panel) depict the impact of the explanatory variables across the distribution of imputed rent. We observe an inverse U-shaped relationship between imputed rent and daily average temperature, suggesting that a temperature around 12°C maximize the imputed rent value, i.e. regions with an annual average temperature of 12° are preferred by EU household because such temperatures agree with their thermal comfort, and for this reason the market attributes a higher imputed rent (value) to properties in these regions. Below 12°C the imputed rent tends to decrease as the temperature drops, after 12°C it drops as the temperature rises. We observe the opposite relationship for moderate and severe floods. The increase in number of flood events in a given region impacts negatively on imputed rent until it reaches its minimum value (16°C for moderate and 7° severe floods); afterwards the value starts to rise, presumably due to preventive and adaptive measures to flood events in the area (dams, land, river, and infrastructure management) or directly improving the house (renovation). The minimum value for the imputed rent is reached faster in the case of severe flood events. The destructive power of these events and the high cost they imply for the affected area and beyond, call for the adoption of urgent and effective adaptation measures.

For poor households, the rise of temperature of 1°C has, on average, a positive impact on imputed rent (4.6%) although the effect fades out around 16°C; rich household are instead sensitive to the rise of temperature, which has on average a negative impact on their imputed rent (-0.9%). The drop of value starts at average annual temperature of 8°C.The occurrence of an additional moderate (severe) flood event increases by 0.5% (1.2%) the imputed rent of poor households but decreases those of rich households by 1% (1.2%) on average. For poor households, the relationship between imputed rent and flood events is U-shaped (as it is for the entire sample), decreasing up to 14 moderate (7 severe) flood events but increasing afterwards, probably due to the adaptation/reconstruction measures put in place by the household or the government. For the rich households, a flood event has always a negative impact on imputed rents.

3.3.6 Costs of climate change adaptation through the asset channel

Adapting to climate changes can be a planned actions undertaken before the occurrence of climate change – related losses of households’ assets (**asset channel**). The insurance reported in the HBS includes health insurance, transport insurance, and dwelling insurance. Our analysis focuses on **dwelling insurance** that seems fit to capture the household investments to shield a very relevant asset, i.e., the dwelling, from multiple hazards. We consider two hazard categories: the moderate and severe flood episode according to the Standardized Precipitation Index (SPI)[32] and the burnt area (km). We run a regression using the Tobit estimator that is tailored to deal with censored data, i.e., 50% of the sample has zero insurance expenditure. One additional moderate (severe) flood episode increases the insurance expenditure by 1.1% (4.6%). The effect of wildfires on purchasing an insurance is negligible, but

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[30] Each Member State can choose the preferred imputed rent estimation method.

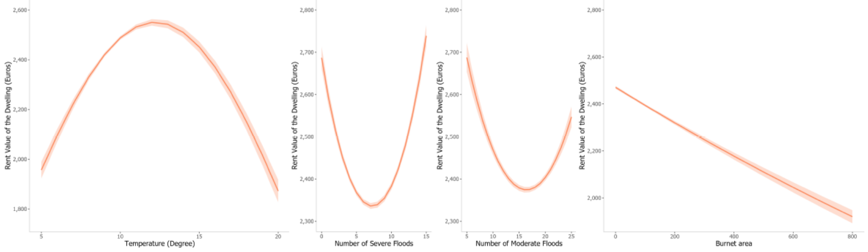
[31] Imputed rent is the sum of imputed rentals of owner occupiers and other imputed rentals (households housed for free and secondary residences).

[32] The Standardized Precipitation Index (SPI) classifies SPI values between 1 and 2 as moderate floods and above 2 as severe floods.

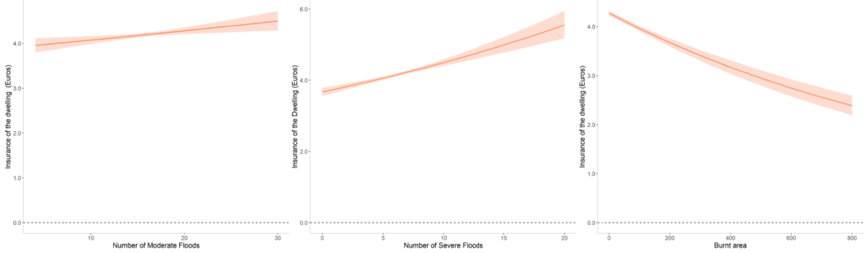
negative. The dwelling insurance expenditure is heterogeneous across terciles: poor households reduce their insurance expenditure at the occurrence of one additional moderate (severe) flood event by 1.1% (4.6%) and 0.002% for one additional squared kilometre burnt; the rich households instead increase their expenditure on dwelling insurance by 3.2% (6%) in the case of one additional moderate (severe) flood episode. A possible explanation for the negative correlation between poor households' insurance expenditure and flood occurrence is limited income availability, which pushes household to divert the expenditure towards current necessary goods and away from future protection form hazards. Rich households instead are not limited by the income availability and can invest more on dwelling insurance as the number of adverse events rise.

3.3.7 Overall costs of climate change impacts and adaptation through productivity and asset channels

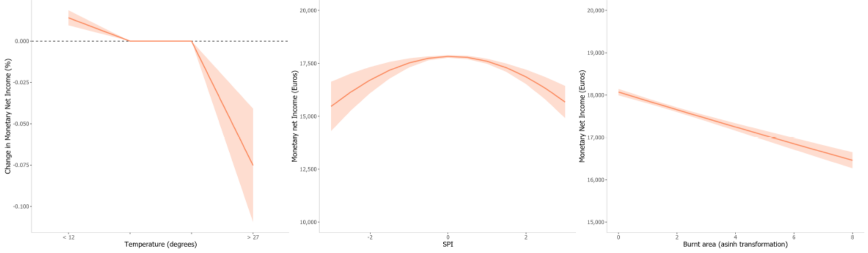
To summarise the overall effect of climate change on the productivity and asset channel we consider the household **net monetary income**, which includes **the labour income, imputed rent**, and three other indistinguishable and confounding elements: **profits, investments, and transfers.** The relationship between monetary net income and temperature bins is very similar to the one observed in Figure 6 B panel-right; an additional day with temperature below 12°C increases marginally labour income by 0.01%, while one additional day with temperature above 27°C brings about a 0.1% drop in income (Figure 7 B panel). The drought/flood and monetary net income relationship is inversely U-shaped, highlighting the optimality of a SPI around zero (no drought and no floods) for monetary income. The monetary income is inversely related to the expansion of burnt area.



A. Imputed rent



A. Insurance



B. Monetary net income

Figure 7: The cost of climate change impacts and adaptation through the asset channel, average

3.4 Projected cost of climate change impacts and adaptation in 2050

This section combines the regression results described in the previous section (and in Appendix D-II) with scenario-specific projections of socioeconomic (Section 3.2.2) and climate variables (Section 3.2.2), to project the household costs of climate change around 2050. The contribution of climate change is assessed by comparing the evolution of households' expenditure and income in a Paris-agreement-consistent climate scenario (SSP2-RCP4.5) and in the high-end impact scenario (SSP5-RCP8.5) with two scenarios sharing the same socioeconomic characteristics of SSP2 and SSP5, but without climate change (climate metrics are at the long-term historical levels). Given the high uncertainty in the determinants of future evolution of the burnt area indicator, we keep the historical values of this variable constant up to 2050. This choice implies that our future climate change cost projections will not include those related to wildfire.

This section presents the main results of our analysis by providing: i) a snapshot of climate change impact and adaptation costs across EU regions, and ii) an assessment of climate/ hazard related costs across households of different affluence by classifying them as poor (1st tercile), medium (2nd tercile), and rich (3rd tercile) on the basis of the distribution of the total expenditure.

3.4.1 Climate change costs across EU regions

We estimate that, due to climate change the **health expenditure,** of EU households will increase by 0.3% and 6.2% in the moderate (RCP 4.5) and severe (RCP 8.5) climate change scenarios, respectively. Figure 8 (A panel) shows the percentage change in health expenditure across climate change scenarios with respect to the corresponding socioeconomic future without climate change. The Member states that experience the highest rise of health expenditure are Cyprus and Greece, followed by Spain, Croatia, Italy, and Portugal. Although North and East Europe reduce health expenditure, the pattern is of rising health expenditure when transitioning from moderate to severe climate change scenarios.

Climate change will also determine an increase in average household **food expenditure** in most EU countries between 0.81% and 0.74% across climate change scenarios. The Member States in the South of Europe like Cyprus, Greece, Spain, Italy Portugal will increase this expenditure item the most, whereas countries in the North-East part of Europe like Finland, Estonia, Lithuania and Sweden will experience a small decease of food expenditure (Figure 8 – B panel).

Under the two climate change scenarios analysed, the **energy expenditure** slightly drops in the EU between 0.5% and 1% across climate change scenarios. The drop characterises most of the EU Member States excluding the very North of Europe, e.g. Denmark, Estonia, Finland, Ireland, and Sweden (Figure 8 – C panel). This is mainly due to a contraction of gas expenditure by 14% (19%) observed across all EU under the moderate (severe) climate change scenario (Figure 8 – E panel). This result masks a moderate increase in electricity expenditures by 3.3% (4.2%) under the moderate (severe) climate change scenario (Figure 8 – D panel).

Summing up, the **total expenditure** of households slightly decreases in EU by 1.2% (1.5%) under the moderate (severe) climate change scenario (Figure 8 – F panel). The reduction of expenditure, mainly concentrated in the South of EU and in particular in Greece (-11% and 10.4%), is probably related to budget constraints namely a concomitant contraction of labour income due to climate change that can be observed in Figure 9.

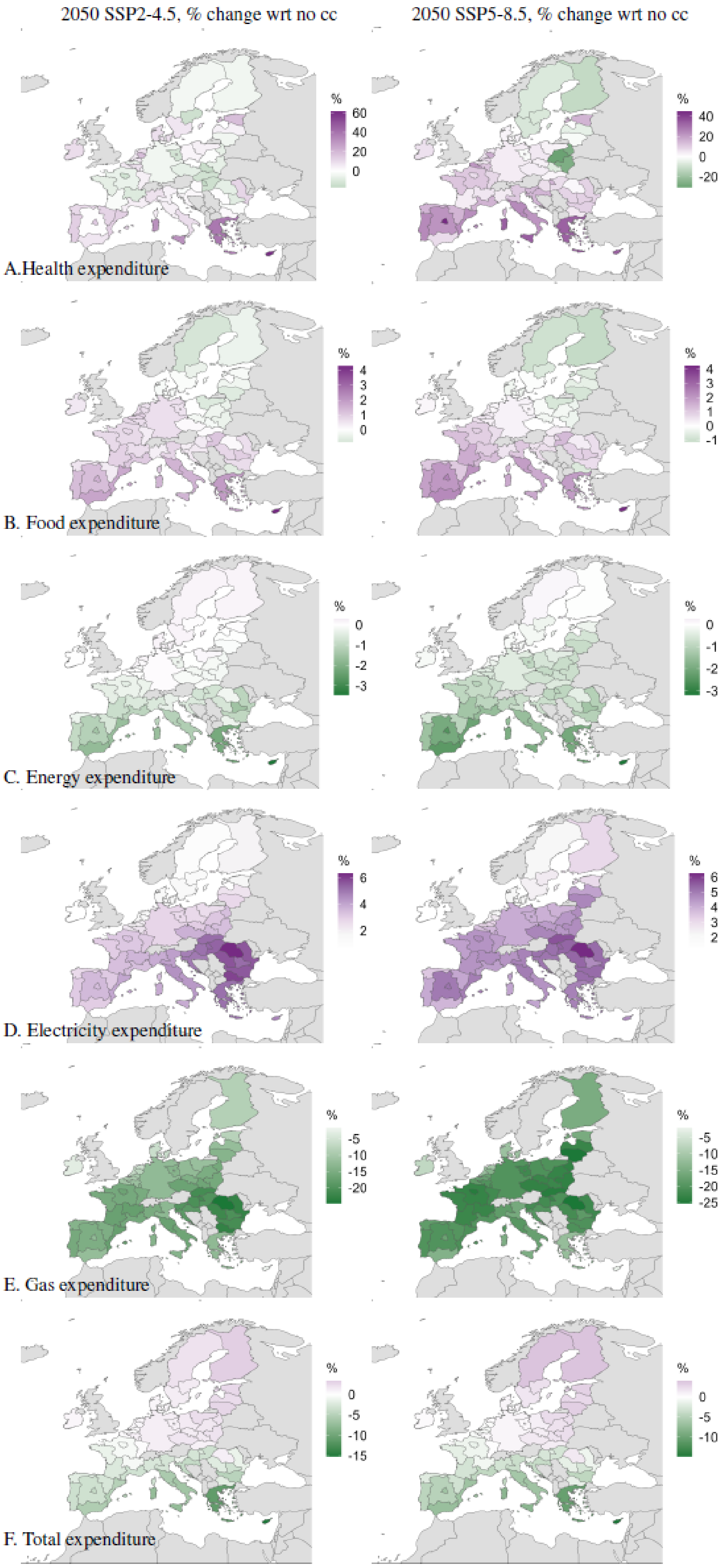


Figure 8: The 2050 cost of climate change through the expenditure channel, %change w.r.t. no climate change scenario

In EU, we observe a rise (marginal drop) of **labour income** by 0.73% (-0.02%) under the moderate (severe) climate change scenario. The highest drop by 5.2% (4%) is Greece, followed by France, Croatia, and Hungary. As highlighted in Figure 9 (A panel), several NUTS of the Northern EU experience a rise of total income in the moderate climate change scenario, that partially phases out under a severe climate change scenario. Poland is the Member States benefiting the most, gaining 3% (2.1%) under the moderate (severe) scenario.

Figure 9 (B, C, and D panel) gives a breakdown by macro-sector of the climate change impact on income. A moderate (severe) scenario in EU increases agricultural income by 5.5% (8.6%), industrial income by 2.4% (0.8%) and services by 4.3% (1.7%). It is worth noticing that the magnitude of impacts is very different across sectors and ranges between -50% and 150% in agriculture, and -20% and 10% in industry and services. Regarding agriculture, the areas at highest risk are Greece, Hungary, and Eastern Spain. The implications of climate change scenarios for industry and services points the same North-South divide observed for agriculture, albeit at a lower magnitude. The projected loss of all sectors in Greece highlights a structural fragility of the country towards future scenarios.

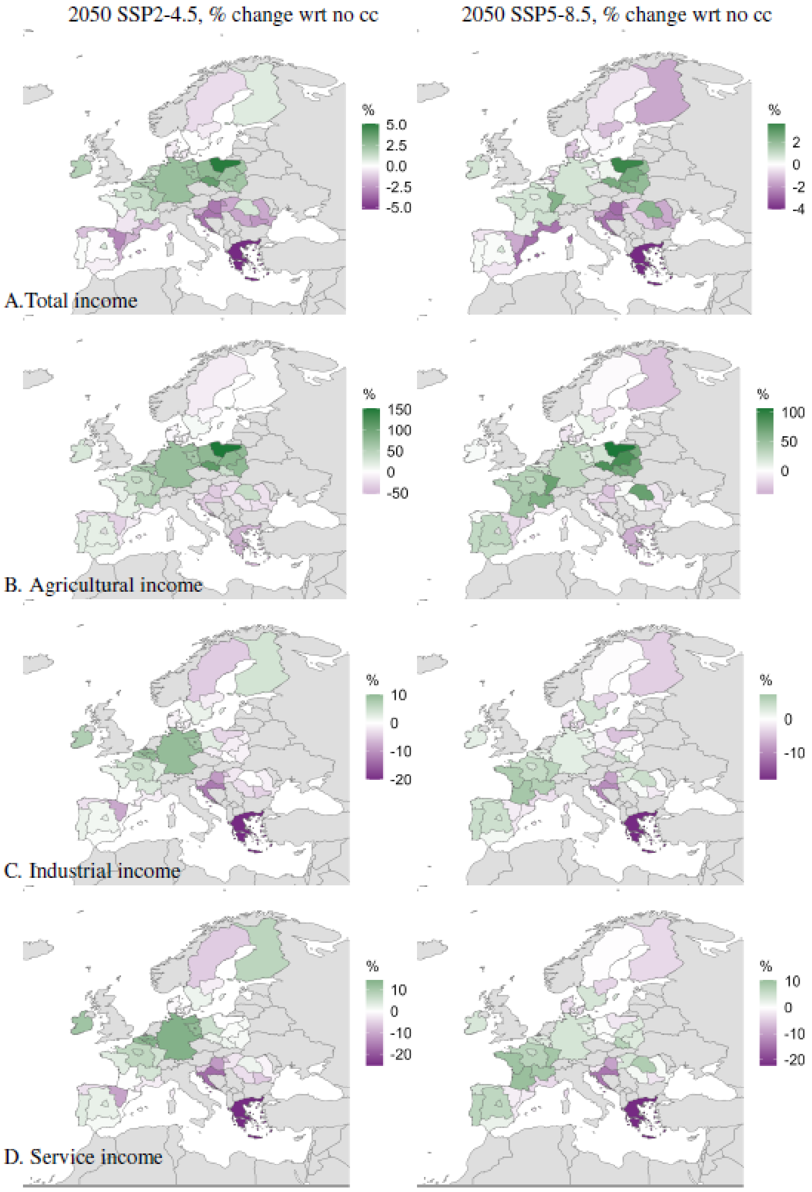


Figure 9: The 2050 cost of climate change through the productivity channel, %change w.r.t. no climate change scenario

The overall impact on EU dwellings’ **imputed rent** under climate change ranges between -0.2% and -0.4% (Figure 10, A panel). The temperature change is the main driver of this outcome, and it increases the value of dwelling in the North of EU, (e.g., in Finland, Lithuania and Latvia) whereas the reduced thermal comfort in the South of EU (e.g., Cyprus, Greece, and Italy) implies a drop of dwelling rent. The result for Greece stands out because it appears to contradict the pattern observed in the southern countries where the more severe is the climate change, the lower is the value of dwellings. Despite a small temperature increase in the severe climate change scenario (compared to the moderate one), the number of moderate floods events slightly drops in the former compared to the latter and pushes upwards the value of dwelling in Greece under severe climate change scenario.

