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Assessing macro-economic effects of climate impacts on labour productivity in EU sub-national regions

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Abstract

In this work we assess the macro-economic effects of climate-induced impacts on labour productivity in the EU sub-national regions. For this purpose, we combine econometric estimates and temperature projections coming from Regional Climate Models with a regionalized version of a Computable General Equilibrium (CGE) model developed for Europe. Climate and socio-economic uncertainty is taken into account by including nine SSP-RCP scenario combinations. The results show that macro-economic losses can be substantial in Southern European regions, bigger than 1% of GDP in most of the scenarios by 2070. Moreover, negative economic effects propagate outside the directly impacted sectors and affect services as well. In some cases, regions belonging to the same country could be at the losing and winning end of climate change, which underlines the relevance of the sub-national detail. This is the case of the Italian regions.

1. Introduction

According to the IPCC AR6 report (Bednar-Friedl, 2022), observed trends and future projections show increases in mean temperature and high temperature extremes across Europe. Precipitations are expected to increase in Northern Europe but expected to decrease in the South. These changes will have large