The mix of country-specific, socio-economic characteristics, familiarity with insurance as an instrument to protect against future climate change damages, and future projections of floods in the areas determines the change in **insurance expenditures** in 2050. The projections foresee a rise by 10.4 % of total EU insurance expenditures due to climate change only under severe climate change scenario (RCP8.5), under the moderate climate change scenario (RCP4.5) insurance expenditures drop by 9.2%. However, Figure 10 (B panel) shows a quite heterogenous pattern across countries; in general the moderate climate change scenario will see a small decrease or no change in the decision of purchasing an insurance; the severe climate change scenario pushes almost all countries to invest to protect from damages, excluding Estonia, Ireland and Poland that according to the elaboration of CMIP6 model outputs will experience a lower number of severe floods with respect to the past. Lithuania and Greece are the Member States experiencing the highest percentage increase in insurance expenditure because the current expenditure on this service is almost null in these countries.

To summarize the climate change impact on income generation (both from labour and asset ownership), we plot the projected change of **monetary net income** (Figure 10- C panel). Despite the lower number of counties available and the confounding effect of investment revenues and social transfers that are included in this variable, we observe a reduction of monetary net rent in EU by 0.8 % (1.1%) under the moderate (severe) climate change scenario. Almost all countries in EU experience this loss excluding Poland and Bulgaria.

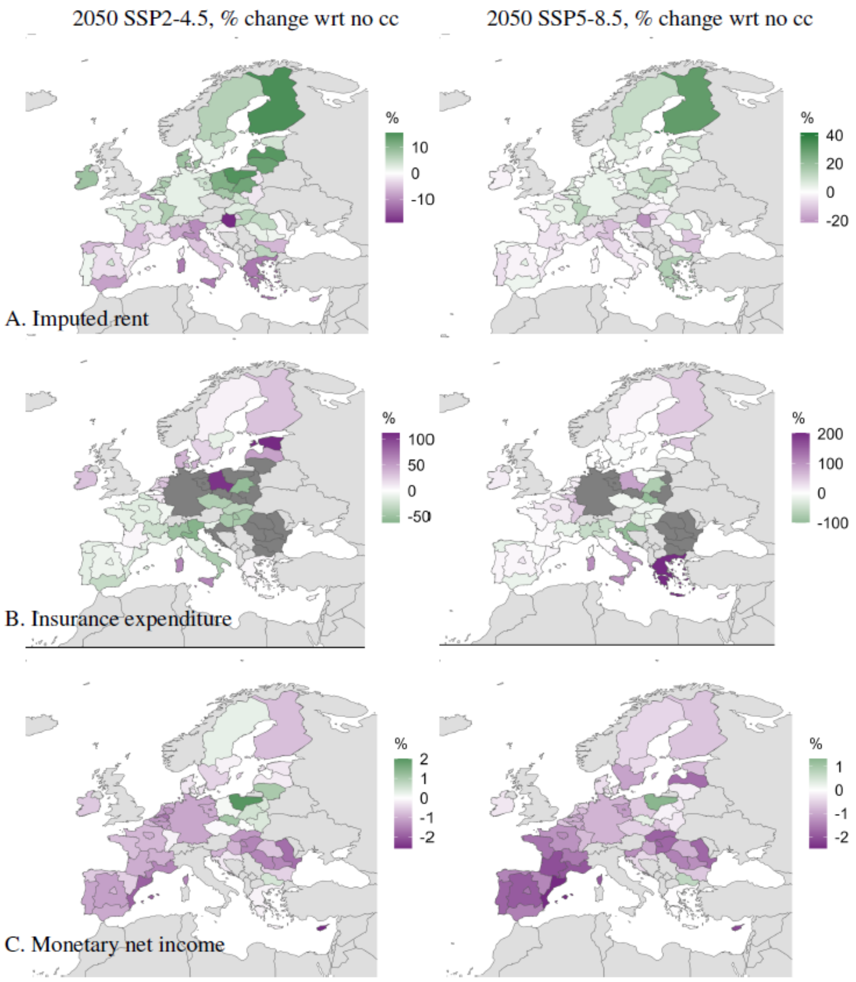


Figure 10: The 2050 cost of climate change through the asset channel, %change w.r.t. no climate change scenario

3.4.2 Climate change costs across EU households

This section gives some insights about the characteristics and the location of the EU households that are mostly affected by the climate change. Households are classified depending by the expenditure tercile (1st tercile – poor, 2nd tercile – medium, and 3rd tercile – rich households) they belong to, and the macro region[33] they live in (North, East, South and West EU).

The **health expenditure** increases across all terciles and scenarios in the Southern EU becoming regressive under the severe climate change scenario (+25.7 % in the 1st and +22.6% in the 3rd tercile under severe climate change with respect to the no climate change scenario). The other macro-regions experience a generalised reduction of health expenditure that intensifies under severe climate change in the Northern EU and phases out in the East and West EU. However, the health expenditure reduction is regressive (it shrinks more for rich households than for poor ones) in these regions excluding the Northern EU under the moderate climate change scenario and Western EU under the severe climate change scenario (Figure 11, A panel). The **food expenditure** increase is more widespread (all macro-regions excluding the Northern one), but smaller in magnitude (Figure 11, B panel). Again, the Southern EU increases the food expenditure the most (+1.6 % in the 1st and +1.7% in the 3rd tercile under severe

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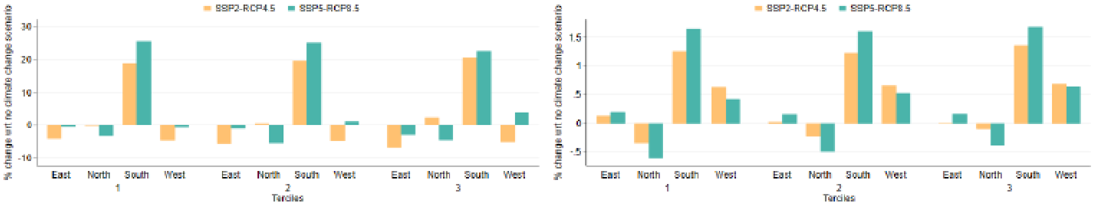
[33] We adopt the macro-region classification of United Nations Statistics Division: https://unstats.un.org/unsd/methodology/m49/#geo-regions

climate change with respect to the no climate change scenario). The increase in expenditure seems to be progressive (higher for richest terciles) or equal across terciles in the South and West EU. However, in the Eastern EU the poorest tercile experiences the highest rise of food expenditure.

The global warming marginally reduces **energy demand** in the EU with a slightly regressive distributional impact in Western and Southern EU (Figure 11, C panel). Electricity expenditure increases across all macro-regions, especially in the Southern and Eastern EU. A slightly regressive impact emerges with respect to **electricity expenditure** in the Northern and Southern EU (Figure 11, D panel). Changes in **gas expenditure** due to climate change are negative and progressive in almost all EU regions (Figure 11, E panel).

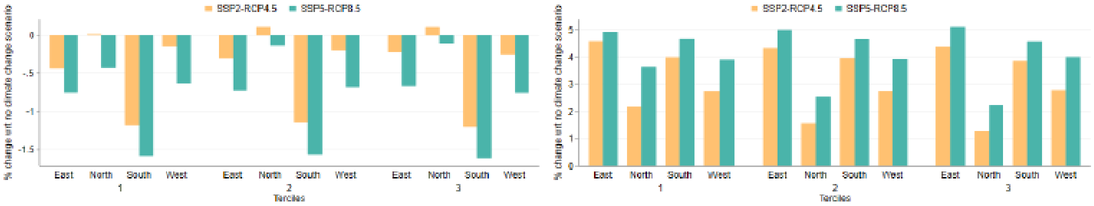
Adapting to climate change by purchasing **insurance** is a behaviour that mainly characterises the severe climate change scenario and the Northern EU (highest rise of insurance expenditure under the moderate climate change scenario). In the North and South of EU, the insurance expenditure is regressive (Figure 11, F panel).

The **total expenditure** slightly shrinks due to the strong contraction observed in the Southern probably related to the labour income reduction. (Figure 11, G panel).



A. Health expenditure

B. Food expenditure

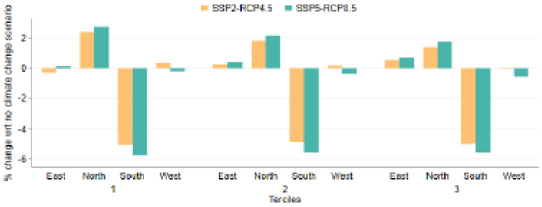


C. Energy expenditure

D. Electricity expenditure

E. Gas expenditure

F. Insurance expenditure



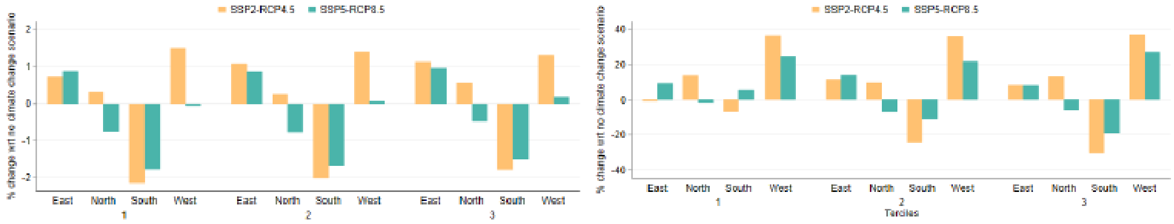
G. Total expenditure

Figure 11: The 2050 cost of climate change across expenditure good and services by tercile, %change w.r.t. no climate change scenario

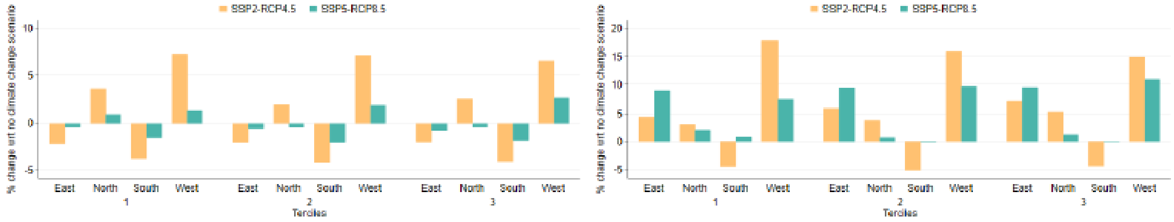
The **total labour income** decreases in the Southern EU and Northern EU (only in the severe climate change scenario). The distributional implications of climate change are regressive across all macro-regions, i.e. the 1st tercile experiences the lowest gains or the strongest reduction of income (Figure 12, A panel). **Agriculture** is the sector experiencing the highest income losses under climate change mostly in Southern EU and Northern EU (the latter only under severe climate change scenario). The impact is progressive in the South of the EU, because most of the loss is suffered by the highest terciles; it is progressive in the North of the EU under moderate climate change, but it turns regressive in the severe climate change scenario (Figure 12, B panel). As observed at the NUTS level, the severe climate change scenario has a positive impact on the poor tercile of Eastern EU and this result is probably lead by the strong rise of agricultural income in Poland under RCP5-8.5. Industrial and service income show some regressive patterns and lower magnitude of change; the change in the construction sector income, as the industrial one, is negative especially in the Southern EU.

The **imputed rent** increases across all macro-regions excluding the Southern one. The highest benefits characterises the Northern EU, they are progressive in the moderate climate change scenario, but become regressive under severe climate change (Figure 12, H panel). Western EU experiences a regressive distributional effect as well. However, the contraction of dwelling value observed in Southern EU is progressive affecting the richest tercile more than the poorest one (Figure 12, G panel).

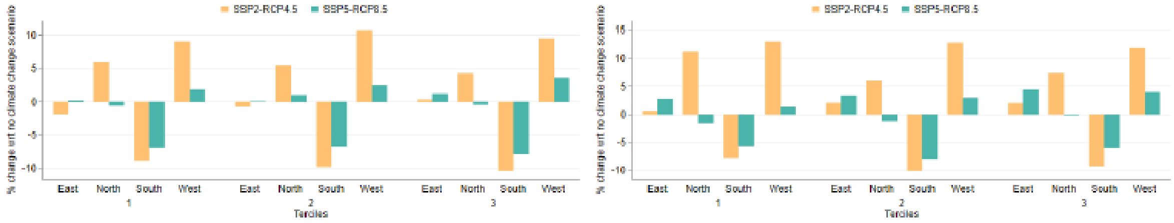
The change in **monetary net income** summarises the changes in labour income, investment and assets revenues and social transfers due to climate changes. Figure 12 (I panel) shows that the monetary income shrinks across almost all terciles and macro-regions (probably due to the negative effect on investments and rent revenues, despite the redistributive effect of social transfers). The highest losses are observed in Southern EU. The impact is progressive in all macro-regions excluding the North EU under severe climate change scenario.



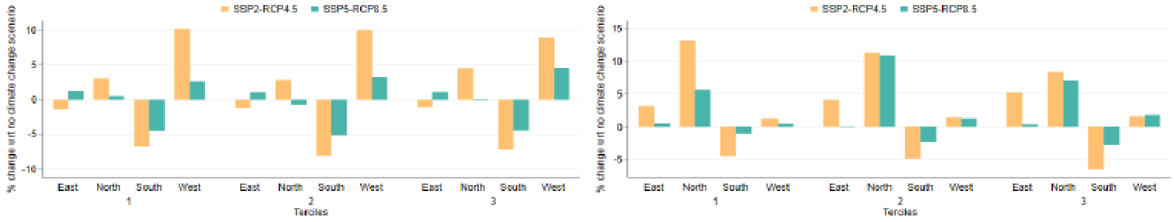
A. Total labour income B. Agricultural income



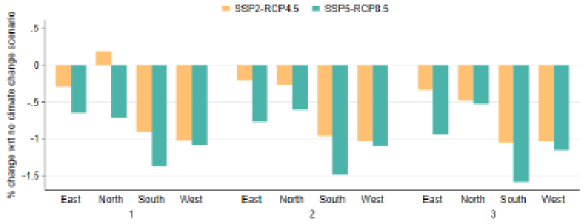
C. Industrial income D. Transport income



E. Construction income F. Finance income



G. Services income H. Imputed rent



I. Monetary net income

Figure 12: The 2050 cost of climate change across income sources by tercile, %change w.r.t. no climate change scenario

3.4.3 Climate change implications on inequality and poverty

The previous sections describe the distribution of climate change costs across NUTS1 regions and households in different income classes in EU; this section aims synthesizing the previous information using a distribution (Gini) and a poverty (at-risk-of-poverty rate) metric and characterising the specific impact at the country level. Appendix C gives a snapshot of the current values of these metrics according to HBS 2010 and 2015 and some insights on their evolution.

In this section, we compare the climate change related impact on the two indicators computed on two relevant income types: the labour income and the net monetary income that includes, in addition to the labour income, the asset revenues and the social transfers. Unfortunately, the HBSs do not allow us to disentangle the effect of climate change on asset revenues (probably negative) and on social transfers (probably positive if the government is already engaged in anticipatory or planned adaptation actions).

The climate change seems to slightly (the range of variation is extremely small) reduce inequality in EU when we consider only the labour income; the **Gini index** rises only in Finland, Ireland, Portugal, Netherlands (only SSP5-8.5) and Denmark (Figure 13 – left). These countries are among those increasing the labour income or marginally losing it under climate change scenarios.

The inequality increases when we consider the monetary income due to the losses experienced in the asset revenues and the insufficient compensatory effect of social transfers (Figure 13- right). This is the case of Croatia, Portugal, Romania, Greece and, marginally, of France. More effective protection of assets against climate change impacts or compensative transfers by governments seem to be already in place in Belgium, Germany, Denmark, Finland, Hungary, Ireland, Sweden and Slovenia.

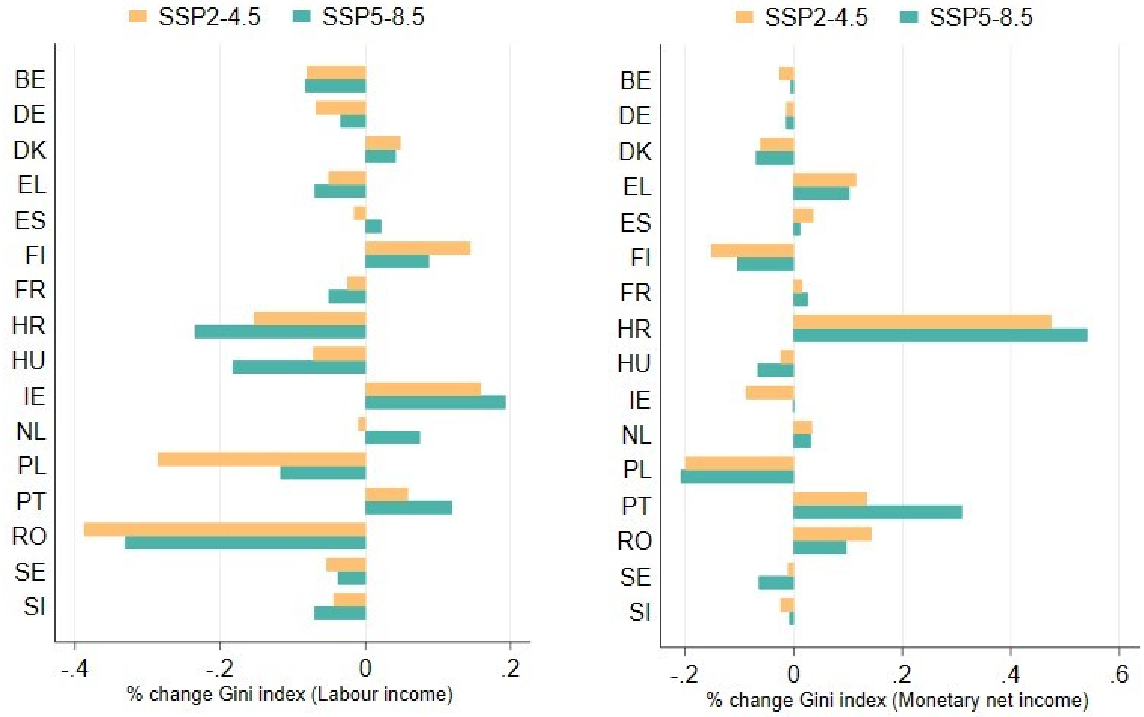


Figure 13: % change of Gini index in 2050 under climate change scenarios w.r.t. no climate change scenario measured on labour income (left) and monetary net income (right)

In 2050, independently of the scenario, the total number of **individuals at-risk-of-poverty** (considering their job income) in a subset of EU Member States[34] is not expected to increase, but slightly falls by 0.7% (0.2%) under the moderate (severe) scenario with respect to the no climate change one (Figure 14 left). However, this result masks divergent outcomes across countries. In the moderate climate change scenario, the number of individuals at-risk-of-poverty shrinks in Poland, France, Ireland, Belgium and Germany. Under the severe climate change scenario, the reduction of the individuals at-risk-of-poverty is less pronounced in these countries and turns into poverty rise in Germany and Belgium. The number

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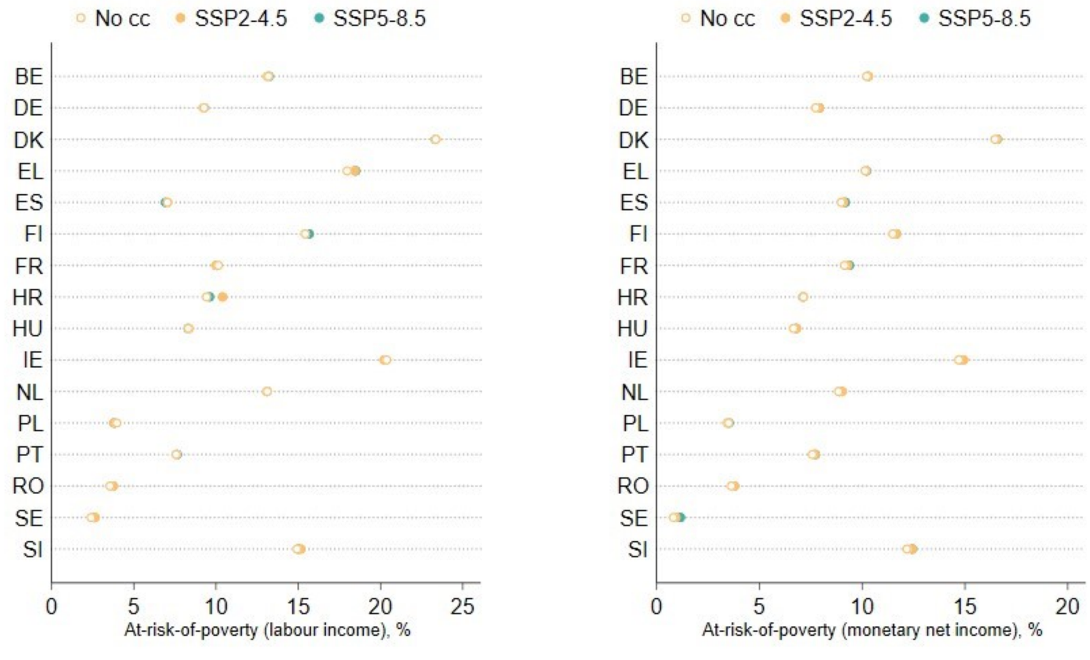
[34] The poverty prevalence is computed using the equivalized labor income and therefore it can be computed only for countries providing this variable in HBS (Belgium, Germany, Denmark, Greece, Spain, Finland, France, Croatia, Hungary, Ireland, Netherlands, Poland, Portugal, Romania, Sweden and Slovenia)

of the individuals at-risk-of-poverty increases by more than 5% in Croatia, Romania and Sweden under the moderate climate change scenario (Figure 14); however it is worth to highlight that, due to the cross-country initial heterogeneity on the number of individuals at-risk-of-poverty, Greece, Croatia and Romania will experience the highest rise in the number of individuals at risk of poverty, respectively 43500, 37000 and 32700 additional individuals falling below the at-risk-of-poverty threshold due to climate change. A more severe global warming scenario (SSP5-8.5) will worsen the outcome for many countries excluding the Eastern ones (Croatia, Hungary, Romania, Sweden and Slovenia). Greece is expected to deface the highest rise of poverty in EU independently on the climate change severity.

Figure 14 (right) describes the variation in individuals at-risk-of-poverty after adding asset revenues and social transfers to the labour income. When we add climate change impacts on the assets, the people at-risk-of-poverty due to climate change rises in EU27 by 1.8% (2.4%) under the moderate (severe) climate change scenario (notwithstanding the implementation of social transfers). Countries like Germany, Spain and France, which were showing a reduction or a small increase on poverty when only the labour income was considered, show the highest increase in population at-risk-of-poverty due to climate change, reaching 2.3% (2.3%) in Germany, 1.3% (2.8%) in Spain, 1.7% (2.8%) in France, and 2.7% (4%) in Poland under the moderate (severe) climate change scenario. Sweden shows again a huge percentage increase in population at-risk-of-poverty that is due to the low poverty prevalence in the country (the percentage of people at-risk-of-poverty shifts from 0.8 % in the no climate change scenario to the 1.2% in the severe climate change scenario). In Greece and Finland (only under SSP2-4.5), we observe that the additional people at-risk-of-poverty due to climate change is lower than in the labour income case highlighting the equalising effect of asset revenues and social transfers.



Inconsistencies in HBS: labour income is not available for the Netherlands and Denmark; monetary income missing for Croatia.

Figure 14: % of individuals at-risk-of-poverty in 2050 under no climate change scenario and climate change scenarios measured on labour income (left) and monetary net income (right)

Up to this point we have considered only the implications on inequality and poverty through the income channel, but climate change can induce the purchase of specific goods as an impact effect or an adaptation action. The rise of the expenditure on a specific good, combined with the change in income availability due to climate change, can increase the budget share devoted to a specific good; when this share become bigger than that of individuals at-risk-of-poverty, the household is commonly classified at risk of deprivation of a specific good/service.

Figure 15 describes the climate change implications for **energy, gas, and electricity poverty**. We already have noted that energy and gas expenditure may decrease under climate change in certain countries; however, the drop in total household expenditure in many cases drags more individuals below the energy poverty threshold. The countries experiencing the highest increase in energy poverty are Greece, rising from 1.4% to 5.2% (1.6% to 5.3%) under the moderate (severe) climate change scenario (Figure 15 left). Other countries with increasing climate related energy poverty prevalence are Cyprus, Italy and Spain. Denmark and Finland show the highest reduction of energy poverty prevalence in EU. The range of variation in natural-gas-related poverty prevalence is narrower compared to the energy one (Figure 15 left). Although the countries with increasing gas-related poverty prevalence are very similar to those observed relatively to energy poverty, in this case Cyprus is the most affected country with a gas-related poverty prevalence rising from 0.8% to 4.1%(0.8% to 4%) under the moderate (severe) climate change scenario (Figure 15 centre). Luxembourg and Latvia are the countries with the highest gas-related poverty prevalence. Electricity-related poverty prevalence is again rising the most in Cyprus, Greece and Italy and decreasing the most in Denmark and Lithuania (Figure 15 right).

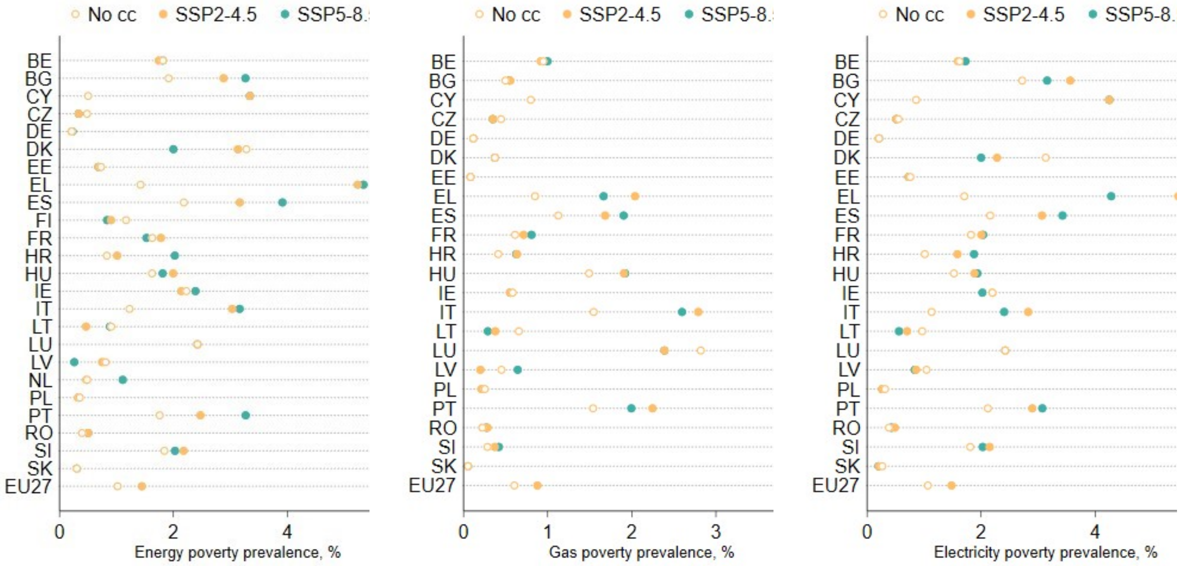


Figure 15: energy, gas and electricity poverty prevalence change due to climate change scenarios in 2050 w.r.t. no climate change scenario, percentage points

4. Poverty and inequality implications of mitigation measures of climate change impacts

Assessing the distributional implications of mitigation and decarbonization policies on EU households is performed by combining the outcomes of a **multi-region Computable General Equilibrium model** (ICES) and a **sequential arithmetic micro-simulation module** (van Ruijven et al., 2015, Campagnolo and De Cian, 2022) relying on 2010 HBS microdata (Eurostat).

This methodology draws on the set of simulations produced by CMCC CGE model (ICES) for the EMF36 study considering two increasingly stringent mitigation scenarios i.e., the first one achieves the NDCs in 2030 (NDC) and the second one is a Paris agreement compatible scenario keeping the global warming at 2°C in 2100 (NDC2DG) (Böhringer *et al.*, 2021; Akin-Olcum *et al.*, 2022). In each scenario, all countries of the world are grouped in macro-regions, and they achieve the emission reduction requirements through regional action (i.e. regional uniform CO_2 prices).[35] The uniform CO_2 price for the European ETS in 2030 for the NDC scenario is 94\$/tCO_2, and 275\$/tCO_2 for the NDC2DG scenario. The revenues of mitigation action are rebated as a lump-sum to a regional representative household. The model focus is on 2030, and it provides information about economy-wide adjustments following the implementation of mitigation policies, (i.e. the change of energy prices faced by consumers, the changes in consumption and production of energy and the related adjustments of price and quantity of other commodities). Both mitigation scenarios do not account for avoided and residual climate change impacts or adaptation measures.

The CGE output embedding the propagation of mitigation policy shocks into the European economies was fed into a sequential arithmetic micro-simulation module (van Ruijven et al., 2015, Campagnolo and De Cian, 2022) relying on Eurostat HBS microdata and allowing the downscaling of country/region level outputs at household level. This method allows analysing how income generation is affected by mitigation policies, because the energy price change alters production costs and optimal output, mainly in the energy sector and indirectly in all other sectors that rely on fossil energy. This determines shifts in the remuneration of labour, capital, and natural resources owned by households, and ultimately in their overall income. However, this method has some limitations. Considering the lack of information in Eurostat HBSs about government transfers, and how they are distributed across terciles in each Member State, it is not possible to guess a redistribution scheme of carbon revenues. In addition, the microdata does not provide information regarding capital and other kind of assets and how they are distributed across households. For this reason, it is not possible to downscale the CGE output regarding the mitigation policy impact on capital and other assets and on the overall income. Therefore, we had to restrict our analysis to the sole labour income changes.

Figure 16 shows the results for a subset of the EU27 countries[36] for Gini index percentage change with respect to a no policy reference scenario and the poverty prevalence across scenarios. We observe a heterogeneous evolution of inequality (left) across EU regions, with Croatia and Romania experiencing the strongest rise of inequality. This is probably due to the generalised contraction of output in these countries due to their high emission intensity (in other countries the contraction is limited to the industrial and transport sectors). However, we see a generalised contraction of the share of population at-risk-of-poverty due to the mitigation policy, on average in EU -1.9% (-5.2%) under the NDC (NDC2DG) scenario. This outcome is only relative to the labour income[37], which increases in EU countries, and to the fact that the (output and occupation) contraction of emission intensive sectors (industry and transport) pushes the occupation towards less energy intensive sectors (agriculture and services); the increased demand of low-skilled workers shifts upwards the remuneration of this category and benefits the income of poor households that strongly rely on the revenues of low-skill labour . The more stringent are the mitigation targets (NDC2DG), the more intense is this effect and the poverty reduction.

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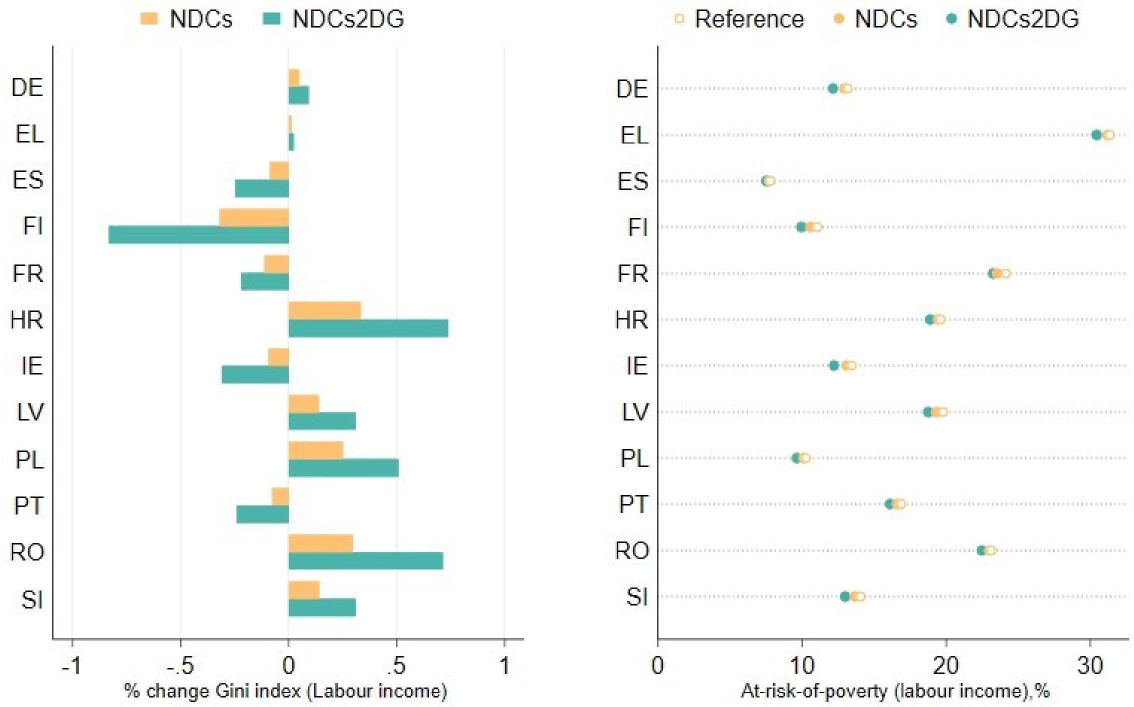
[35] The ICES model considered eight countries/regions within Europe with a European Trading Scheme (ETS) implemented to exchange CO_2 emission permits among European countries. The eight European countries and regions are: Italy, France, Germany, Rest of the initial EU15 countries, rest of EU, UK, North Europe and the rest of Europe.

[36] In HBS, labour income is not available for the Netherlands and Denmark; and monetary income missing for Croatia. Furthermore, the microsimulation was not able to find a solution for Belgium, Denmark, France, Hungary and Sweden.,

[37] The assessment in Vandyck et al. (2021) is relative to the total income and draws different conclusions on the distributional impact of mitigation policies.



**Inconsistencies in HBS: labour income is not available for the Netherlands and Denmark; monetary income missing for Croatia. The microsimulation is not finding a solution for Belgium, Denmark, France, Hungary and Sweden*

Figure 16: % change of Gini index in 2030 under the mitigation scenarios w.r.t. reference scenario (left) and individuals at-risk-of-poverty in 2030 across scenarios (right)

5. EU policies to curb distributional implications of climate change

5.1 Policies curbing distributional implication of impacts and adaptation

The increasing attention of the EU policy framework towards equity and social justice has prompted in recent years a reconsideration of EU climate policy under the lens of the ethical consequences of climate policy action. The European Green Deal and the policy tools related to its implementation (e.g. the Just Transition Mechanism, the EU Strategy on Climate Adaptation and the EU Mission on Adaptation to Climate Change) all pay attention to the justice criteria.

A recent study by EEA (Lager et al. 2023) has proposed an approach to streamline within **adaptation policy actions** the consideration of justice, including distributive justice which most directly relates to the households' implications analysed in this report[38]. Lager et al. (2023) show that justice still has a very limited relevance within the National Adaptation Plans (NAPs) of European countries.[39] The EU countries that have somehow considered issues of equity, justice, and just transition in their NAPs are only ten out of 27 - namely Austria, Estonia, Finland, France, Greece, Latvia, Malta, Romania, Spain, Sweden. Only two countries (Greece and Romania) mention the implementation of **income support measures** for low-income households targeting adaptation in **buildings** and **drought-related income losses for agricultural households**. The rest of these ten countries have a clear mapping of economic vulnerable groups whose situation is going to be exacerbated by climate change, and a commitment to

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[38] See Lager et al. (2023) for definitions of other dimensions of justice, including procedural and recognition justice.

[39] National Adaptation Plans (NAPs) were first put forward within the UNFCCC framework following the 2010 under the Cancun Adaptation Framework, an outcome of the 16th Conference of the Parties to the UNFCCC. The main idea is to foster the streamlining of medium- and long-term adaptation planning within national policies. At the EU level, the adoption of National Adaptation Strategies and National Adaptation Plans is a pillar of the 2013 European Adaptation Strategy, as revised in 2021 following the 2018 evaluation. By 2020 All EU countries had either a NAS or a NAP, or both in place (Leitner et al., 2020).

monitor their situation and gear future policy measures in a way that prioritise their needs, despite not having yet put in place specific measures to support low-income households. Austria, Finland, France, Latvia and Estonia demonstrate a proactive attitude in their NAPs, and future measures supporting adaptation of low-income households are likely to be put in place in these countries. France, Spain, and Finland also appear to give particular relevance to the procedural angle of streamlining justice considerations into adaptation policies. EU policy strategies in **other policy areas** can have a direct bearing on households' income, particularly when this income comes from economic sectors under the EU policy focus. For example, the European Adaptation Strategy calls for streamlining climate change adaptation and mitigation in the **Common Agricultural Policy (CAP),** and a major pillar of CAP is income support to farmers (European Commission, 2023). More specifically, farmer support within the current CAP also include support to tackle climate change and the sustainable management of natural resources. For **energy sector policies**, social justice is mainly leveraged through the link between energy poverty and (efficient) residential energy use. The Fit-for-55 Package (European Commission, 2021) identifies key sources of energy-poverty risks (excessively high energy prices, low household income and poor energy-efficient buildings and appliances) and ways to tackle them, for example through the revision of the Energy Efficiency Directive. The distinction between adaptation and mitigation measures in this contest is not relevant, as the abovementioned interventions would support households' resilience towards price as well as weather shocks.

As for the **EU health policy**, there seems to be little indication of measures specifically addressing distributive justice for households, as the focus is either on general cross-border preparedness to major health crises in the wake of the COVID-19 pandemics or, at the individual level, on causes of personal vulnerability such as chronic pathologies, age, and disabilities. The latter focus can be interpreted as relevant to the households of such vulnerable individuals. The general vision is outlined in the EU4Health Programme which includes a proposal for a EU4Health Regulation aiming, among other goals, to “contribute to tackling the negative impact of climate change and environmental degradation on human health”. Yet, most actions concern institutional and behavioural measures, rather than income support. Streamlining adaptation in the **insurance sector** (Christophersen et al., 2023) is generally treated as a reform of the insurance markets, so that premiums are lower for those who can show that they have taken preventive measures against various disasters (for medium-low risk). As to catastrophic events, the policy focus is mainly on the reinsurance market and catastrophe bonds; European solidarity funds can be interpreted in terms of monetary aid to cope with the difficulty of adequately insured major catastrophic events.

A recent study by EEA (Lager et al., 2023) has analysed the relevance of just resilience in the National Adaptation Plans (NAPs) of EEA Member states, and proposed an approach to streamline the consideration of justice within adaptation policy action. Focusing on NAPs issued by 2022, the study screened country by country and sector by sector the inclusion of three classes of justice considerations into these plans: distributive, procedural, and recognition justice. Distributive justice most directly relates to households' budget use and to the poverty implications analysed in this report. Procedural justice (i.e, the active involvement of vulnerable groups into the policy process), can offer them an important opportunity to shape future policy action in a way that is likely to protect households also in financial terms. Lager et al. (2023) shows that justice still has a very limited relevance within the adaptation plans of European countries. The EU countries that have somehow considered issues of equity, justice, and just transition in their NAPs are only ten out of 27 - namely Austria, Estonia, Finland, France, Greece, Latvia, Malta, Romania, Spain, Sweden. Evidence of some degree of consideration of distributive justice can be found in the NAPs of all these ten countries. However, it often boils down to mere mentions of the issues, declarations of intent for future policy actions, or at best in a commitment to deal with a specific issue in the future. In general, very few measures are implemented in practice, and even fewer have direct consequences on household income. Only two countries (Greece and Romania) mention the implementation of **income support measures** for low-income households as measures targeting adaptation in **buildings** by means of incentive programmes for private houses giving priority to vulnerable groups, and **respectively, drought-related income losses for agricultural households**. Most of the rest of these ten countries have a clear mapping of economic vulnerable groups whose situation is going to be exacerbated by climate change, and a commitment to monitor their situation and gear future policy measures in a way that prioritise their needs, despite not having yet put in place specific measures to support low-income households. Austria, Finland, France, Latvia and Estonia among others demonstrate a proactive attitude in their NAPs, and future measures supporting adaptation of low-income households are likely to be put in place in these countries. France, Spain, and Finland also appear to give particular relevance to the procedural angle of streamlining justice considerations into adaptation policies.

5.2 Policies curbing distributional implication of mitigation

A recent study assesses the extent to which EU policy frameworks examines the distributional impacts of climate policies (Gancheva et al, 2023).[40] Among the regressive policy instruments, carbon or energy taxes are the most studied. Their regressivity is confirmed, but it can be offset by additional policies such as **revenue recycling schemes**. Subsidy schemes are also considered regressive when they are deployed in the absence of mechanisms supporting low-income households, given that the subsidy alone could potentially exacerbate existing inequalities. Similarly, other policy instruments such as feed-in tariffs (FITs)[41], efficiency standards, trade policies, emission trading schemes, coal phase-out policies and renewable energy deployment, could end-up benefit higher-income households while imposing a burden on low-income ones. Fewer policy instruments are considered to have a progressive effect, for instance **public investments** leading to reduced inequality and poverty, increased electricity affordability and access depending on the project and on the specific context. **Direct procurement** showed also similar positive effects in low-income countries as well. Building performance certificates are also likely to be progressive, as they foster energy efficiency for low-income households as well as the creation of new jobs to comply and verify with the specific standards of those certificates. The study provides additional details on the type of socioeconomic impact, although such information is only available for some types of policy. For instance, access to services and employment are the most studied impacts with most progressive effects coming from public investments, direct procurement, certificates, and the deployment of renewable energies. On the regressive side of emission trading policies and coal phase-out, the impacts have to do with access to services which is in line with the findings of Vandyck et al (2021). Gancheva et al. (2023) also revise twelve **EU funds** that could curb directly or indirectly socioeconomic impacts from climate policies. From these, only three aim to directly address negative impacts of such policies: the Just Transition Mechanism (JTM), the Social Climate Fund (SCF) and the European Globalisation Adjustment Fund for Displaced Workers (EGF). Within the European Green Deal, fairness concerns have been embedded in energy and climate policy action through the Just Transition Fund mechanism and the Social Climate Fund of the Fit-for-55 package. Given the somewhat narrow scope and limited budget of such mechanisms (the Social Climate Fund for instance, mainly compensates for distributional issues arising from the EU ETS), concerns have been raised about the capability of the current EU climate policy framework to take into full account the needs of disadvantaged groups (Defard and Thalberg, 2022; Akgüç et al, 2022; 2022). Finally, Gancheva et al.

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[40] For the list of specific policy instruments and a detailed discussion about their recognition of distributional effects the interested reader can refer to chapter 2 of Gancheva et al. (2023).

[41] FIT is the acronym for feed-in tariff. It is a policy mechanism designed to accelerate investment in renewable energy technologies.

(2023) provides a series of recommendations regarding the **design, implementation and assessment of policies and the use of EU funds**. More guidance should be provided for i) assessing the social impacts of climate policies and set clear EU-wide definitions; "such as for 'vulnerable consumers' and 'energy/transport poverty' "; and ii) assessing the social impacts of climate policies throughout the policy cycle in a consistent way. The use of EU funds should: i) increase their efforts to reach final recipients; ii) request an assessment of the social impacts of climate policies to clearly address them before disbursing funds; iii) ensure the contribution to inequality reduction during the funding programs' implementation considering the EU funds horizontal principles; iv) guarantee a complementarity between different EU funds; while v) assessing the performance of existing EU funds. These recommendations resonate with Eurofound (2021)'s suggestions to **integrate approaches across different public policy areas** (e.g. energy, housing and employment) when designing and implementing specific measures and to use a comprehensive systemic approach when EU funds provide support for specific solutions.

6. Recommendations for future actions

The European Green Deal and the policy tools related to its implementation all pay attention to the justice criteria, but existing initiatives to streamline the distributional implications of climate change costs in dedicated as well as different policy areas in the EU are still embryonal. This report provides new knowledge on the social impacts of the costs of climate change for Europe that could inform future policy actions. Specifically:

- EU subnational regions and socio-economic groups will bear differentiated impacts from climate change.
- The increased households' expenditure on specific goods/services such as health, food and energy to cope with climate impacts and to adapt to climate change will place a particularly high burden on poor households and bear the risk of rising their likelihood of experiencing multidimensional poverty. This dimension need to be addressed in addition to the climate change impacts on the income sources.
- Negative and regressive (worsening the wellbeing of poor households) impacts for a wide set of expenditures and income sources will be observed in the Southern Europe (Greece in particular) and marginally in the Northern EU. In the Eastern EU, impacts on food expenditure call for an urgent action.
- Climate change impacts increase the population at risk of poverty across EU. Income support measures for low-income households, as currently planned in Greece and Romania, should be strengthen and tailored to the most vulnerable segments of the population. The potential role of social transfers in compensating for the impacts of climate change on poverty and inequality calls for more research on the role of compensatory measures related to this specific risk.
- The impact of mitigation policies on the labour income seems to favour a reduction of poverty prevalence.
- Agriculture, energy, and health are the areas in which major disparities are present and/or likely to increase. Considering the nexus among health, energy, and nutrition that is driven by adverse climate change impacts hitting simultaneously, leading to compounded adverse outcomes for households (for instance, drought-induced food scarcity, heat-related health issues and energy disruptions during heatwaves), horizontal policy integration is expected to lead to more effective policy making compared to a silo-thinking approach. A priority in this sense would be to streamline climate change adaptation and climate justice within the EU4Health programme, the main EU-level health policy tool deployed as a response to the COVID-19 crisis and in general

to foster crisis preparedness in the EU. It is indeed striking that climate -induced health impacts are not mentioned within this program (Haas et al, 2023).

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Appendices

Appendix A Climate data, metrics and projections

Meteorological data variables (e.g. temperature, precipitation, wind, humidity) can be obtained from at least three different sources: (i) ground station as single point location or network of locations; (ii) gridded data derived from network of locations; (iii) reanalysis data (Mistry, 2022). Since the quality of source (i) and (ii) depends on weather data availability and the density of measurement locations that are commonly scattered and with low density, source (iii) can provide multiple variables that are consistent across space and time.

Reanalysis data products use data assimilation to combine observational data with physical dynamic models to extend information from data-rich regions to data-poor places. Reanalysis data products, also referred to as "retrospective analysis" have found wide applications in climate sciences dating back to the early 1990 (Mistry 2022).

Two are the main input data that have been used to compute the climate metrics used in this empirical study:

- The **ECMWF Reanalysis v5 (ERA5)** data of the global climate, covering the period from January 1940 to present. We extracted variables of **air temperature and precipitation**[42].
- The Terra and Aqua combined MCD64A1 Version 6 **Burned Area data product** from **NASA's MODIS satellite**[43]**.**

These variables are processed to obtain the relevant climate/hazards metrics for the econometric analysis, namely:

- Population-weighted (at the grid cell-level, using the GHS-POP gridded population from the EC-JRC[44]) **mean temperature** (historically, e.g. for the 1980-survey year period, and for each specific survey year)
- Population-weighted **cooling degree and heating degree days** (**CDD, HDD**), e.g. measures of how much (in Celsius degrees), and for how long (in days), air temperature was higher/lower than a specific base temperature (set at **18° C** in our analysis).
- The **Standard Precipitation Index (SPI)** for determining the onset, duration and magnitude of drought or flood conditions. By using a reference scale (deficit/surplus accumulation period) of **12 months**, we calculate the magnitude and cumulative count in time of:
  - Moderate droughts, months where $-2 < SPEI/SPI < -1.5$
  - Severe droughts, months where $SPEI/SPI < -2$
  - Moderate floods, months where $1.5 < SPEI/SPI < 2$
  - Severe floods, months where $SPEI/SPI > 2$
- The absolute magnitude and fraction of **burnt area** because of fires detected from the MODIS Surface Reflectance imagery and based on a burn sensitive vegetation index.

The **future projections of selected climate/hazard metrics up to 2050** are constructed by adding to the historical climate data the difference between the CMIP6 climate models bias-corrected, downscaled

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[42] https://www.ecmwf.int/en/forecasts/dataset/ecmwf-reanalysis-v5

[43] https://developers.google.com/earth-engine/datasets/catalog/MODIS_061_MCD64A1#description

[44] https://ghsl.jrc.ec.europa.eu/ghs_pop.php

output[45] around 2050 (2045-2055) and the simulated historical period (1995-2014); the hazard metrics described above are then computed around 2050 based on the CMIP6 projections data.

Appendix B Future climate and socioeconomic scenarios

Future assessments of climate change impacts and adaptation rely on scenarios, namely a description of how the future may develop, based on a coherent and internally consistent set of assumptions about key drivers including demography, economic processes, technological innovation, governance, lifestyles, and relationship s among these driving forces (IPCC, 2021; Rounsevell and Metzger, 2010; O’Neill et al., 2014). Scenarios are not predictions; instead, they provide a ‘what-if’ investigation (Moss et al., 2010) of possible future trajectories. The "Shared Socio-Economic Pathways" framework is the most widely used set of scenarios in the climate change literature and characterizes the future evolution of the world depending on various factors, such as socioeconomic development, technological advancements, policy decisions, and global cooperation. The SSPs differ in terms of the socioeconomic challenges they present for climate change mitigation and adaptation (Rothman et al., 2014; Schweizer and O’Neill, 2014). These pathways range from SSP1 to SSP5, representing plausible trends in the evolution of society over the 21st century: SSP1) *‘sustainability’*; SSP2) *‘middle-of the-road’*; SSP3) *‘regional rivalry’*; SSP4) *‘inequality’*; SSP5) *‘fossil fuel-intensive development’* (O’Neill et al., 2017a). In the CMIP6 exercises (Tebaldi et al., 2021; Gidden et al.2019) and IPCC AR6 (2021)[46], each SSP has been associated with one or more Representative Concentrations Pathways (RCPs), matching the socioeconomic trend with the expected greenhouse gas emissions and radiative forcing changes at the end of the 21st century, and translating them into projections of average mean global surface temperature change. Table 1 reports global average surface temperature increase in the short, mid, and long term relative to two historical periods 1850-1900 and 1995-2014 (AR6 IPCC, 2021 pag. 572). In the current report, we refer to a temperature changes in 2081-2100 with respect to the 1850-1900 period, but we report both reference periods for the sake of comparison in the literature section.

Table 1: Changes in global surface temperature with respect to the historical period 1850–1900 and 1995-2014 . Source: IPCC AR6 (2021), pag.572

SSP-RCP	Scenario	CMIP6	2021–2040	2041–2060	2081–2100
SSP1-1.9	Very low GHG emissions: CO2 emissions cut to net zero around 2050	Relative to 1995/2014	0.7	0.8	0.7
		Relative to 1850/1900	1.5	1.7	1.5
SSP1-2.6	Low GHG emissions: CO2 emissions cut to net zero around 2075	Relative to 1995/2014	0.7	1	1.2
		Relative to 1850/1900	1.6	1.9	2
SSP2-4.5	Intermediate GHG emissions: CO2 emissions around current levels until 2050, then falling but not reaching net zero by 2100	Relative to 1995/2014	0.7	1.3	2
		Relative to 1850/1900	1.6	2.1	2.9
SSP3-7.0	High GHG emissions: CO2 emissions double by 2100	Relative to 1995/2014	0.7	1.4	3.1
		Relative to 1850/1900	1.6	2.3	3.9
SSP5-8.5	Very high GHG emissions: CO2 emissions triple by 2075	Relative to 1995/2014	0.8	1.7	4
		Relative to 1850/1900	1.7	2.6	4.8

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[45] Specifically, we consider the NEX-GDDP-CMIP6 global daily downscaled bias-corrected projections (DOI: 10.7917/OFSG3345) using the median value of 14 global climate models (ACCESS-ESM1-5, BCC-CSM2-MR, CMCC-CM2-SR5, CMCC-ESM2, FGOALS-g3, GFDL-CM4, GFDL-ESM4, GISS-E2-1-G, MIROC-ES2L, MIROC6, MPI-ESM1-2-HR, MPI-ESM1-2-LR, MRI-ESM2-0, orESM2-LM), using the air temperature and precipitation variables.

[46] IPCC AR6 (2021) considers a smaller set of CMIP6 models with respect to Tebaldi et al. (2021), for this reason the changes in global surface temperature are slightly lower in the AR6.

All scenarios are considered theoretically plausible. However, the RCP5-8.5 (+4.8 °C), a severe climate change scenario, is less likely to materialise considering the future extension of current mitigation policies until the end of the century. According to the UNDP (2022), extending current policies at the end of the century will imply a 2.7°C warming above pre-industrial levels, while the full implementation of Paris Agreement's NDCs (Intended Nationally Determined Contributions) will limit warming to 2.4°C in 2100, a value in between SSP2-4.5 (the moderate climate change scenario in this report, +2.9°C) and SSP1-2.6 (+2°C). When binding long-term and net-zero targets are included, warming would be limited to about 2°C, meeting the lower bound target of Paris Agreement (Climate Action Tracker, 2022). The difference between full implementation of the Paris NDCs and the emission reduction needed to limit global warming to 1.5°C relative to pre-industrial levels is referred as the Emission Gap (UNEP, 2022).

Appendix C Distributional and poverty metrics in the Eurostat's HBS

We use the Gini index to characterise the income distribution within EU27 Member States and the prevalence of at-risk-of-poverty population to highlight the fragile layers of the population. The Gini index is commonly computed by Eurostat using the equivalised disposable income (EUSILC source); the HBSs, used in this assessment, do not report this variable, but the monetary income, which differently form the disposable income may not include the between-household and social transfers. Therefore the two income measures are not overlapping as well as the related Gini index (Figure 17). We observe that disposable income is more unequally distributed than the net income especially in Eastern countries.

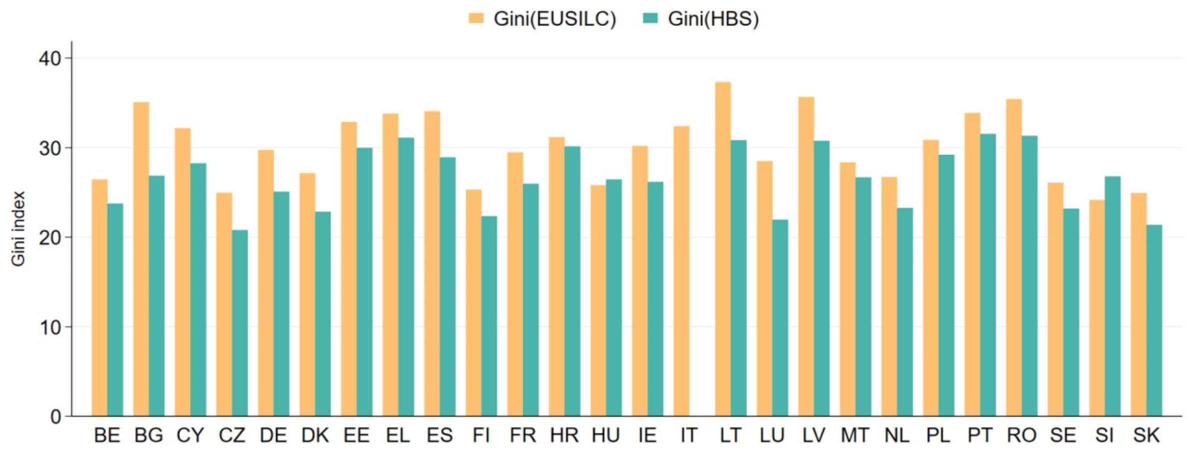

Figure 17: Gini index according to HBS and EUSILC, average of 2010 and 2015 data

We measure the share of people at-risk-of-poverty summing up the individuals living in households with an equivalised[47] net monetary income below the at-risk-of-poverty threshold (60 % of the national median equivalised net monetary income). The at-risk-of-poverty rate computed using the net monetary income (HBS) is in many cases lower than the one computed using the disposable income (EUSILC) (Figure 18).

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[47] To derive the equivalized income, we use the OECD-modified equivalence scale to rescale household flows depending on the household size and the age of household members. This scale assigns a value of 1 to the household head, of 0.5 to each additional adult member and of 0.3 to each child. See https://www.oecd.org/els/soc/OECD-Note-EquivalenceScales.pdf

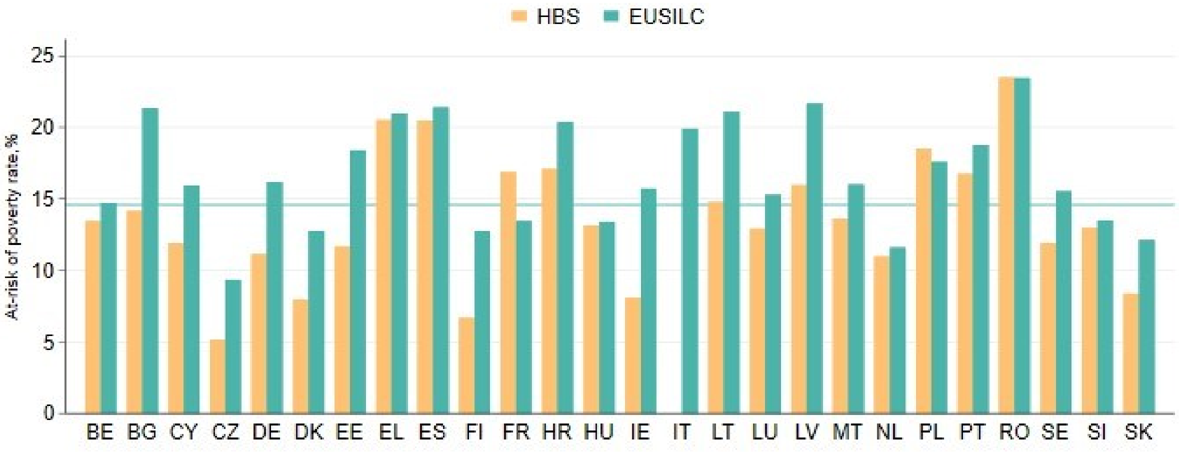

Figure 18: At-risk-of-poverty rate according to HBS and EUSILC, average of 2010 and 2015 data (missing imputed rent in CZ, IE, SE, SI, UK)

Figure 19 (left) highlights the labour income is slightly more unequally distributed with respect to the monetary income, due to the equalising effect of social transfers in the latter aggregate. The at-risk-of-poverty indicator (Figure 19 – right) highlights a stronger discrepancy in results depending on the income category considered. It is much higher if it is measured on the labour income and lower if we account for investment and transfer components included in the monetary net income[48].

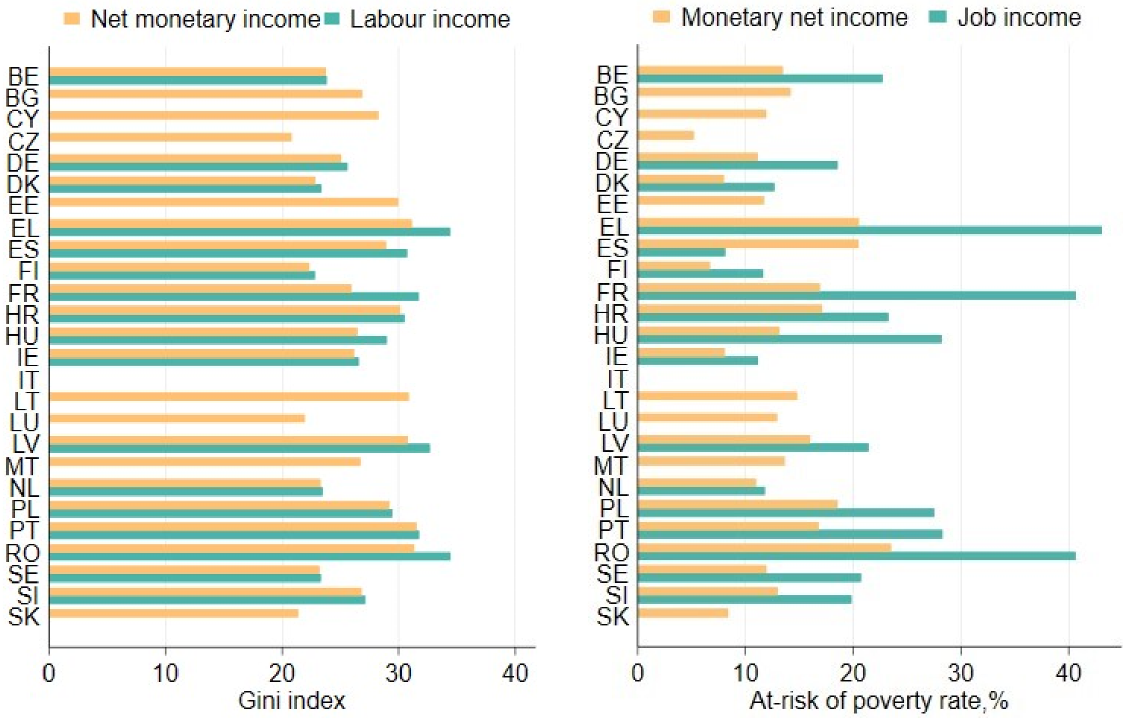

Figure 19: Gini index computed on the net monetary income and on the labour income (left) and at-risk-of-poverty rate measured using net monetary income and job income Average of 2010 and 2015 data

Appendix D Additional results

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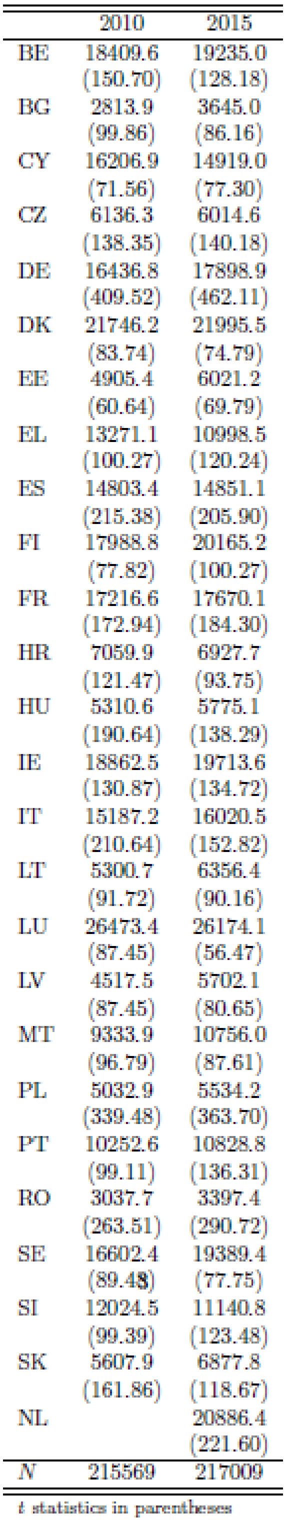
[48] The different magnitude of results when comparing Gini index and at-risk-of-poverty indicator is not surprising considering the low sensitivity of the Gini index to the tails of the income distribution (Cobham and Sumner, 2014) and the fact that instead poverty indicators focus on the left tail of the distribution.

Appendix D-I. Descriptive statistics

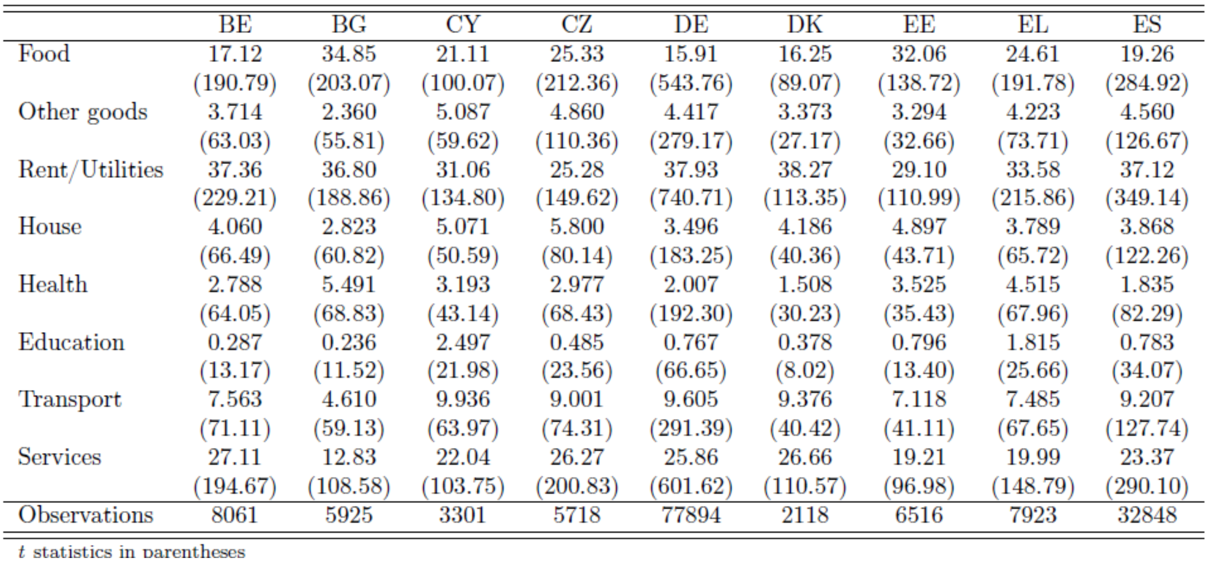
Table 2 Equivalised expenditure by country and year, Euro



	2010	2015
BE	18409.6	19235.0
	(150.70)	(128.18)
BG	2813.9	3645.0
	(99.86)	(86.16)
CY	16206.9	14919.0
	(71.56)	(77.30)
CZ	6136.3	6014.6
	(138.35)	(140.18)
DE	16436.8	17898.9
	(409.52)	(462.11)
DK	21746.2	21995.5
	(83.74)	(74.79)
EE	4905.4	6021.2
	(60.64)	(69.79)
EL	13271.1	10998.5
	(100.27)	(120.24)
ES	14803.4	14851.1
	(215.38)	(205.90)
FI	17988.8	20165.2
	(77.82)	(100.27)
FR	17216.6	17670.1
	(172.94)	(184.30)
HR	7059.9	6927.7
	(121.47)	(93.75)
HU	5310.6	5775.1
	(190.64)	(138.29)
IE	18862.5	19713.6
	(130.87)	(134.72)
IT	15187.2	16020.5
	(210.64)	(152.82)
LT	5300.7	6356.4
	(91.72)	(90.16)
LU	26473.4	26174.1
	(87.45)	(56.47)
LV	4517.5	5702.1
	(87.45)	(80.65)
MT	9333.9	10756.0
	(96.79)	(87.61)
PL	5032.9	5534.2
	(339.48)	(363.70)
PT	10252.6	10828.8
	(99.11)	(136.31)
RO	3037.7	3397.4
	(263.51)	(290.72)
SE	16602.4	19389.4
	(89.48)	(77.75)
SI	12024.5	11140.8
	(99.39)	(123.48)
SK	5607.9	6877.8
	(161.86)	(118.67)
NL		20886.4
		(221.60)
N	215569	217009

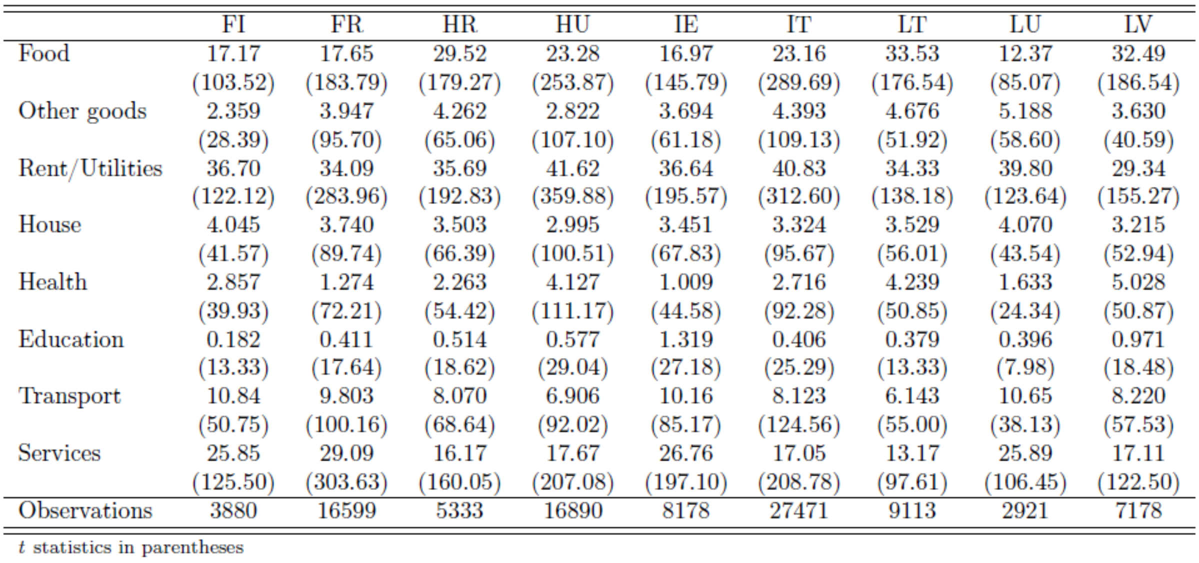
t statistics in parentheses

Table 3 Equivalised expenditure shares by country, Euro/year



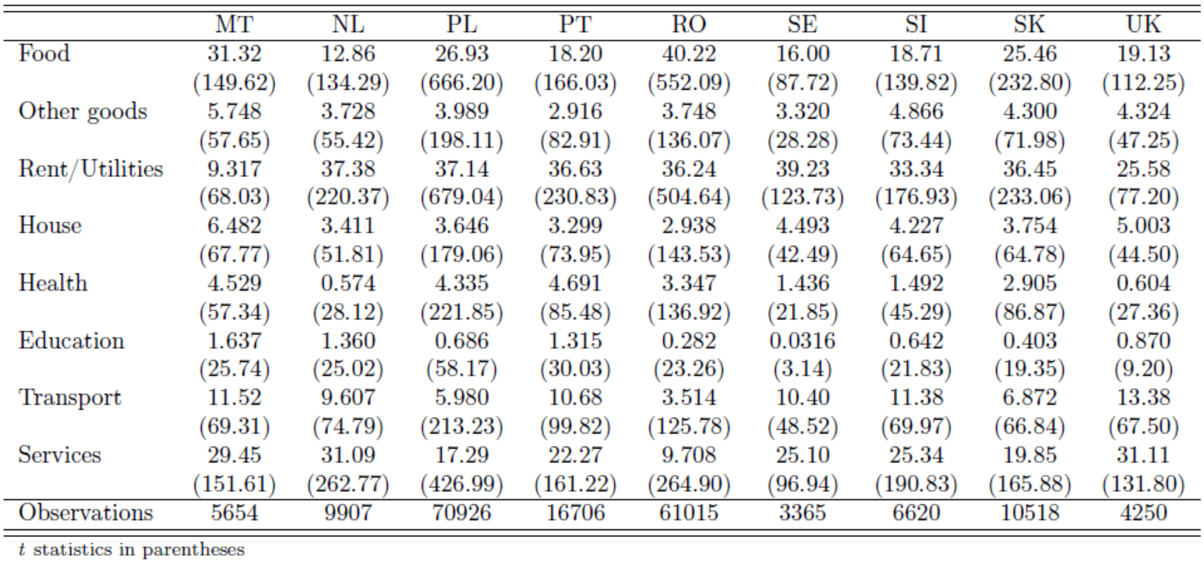
	BE	BG	CY	CZ	DE	DK	EE	EL	ES
Food	17.12	34.85	21.11	25.33	15.91	16.25	32.06	24.61	19.26
	(190.79)	(203.07)	(100.07)	(212.36)	(543.76)	(89.07)	(138.72)	(191.78)	(284.92)
Other goods	3.714	2.360	5.087	4.860	4.417	3.373	3.294	4.223	4.560
	(63.03)	(55.81)	(59.62)	(110.36)	(279.17)	(27.17)	(32.66)	(73.71)	(126.67)
Rent/Utilities	37.36	36.80	31.06	25.28	37.93	38.27	29.10	33.58	37.12
	(229.21)	(188.86)	(134.80)	(149.62)	(740.71)	(113.35)	(110.99)	(215.86)	(349.14)
House	4.060	2.823	5.071	5.800	3.496	4.186	4.897	3.789	3.868
	(66.49)	(60.82)	(50.59)	(80.14)	(183.25)	(40.36)	(43.71)	(65.72)	(122.26)
Health	2.788	5.491	3.193	2.977	2.007	1.508	3.525	4.515	1.835
	(64.05)	(68.83)	(43.14)	(68.43)	(192.30)	(30.23)	(35.43)	(67.96)	(82.29)
Education	0.287	0.236	2.497	0.485	0.767	0.378	0.796	1.815	0.783
	(13.17)	(11.52)	(21.98)	(23.56)	(66.65)	(8.02)	(13.40)	(25.66)	(34.07)
Transport	7.563	4.610	9.936	9.001	9.605	9.376	7.118	7.485	9.207
	(71.11)	(59.13)	(63.97)	(74.31)	(291.39)	(40.42)	(41.11)	(67.65)	(127.74)
Services	27.11	12.83	22.04	26.27	25.86	26.66	19.21	19.99	23.37
	(194.67)	(108.58)	(103.75)	(200.83)	(601.62)	(110.57)	(96.98)	(148.79)	(290.10)
Observations	8061	5925	3301	5718	77894	2118	6516	7923	32848

t statistics in parentheses



	FI	FR	HR	HU	IE	IT	LT	LU	LV
Food	17.17	17.65	29.52	23.28	16.97	23.16	33.53	12.37	32.49
	(103.52)	(183.79)	(179.27)	(253.87)	(145.79)	(289.69)	(176.54)	(85.07)	(186.54)
Other goods	2.359	3.947	4.262	2.822	3.694	4.393	4.676	5.188	3.630
	(28.39)	(95.70)	(65.06)	(107.10)	(61.18)	(109.13)	(51.92)	(58.60)	(40.59)
Rent/Utilities	36.70	34.09	35.69	41.62	36.64	40.83	34.33	39.80	29.34
	(122.12)	(283.96)	(192.83)	(359.88)	(195.57)	(312.60)	(138.18)	(123.64)	(155.27)
House	4.045	3.740	3.503	2.995	3.451	3.324	3.529	4.070	3.215
	(41.57)	(89.74)	(66.39)	(100.51)	(67.83)	(95.67)	(56.01)	(43.54)	(52.94)
Health	2.857	1.274	2.263	4.127	1.009	2.716	4.239	1.633	5.028
	(39.93)	(72.21)	(54.42)	(111.17)	(44.58)	(92.28)	(50.85)	(24.34)	(50.87)
Education	0.182	0.411	0.514	0.577	1.319	0.406	0.379	0.396	0.971
	(13.33)	(17.64)	(18.62)	(29.04)	(27.18)	(25.29)	(13.33)	(7.98)	(18.48)
Transport	10.84	9.803	8.070	6.906	10.16	8.123	6.143	10.65	8.220
	(50.75)	(100.16)	(68.64)	(92.02)	(85.17)	(124.56)	(55.00)	(38.13)	(57.53)
Services	25.85	29.09	16.17	17.67	26.76	17.05	13.17	25.89	17.11
	(125.50)	(303.63)	(160.05)	(207.08)	(197.10)	(208.78)	(97.61)	(106.45)	(122.50)
Observations	3880	16599	5333	16890	8178	27471	9113	2921	7178

t statistics in parentheses



	MT	NL	PL	PT	RO	SE	SI	SK	UK
Food	31.32	12.86	26.93	18.20	40.22	16.00	18.71	25.46	19.13
	(149.62)	(134.29)	(666.20)	(166.03)	(552.09)	(87.72)	(139.82)	(232.80)	(112.25)
Other goods	5.748	3.728	3.989	2.916	3.748	3.320	4.866	4.300	4.324
	(57.65)	(55.42)	(198.11)	(82.91)	(136.07)	(28.28)	(73.44)	(71.98)	(47.25)
Rent/Utilities	9.317	37.38	37.14	36.63	36.24	39.23	33.34	36.45	25.58
	(68.03)	(220.37)	(679.04)	(230.83)	(504.64)	(123.73)	(176.93)	(233.06)	(77.20)
House	6.482	3.411	3.646	3.299	2.938	4.493	4.227	3.754	5.003
	(67.77)	(51.81)	(179.06)	(73.95)	(143.53)	(42.49)	(64.65)	(64.78)	(44.50)
Health	4.529	0.574	4.335	4.691	3.347	1.436	1.492	2.905	0.604
	(57.34)	(28.12)	(221.85)	(85.48)	(136.92)	(21.85)	(45.29)	(86.87)	(27.36)
Education	1.637	1.360	0.686	1.315	0.282	0.0316	0.642	0.403	0.870
	(25.74)	(25.02)	(58.17)	(30.03)	(23.26)	(3.14)	(21.83)	(19.35)	(9.20)
Transport	11.52	9.607	5.980	10.68	3.514	10.40	11.38	6.872	13.38
	(69.31)	(74.79)	(213.23)	(99.82)	(125.78)	(48.52)	(69.97)	(66.84)	(67.50)
Services	29.45	31.09	17.29	22.27	9.708	25.10	25.34	19.85	31.11
	(151.61)	(262.77)	(426.99)	(161.22)	(264.90)	(96.94)	(190.83)	(165.88)	(131.80)
Observations	5654	9907	70926	16706	61015	3365	6620	10518	4250

t statistics in parentheses

Table 4 Equivalised expenditure by category and quintile, Euro/year

	Q1	Q2	Q3	Q4	Q5
Total	3117.0	6081.2	10621.5	15787.1	22851.5
	(429.53)	(465.68)	(605.31)	(627.74)	(564.37)
Food	993.4	1458.6	2094.1	2816.0	3399.6
	(326.01)	(288.71)	(321.94)	(354.48)	(380.96)
Other goods	70.56	189.0	393.7	689.6	1127.4
	(79.90)	(92.63)	(126.10)	(156.14)	(201.37)
Rent/Utilities	1344.3	2646.7	4367.9	5669.0	6563.4
	(263.20)	(249.30)	(321.13)	(344.76)	(344.70)
House	79.25	180.0	364.4	630.3	1051.6
	(90.12)	(79.90)	(99.27)	(123.97)	(160.50)
Health	143.2	184.1	235.2	311.1	398.2
	(137.12)	(120.83)	(121.01)	(131.50)	(142.32)
Education	3.157	19.79	45.95	89.18	253.5
	(17.32)	(25.23)	(30.20)	(30.97)	(35.91)
Transport	84.56	316.3	774.1	1539.7	3163.1
	(65.40)	(83.50)	(132.61)	(170.70)	(180.42)
Services	398.6	1086.7	2346.2	4042.0	6894.5
	(105.81)	(167.20)	(263.89)	(324.33)	(302.94)
N	87366	87371	87360	87367	87364

t statistics in parentheses

Table 5 Equivalised expenditure share by category and quintile

	Q1	Q2	Q3	Q4	Q5
Food	35.10	25.94	20.96	18.84	15.76
	(396.25)	(351.27)	(363.53)	(389.83)	(398.71)
Other goods	2.267	3.249	3.833	4.458	5.052
	(102.22)	(117.75)	(145.43)	(170.60)	(216.41)
Rent/Utilities	41.12	41.73	40.00	35.33	28.96
	(420.71)	(386.94)	(436.34)	(459.34)	(438.52)
House	2.501	3.009	3.433	3.893	4.496
	(121.48)	(100.69)	(118.88)	(142.46)	(178.14)
Health	4.433	3.153	2.315	1.988	1.766
	(152.67)	(142.63)	(139.87)	(145.66)	(154.31)
Education	0.102	0.369	0.495	0.634	1.163
	(20.24)	(31.72)	(39.28)	(36.90)	(42.76)
Transport	2.607	5.389	7.405	9.761	13.40
	(81.08)	(113.76)	(156.96)	(197.81)	(217.82)
Services	11.87	17.17	21.56	25.10	29.40
	(145.88)	(233.62)	(331.78)	(412.43)	(463.39)
N	87366	87371	87360	87367	87364

t statistics in parentheses

Table 6 Equivalised labor income by category and quintile, Euro/year

	Q1	Q2	Q3	Q4	Q5
Net income	4180.3	7806.9	13819.8	20645.5	29025.6
	(171.19)	(208.36)	(284.98)	(286.85)	(329.62)
Monetary income	3181.2	6738.9	12365.9	18253.1	25653.8
	(124.84)	(178.28)	(265.23)	(266.35)	(306.72)
Job income	2352.1	5726.8	10957.3	16456.6	23229.3
	(115.77)	(156.54)	(219.93)	(231.28)	(270.57)
Imputed rent	734.3	926.5	1417.0	2485.3	3705.3
	(200.94)	(121.40)	(111.90)	(156.70)	(219.22)
Inkind income	269.0	156.0	118.2	146.3	184.4
	(122.58)	(72.63)	(47.88)	(40.61)	(48.52)
N	70408	66062	62102	63540	68095

t statistics in parentheses

Table 7 Equivalised labor income by source and quintile, Euro/year

	Q1	Q2	Q3	Q4	Q5
Agriculture	220.4	632.3	883.2	1935.1	2445.6
	(4.45)	(7.74)	(9.47)	(5.30)	(3.07)
Industry	496.5	1188.5	1815.7	2316.3	5428.3
	(6.84)	(16.04)	(18.25)	(8.52)	(5.55)
Services	380.2	1082.5	1543.8	2246.9	3871.6
	(6.64)	(18.61)	(17.40)	(9.02)	(5.50)
Other	92.41	212.6	366.1	309.8	649.9
	(2.34)	(7.05)	(8.76)	(4.47)	(2.48)
N	78	226	228	87	49

t statistics in parentheses

Table 8 Equivalised labour income share by source and country

	BE	DE	DK	EL	ES	FI	FR	HR	HU
Agriculture	1.268	0.351	1.044	2.431	3.562	1.628	1.010	4.900	4.979
	(8.62)	(15.32)	(4.66)	(14.32)	(25.53)	(8.19)	(13.00)	(18.41)	(29.77)
Industry	15.44	6.869	12.90	5.053	13.17	9.864	8.471	14.18	23.36
	(34.10)	(73.29)	(18.31)	(20.78)	(51.02)	(19.60)	(38.88)	(33.10)	(69.71)
Services	59.27	20.74	48.19	20.81	26.70	35.77	26.11	29.93	44.20
	(95.52)	(135.07)	(41.78)	(43.91)	(75.90)	(42.64)	(73.89)	(50.55)	(109.16)
Other	23.95	71.82	37.80	71.25	14.52	52.69	62.13	50.88	26.62
	(40.99)	(409.14)	(32.07)	(130.48)	(66.36)	(58.71)	(155.90)	(77.44)	(77.98)
Observations	7977	77894	2118	7923	21963	3880	16599	5326	16890

t statistics in parentheses

	IE	LV	NL	PL	PT	RO	SE	SI	UK
Agriculture	4.888	4.659	0	3.834	8.993	13.50	0.579	1.036	0.627
	(17.10)	(13.20)	(.)	(63.99)	(37.65)	(86.89)	(4.50)	(9.71)	(5.75)
Industry	18.94	14.09	0	19.97	28.77	19.50	13.17	18.58	12.38
	(45.58)	(23.70)	(.)	(150.78)	(69.37)	(103.86)	(21.11)	(37.24)	(27.31)
Services	65.67	37.89	0	33.72	57.91	28.60	58.05	31.82	45.75
	(124.86)	(45.98)	(.)	(206.11)	(127.62)	(132.79)	(58.17)	(53.86)	(63.06)
Other	10.33	40.28	100.00	40.98	2.700	24.39	27.83	48.07	40.99
	(30.03)	(48.72)	(1.65e+17)	(234.70)	(18.64)	(139.46)	(29.34)	(73.32)	(55.10)
Observations	8178	3604	9907	70926	16706	61015	3365	6620	4250

t statistics in parentheses

Appendix D-II.Regression results

Table 9 Regression results for all households and terciles

Health expenditure

	Full Sample (1)	Poor (2)	Medium (3)	Rich (4)
T	-0.169***	-0.292***	-0.215**	-0.108
	(0.046)	(0.098)	(0.088)	(0.066)
T^2	0.00906***	0.0142***	0.0117***	0.00646**
	(0.002)	(0.004)	(0.003)	(0.003)
Floods	0.0876***	0.116***	0.124***	0.0493*
	(0.017)	(0.029)	(0.031)	(0.030)
Floods^2	-0.00147***	-0.00222***	-0.00209***	-0.000669
	(0.000)	(0.001)	(0.001)	(0.001)
asinh(Burnt Area)	0.00769	-0.0141	0.0426***	0.0124
	(0.006)	(0.010)	(0.012)	(0.009)
$\epsilon_{H,T}$	0.028	0.001	0.047	0.037
$\epsilon_{H,F}$	0.019	0.010	0.027	0.018
Controls	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes
Wave FE	Yes	Yes	Yes	Yes
Observations	425807	208474	104388	112945

Notes: The dependent variable is expressed using inverse hyperbolic sine. (1)-(4) clustered std. errors at household level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All regressions are conducted using survey weights. ϵ_H, T is the temperature semi-elasticity of health expenditure at the averages, e.g. one-degree increase in temperature leads to an increase in health expenditure between 0.1 and 4.7% on average.

Energy expenditure, all households

	Energy (1)	Electricity (2)	Gas (3)
$\overline{CDD}$	-0.00375***	0.0125***	-0.111***
	(0.001)	(0.001)	(0.003)
$\overline{CDD}^2$	-0.000242***	-0.000190***	0.00356***
	(0.000)	(0.000)	(0.000)
$\overline{HDD}$	-0.00174***	-0.00611***	0.00848***
	(0.000)	(0.000)	(0.001)
$\overline{HDD}^2$	-0.00000352*	0.0000217***	-0.0000358***
	(0.000)	(0.000)	(0.000)
$\epsilon_{E,CDD}$	-0.005	0.011	-0.091
$\epsilon_{E,HDD}$	-0.002	-0.005	0.006
Precipitations Controls	Yes	Yes	Yes
Socio-Demographic Controls	Yes	Yes	Yes
Country FE	Yes	Yes	Yes
Wave FE	Yes	Yes	Yes
R^2	0.431	0.492	0.376
Observations	415345	355702	267577

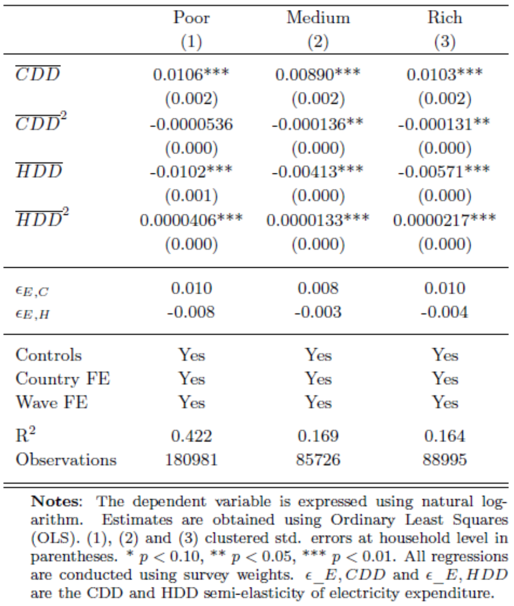
Notes: The dependent variable is expressed using natural logarithm. (1), (2) and (3) clustered std. errors at household level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All regressions are conducted using survey weights. $\epsilon_{E,CDD}$ and $\epsilon_{E,HDD}$ are the CDD and HDD semi-elasticity of energy, electricity and gas expenditure.

Energy expenditure by tercile

	Poor (1)	Medium (2)	Rich (3)
$\overline{CDD}$	0.00937***	-0.0234***	-0.0178***
	(0.002)	(0.002)	(0.002)
$\overline{CDD}^2$	-0.000591***	0.000288***	0.000198***
	(0.000)	(0.000)	(0.000)
$\overline{HDD}$	-0.00649***	0.00101**	-0.00125***
	(0.001)	(0.000)	(0.000)
$\overline{HDD}^2$	0.0000203***	-0.0000140***	-0.00000275
	(0.000)	(0.000)	(0.000)
$\epsilon_{E,C}$	0.006	-0.022	-0.017
$\epsilon_{E,H}$	-0.005	0.000	-0.001
Controls	Yes	Yes	Yes
Country FE	Yes	Yes	Yes
Wave FE	Yes	Yes	Yes
R^2	0.355	0.148	0.175
Observations	201255	102379	111711

Notes: The dependent variable is expressed using natural logarithm. Estimates are obtained using Ordinary Least Squares (OLS). (1), (2) and (3) clustered std. errors at household level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All regressions are conducted using survey weights. ϵ_E, CDD and ϵ_E, HDD are the CDD and HDD semi-elasticity of energy expenditure.

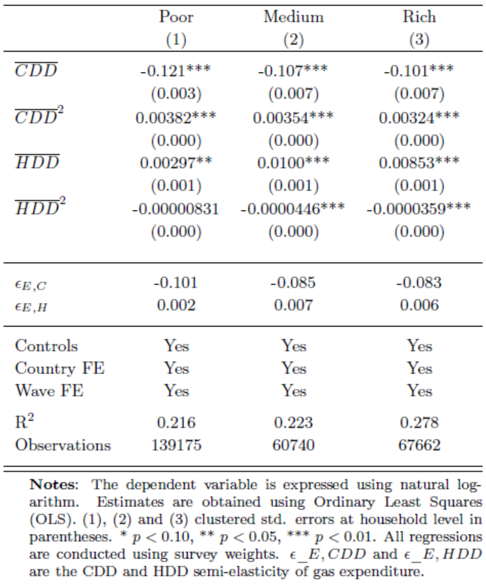
Electricity by tercile



	Poor (1)	Medium (2)	Rich (3)
$\overline{CDD}$	0.0106***	0.00890***	0.0103***
	(0.002)	(0.002)	(0.002)
$\overline{CDD}^2$	-0.0000536	-0.000136**	-0.000131**
	(0.000)	(0.000)	(0.000)
$\overline{HDD}$	-0.0102***	-0.00413***	-0.00571***
	(0.001)	(0.000)	(0.000)
$\overline{HDD}^2$	0.0000406***	0.0000133***	0.0000217***
	(0.000)	(0.000)	(0.000)
$\epsilon_{E,C}$	0.010	0.008	0.010
$\epsilon_{E,H}$	-0.008	-0.003	-0.004
Controls	Yes	Yes	Yes
Country FE	Yes	Yes	Yes
Wave FE	Yes	Yes	Yes
R^2	0.422	0.169	0.164
Observations	180981	85726	88995

Notes: The dependent variable is expressed using natural logarithm. Estimates are obtained using Ordinary Least Squares (OLS). (1), (2) and (3) clustered std. errors at household level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All regressions are conducted using survey weights. ϵ_E, CDD and ϵ_E, HDD are the CDD and HDD semi-elasticity of electricity expenditure.

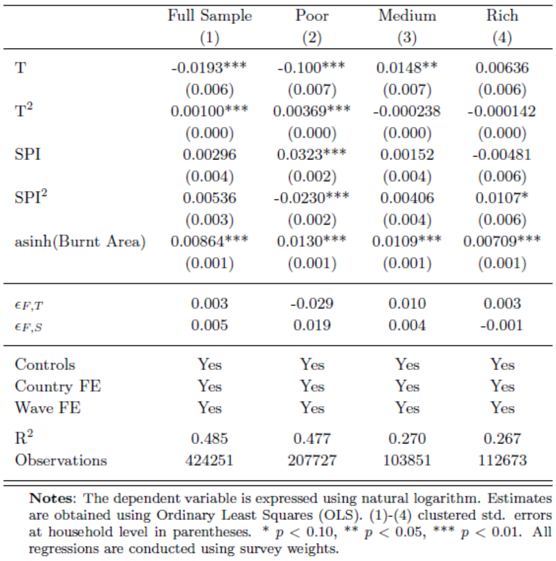
Natural gas by tercile



	Poor (1)	Medium (2)	Rich (3)
$\overline{CDD}$	-0.121***	-0.107***	-0.101***
	(0.003)	(0.007)	(0.007)
$\overline{CDD}^2$	0.00382***	0.00354***	0.00324***
	(0.000)	(0.000)	(0.000)
$\overline{HDD}$	0.00297**	0.0100***	0.00853***
	(0.001)	(0.001)	(0.001)
$\overline{HDD}^2$	-0.00000831	-0.0000446***	-0.0000359***
	(0.000)	(0.000)	(0.000)
$\epsilon_{E,C}$	-0.101	-0.085	-0.083
$\epsilon_{E,H}$	0.002	0.007	0.006
Controls	Yes	Yes	Yes
Country FE	Yes	Yes	Yes
Wave FE	Yes	Yes	Yes
R^2	0.216	0.223	0.278
Observations	139175	60740	67662

Notes: The dependent variable is expressed using natural logarithm. Estimates are obtained using Ordinary Least Squares (OLS). (1), (2) and (3) clustered std. errors at household level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All regressions are conducted using survey weights. ϵ_E, CDD and ϵ_E, HDD are the CDD and HDD semi-elasticity of gas expenditure.

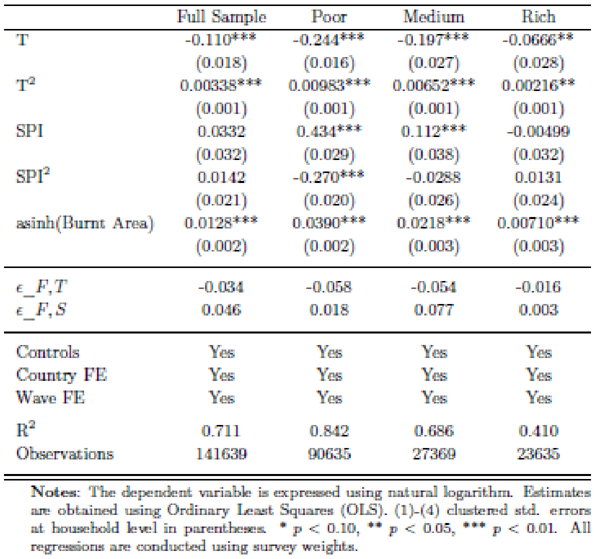
Food expenditure



	Full Sample (1)	Poor (2)	Medium (3)	Rich (4)
T	-0.0193***	-0.100***	0.0148**	0.00636
	(0.006)	(0.007)	(0.007)	(0.006)
T^2	0.00100***	0.00369***	-0.000238	-0.000142
	(0.000)	(0.000)	(0.000)	(0.000)
SPI	0.00296	0.0323***	0.00152	-0.00481
	(0.004)	(0.002)	(0.004)	(0.006)
SPI^2	0.00536	-0.0230***	0.00406	0.0107*
	(0.003)	(0.002)	(0.004)	(0.006)
asinh(Burnt Area)	0.00864***	0.0130***	0.0109***	0.00709***
	(0.001)	(0.001)	(0.001)	(0.001)
$\epsilon_{F,T}$	0.003	-0.029	0.010	0.003
$\epsilon_{F,S}$	0.005	0.019	0.004	-0.001
Controls	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes
Wave FE	Yes	Yes	Yes	Yes
R^2	0.485	0.477	0.270	0.267
Observations	424251	207727	103851	112673

Notes: The dependent variable is expressed using natural logarithm. Estimates are obtained using Ordinary Least Squares (OLS). (1)-(4) clustered std. errors at household level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All regressions are conducted using survey weights.

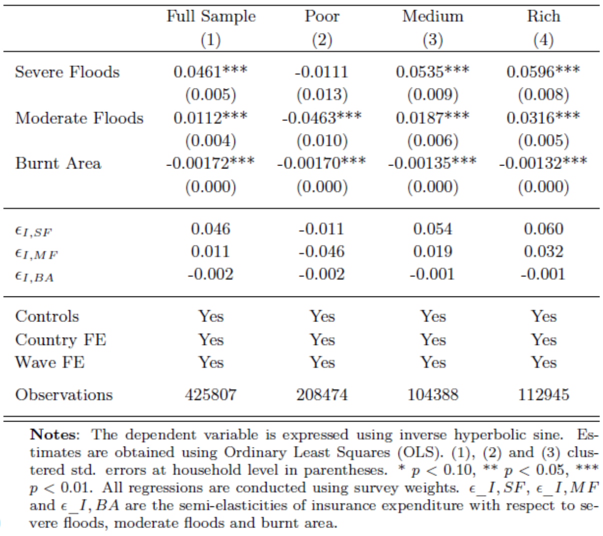
Food quantity



	Full Sample	Poor	Medium	Rich
T	-0.110***	-0.244***	-0.197***	-0.0666**
	(0.018)	(0.016)	(0.027)	(0.028)
T^2	0.00338***	0.00983***	0.00652***	0.00216**
	(0.001)	(0.001)	(0.001)	(0.001)
SPI	0.0332	0.434***	0.112***	-0.00499
	(0.032)	(0.029)	(0.038)	(0.032)
SPI^2	0.0142	-0.270***	-0.0288	0.0131
	(0.021)	(0.020)	(0.026)	(0.024)
asinh(Burnt Area)	0.0128***	0.0390***	0.0218***	0.00710***
	(0.002)	(0.002)	(0.003)	(0.003)
ϵ_F, T	-0.034	-0.058	-0.054	-0.016
ϵ_F, S	0.046	0.018	0.077	0.003
Controls	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes
Wave FE	Yes	Yes	Yes	Yes
R^2	0.711	0.842	0.686	0.410
Observations	141639	90635	27369	23635

Notes: The dependent variable is expressed using natural logarithm. Estimates are obtained using Ordinary Least Squares (OLS). (1)-(4) clustered std. errors at household level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All regressions are conducted using survey weights.

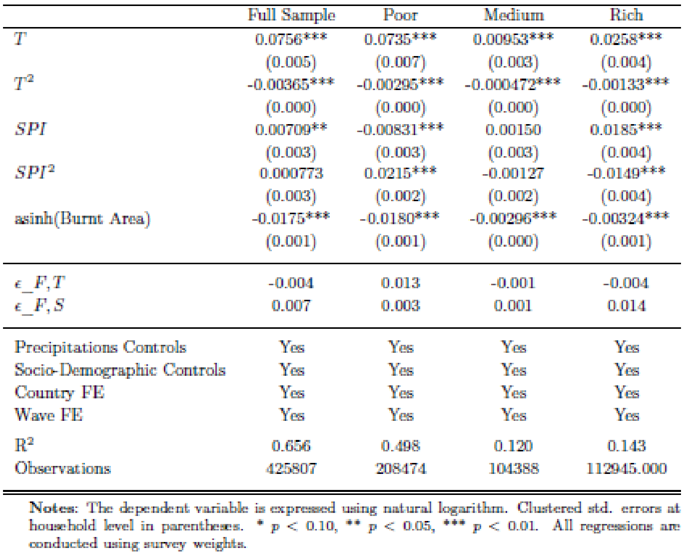
Insurance expenditure



	Full Sample (1)	Poor (2)	Medium (3)	Rich (4)
Severe Floods	0.0461***	-0.0111	0.0535***	0.0596***
	(0.005)	(0.013)	(0.009)	(0.008)
Moderate Floods	0.0112***	-0.0463***	0.0187***	0.0316***
	(0.004)	(0.010)	(0.006)	(0.005)
Burnt Area	-0.00172***	-0.00170***	-0.00135***	-0.00132***
	(0.000)	(0.000)	(0.000)	(0.000)
$\epsilon_{I,SF}$	0.046	-0.011	0.054	0.060
$\epsilon_{I,MF}$	0.011	-0.046	0.019	0.032
$\epsilon_{I,BA}$	-0.002	-0.002	-0.001	-0.001
Controls	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes
Wave FE	Yes	Yes	Yes	Yes
Observations	425807	208474	104388	112945

Notes: The dependent variable is expressed using inverse hyperbolic sine. Estimates are obtained using Ordinary Least Squares (OLS). (1), (2) and (3) clustered std. errors at household level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All regressions are conducted using survey weights. ϵ_I, SF, ϵ_I, MF and ϵ_I, BA are the semi-elasticities of insurance expenditure with respect to severe floods, moderate floods and burnt area.

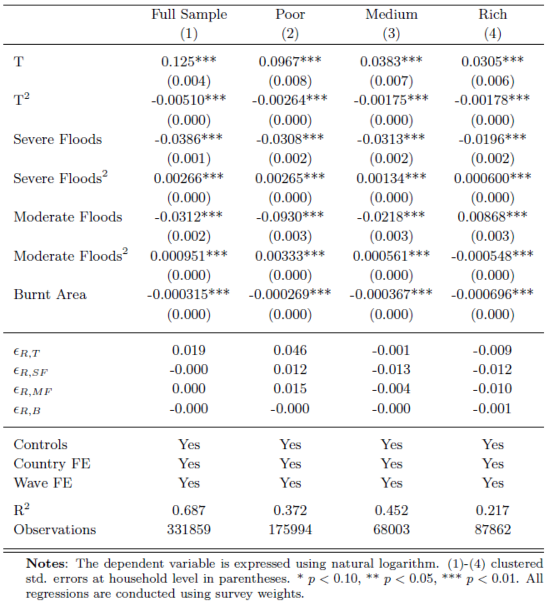
Total expenditure



	Full Sample	Poor	Medium	Rich
T	0.0756***	0.0735***	0.00953***	0.0258***
	(0.005)	(0.007)	(0.003)	(0.004)
T^2	-0.00365***	-0.00295***	-0.000472***	-0.00133***
	(0.000)	(0.000)	(0.000)	(0.000)
SPI	0.00709**	-0.00831***	0.00150	0.0185***
	(0.003)	(0.003)	(0.003)	(0.004)
SPI^2	0.000773	0.0215***	-0.00127	-0.0149***
	(0.003)	(0.002)	(0.002)	(0.004)
asinh(Burnt Area)	-0.0175***	-0.0180***	-0.00296***	-0.00324***
	(0.001)	(0.001)	(0.000)	(0.001)
ϵ_F,T	-0.004	0.013	-0.001	-0.004
ϵ_F,S	0.007	0.003	0.001	0.014
Precipitations Controls	Yes	Yes	Yes	Yes
Socio-Demographic Controls	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes
Wave FE	Yes	Yes	Yes	Yes
R^2	0.656	0.498	0.120	0.143
Observations	425807	208474	104388	112945.000

Notes: The dependent variable is expressed using natural logarithm. Clustered std. errors at household level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All regressions are conducted using survey weights.

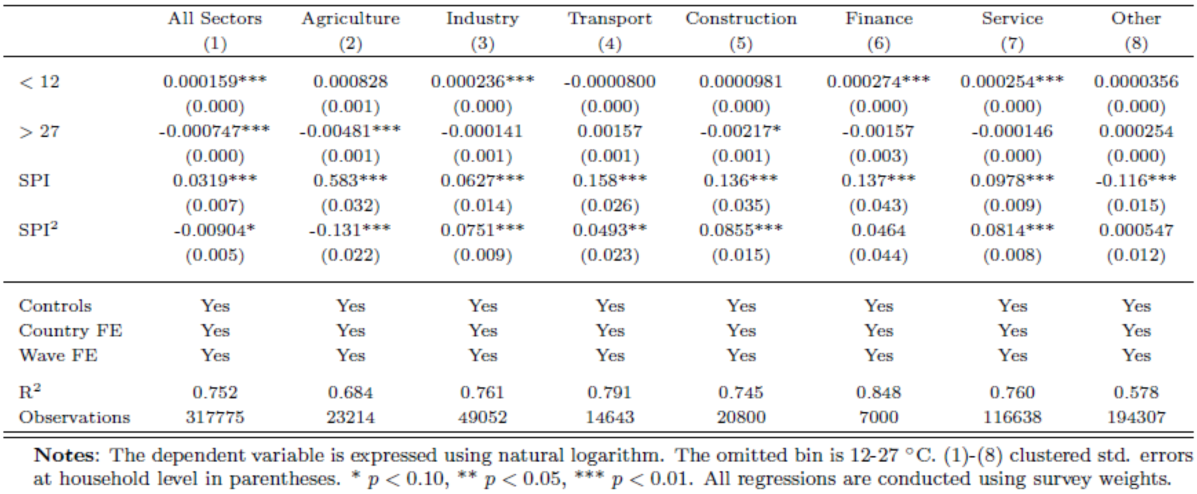
Imputed rent



	Full Sample (1)	Poor (2)	Medium (3)	Rich (4)
T	0.125***	0.0967***	0.0383***	0.0305***
	(0.004)	(0.008)	(0.007)	(0.006)
T^2	-0.00510***	-0.00264***	-0.00175***	-0.00178***
	(0.000)	(0.000)	(0.000)	(0.000)
Severe Floods	-0.0386***	-0.0308***	-0.0313***	-0.0196***
	(0.001)	(0.002)	(0.002)	(0.002)
Severe Floods^2	0.00266***	0.00265***	0.00134***	0.000600***
	(0.000)	(0.000)	(0.000)	(0.000)
Moderate Floods	-0.0312***	-0.0930***	-0.0218***	0.00868***
	(0.002)	(0.003)	(0.003)	(0.003)
Moderate Floods^2	0.000951***	0.00333***	0.000561***	-0.000548***
	(0.000)	(0.000)	(0.000)	(0.000)
Burnt Area	-0.000315***	-0.000269***	-0.000367***	-0.000696***
	(0.000)	(0.000)	(0.000)	(0.000)
$\epsilon_{R,T}$	0.019	0.046	-0.001	-0.009
$\epsilon_{R,SF}$	-0.000	0.012	-0.013	-0.012
$\epsilon_{R,MF}$	0.000	0.015	-0.004	-0.010
$\epsilon_{R,B}$	-0.000	-0.000	-0.000	-0.001
Controls	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes
Wave FE	Yes	Yes	Yes	Yes
R^2	0.687	0.372	0.452	0.217
Observations	331859	175994	68003	87862

Notes: The dependent variable is expressed using natural logarithm. (1)-(4) clustered std. errors at household level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All regressions are conducted using survey weights.

Total income (w/o burnt area)



	All Sectors (1)	Agriculture (2)	Industry (3)	Transport (4)	Construction (5)	Finance (6)	Service (7)	Other (8)
< 12	0.000159***	0.000828	0.000236***	-0.0000800	0.0000981	0.000274***	0.000254***	0.0000356
	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
> 27	-0.000747***	-0.00481***	-0.000141	0.00157	-0.00217*	-0.00157	-0.000146	0.000254
	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.003)	(0.000)	(0.000)
SPI	0.0319***	0.583***	0.0627***	0.158***	0.136***	0.137***	0.0978***	-0.116***
	(0.007)	(0.032)	(0.014)	(0.026)	(0.035)	(0.043)	(0.009)	(0.015)
SPI^2	-0.00904*	-0.131***	0.0751***	0.0493**	0.0855***	0.0464	0.0814***	0.000547
	(0.005)	(0.022)	(0.009)	(0.023)	(0.015)	(0.044)	(0.008)	(0.012)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wave FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.752	0.684	0.761	0.791	0.745	0.848	0.760	0.578
Observations	317775	23214	49052	14643	20800	7000	116638	194307

Notes: The dependent variable is expressed using natural logarithm. The omitted bin is 12-27 °C. (1)-(8) clustered std. errors at household level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All regressions are conducted using survey weights.

Total income (w burnt area)

	All Sectors (1)	Agriculture (2)	Industry (3)	Transport (4)	Construction (5)	Finance (6)	Service (7)	Other (8)
< 12	0.000138***	0.000763	0.000236***	-0.0000875	0.0000900	0.000272***	0.000250***	-0.0000136
	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
> 27	-0.00111***	-0.00166	0.0000773	0.00151	-0.00188	-0.00177	-0.000239	-0.000340
	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.003)	(0.000)	(0.000)
SPI	0.0315***	0.565***	0.0609***	0.162***	0.132***	0.134***	0.100***	-0.121***
	(0.007)	(0.032)	(0.014)	(0.026)	(0.035)	(0.043)	(0.009)	(0.015)
SPI^2	-0.00295	-0.150***	0.0808***	0.0515**	0.0874***	0.0495	0.0825***	0.00919
	(0.005)	(0.022)	(0.009)	(0.023)	(0.015)	(0.044)	(0.008)	(0.012)
asinh(Burnt Area)	-0.0387***	-0.0722***	-0.0284***	-0.0404***	-0.0541***	-0.0277**	-0.0330***	-0.0482***
	(0.002)	(0.006)	(0.004)	(0.005)	(0.005)	(0.011)	(0.003)	(0.004)
Precipitations Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Socio-Demographic Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wave FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.753	0.688	0.761	0.792	0.747	0.848	0.761	0.579
Observations	317775	23214	49052	14643	20800	7000	116638	194307

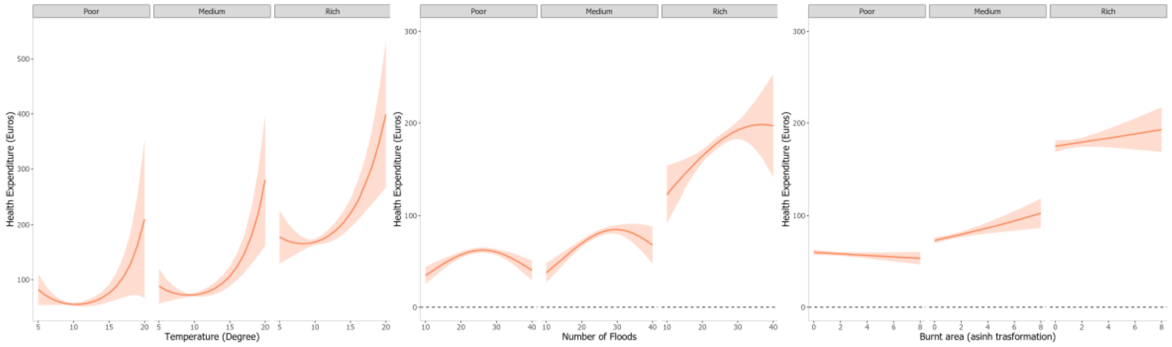
Notes: The dependent variable is expressed using natural logarithm. The omitted bin is 12-27 °C. (1)-(8) clustered std. errors at household level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All regressions are conducted using survey weights.

Monetary net income

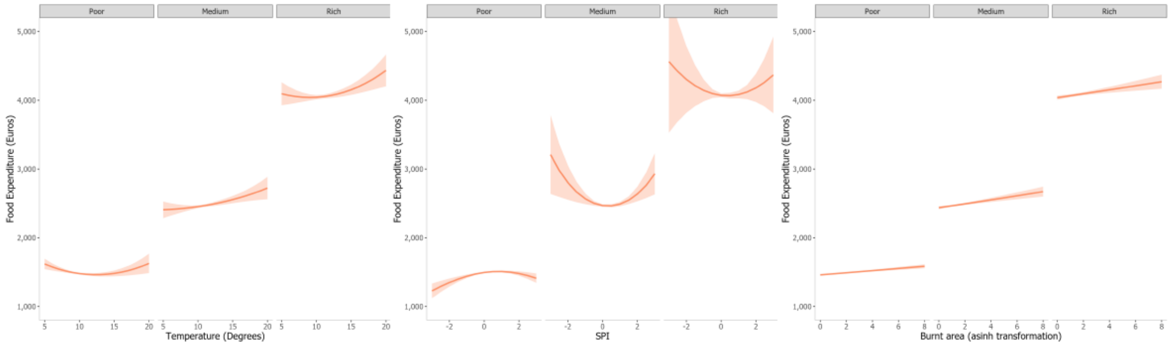
	Monetary net income	Poor	Medium	Rich
< 12	0.000140***	0.0000808	0.0000871**	0.0000912***
	(0.000)	(0.000)	(0.000)	(0.000)
> 27	-0.000752***	-0.00165***	-0.000536**	-0.000494*
	(0.000)	(0.000)	(0.000)	(0.000)
SPI	0.00225	-0.00462	0.00122	0.0170*
	(0.004)	(0.005)	(0.008)	(0.009)
SPI^2	-0.0150***	0.0172***	-0.0386***	-0.0481***
	(0.003)	(0.004)	(0.007)	(0.010)
asinh(Burnt Area)	-0.0117***	-0.0143***	-0.00681***	-0.00544***
	(0.001)	(0.001)	(0.002)	(0.002)
ϵ_F,T	-0.001	0.003	-0.004	0.014
Precipitations Controls	Yes	Yes	Yes	Yes
Socio-Demographic Controls	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes
Wave FE	Yes	Yes	Yes	Yes
Observations	0.635	0.523	0.226	0.229
N	395302	202674	92480	100148

Notes: The dependent variable is expressed using natural logarithm. The omitted bin is 12-27 °C. (1)-(8) clustered std. errors at household level in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All regressions are conducted using survey weights.

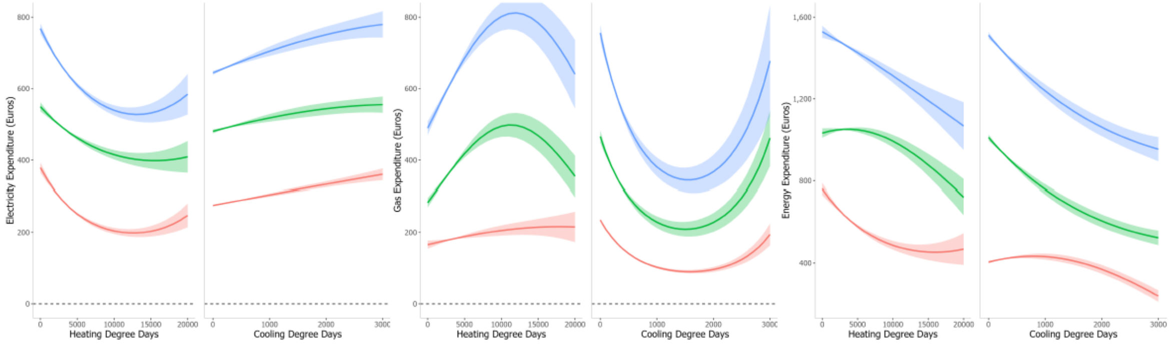
Appendix D-III. The relationship between climate/hazard metrics and the cost of climate change at tercile level



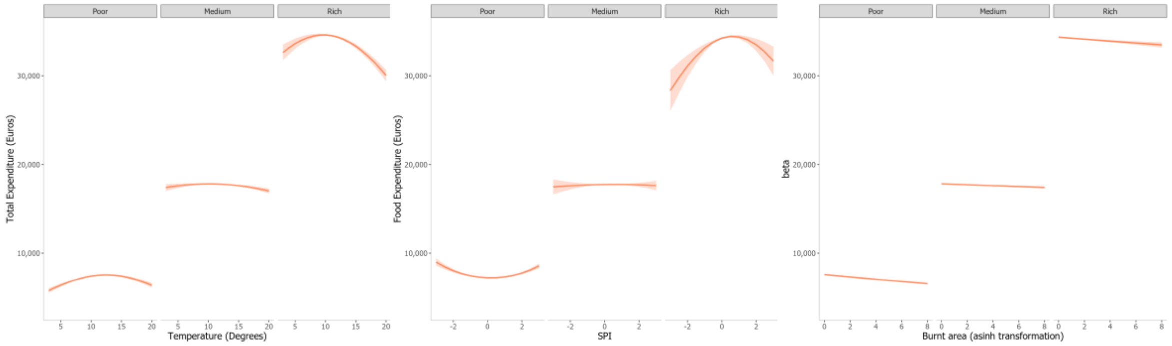
A. Health expenditure



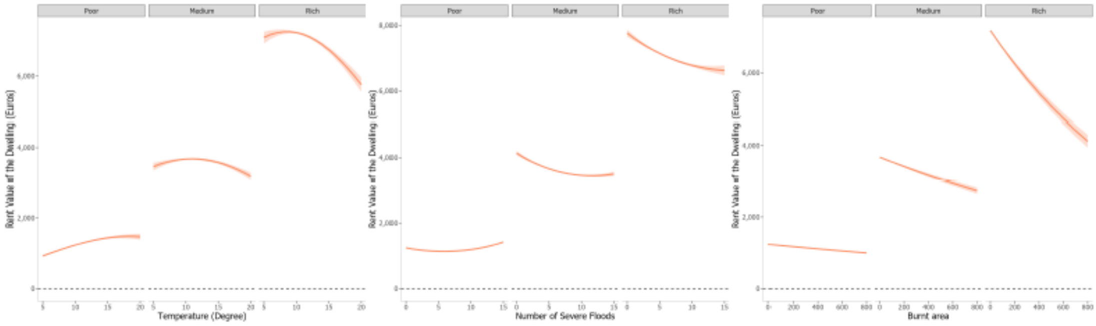
B. Food expenditure



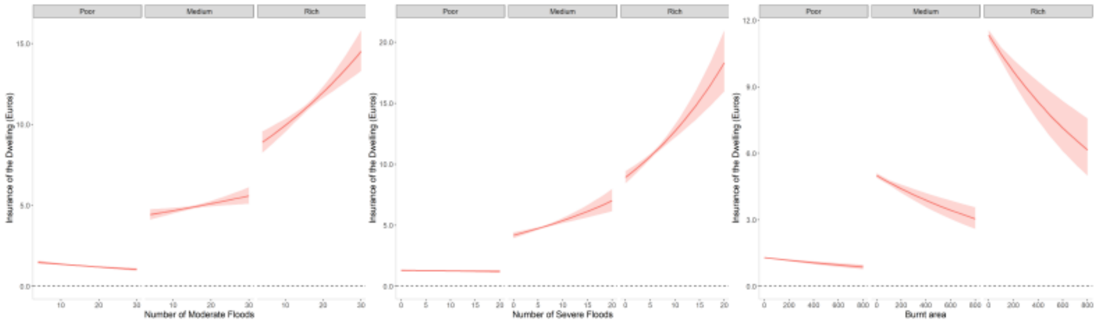
C. Electricity expenditure D. Gas expenditure E. Energy expenditure



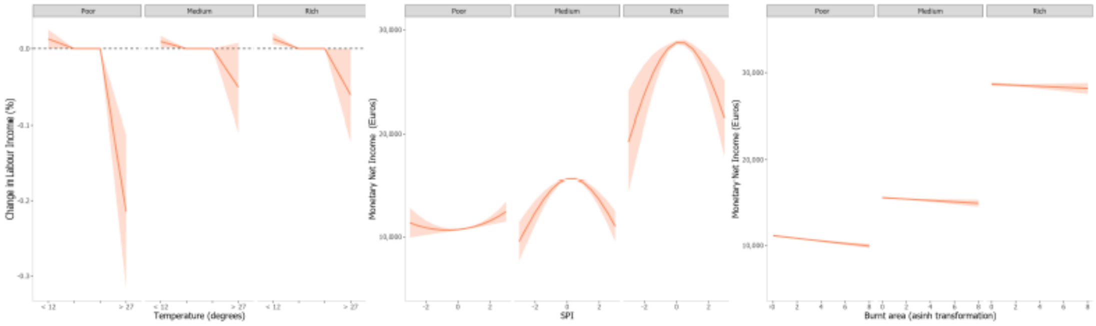
F. Total expenditure



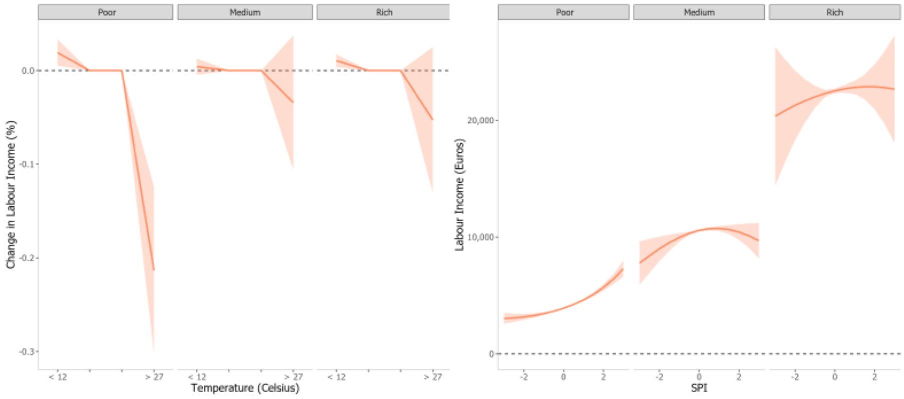
A. Imputed rent



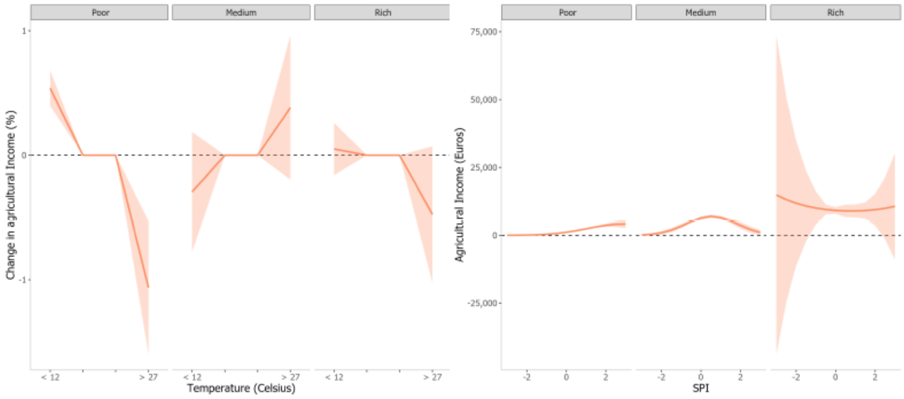
A. Insurance



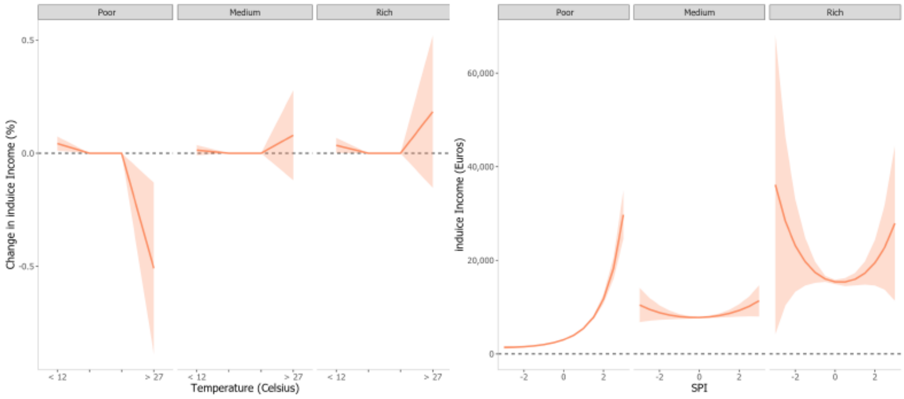
B. Monetary net income



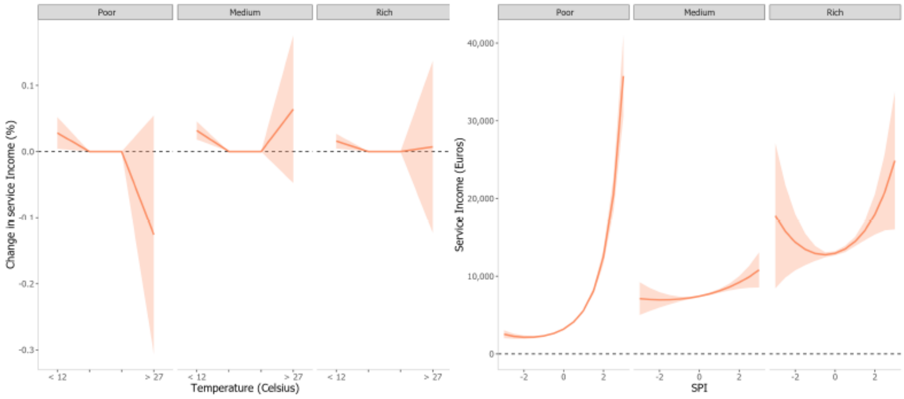
A. Total labour income



B. Agricultural income



C. Industrial income



D. Service income

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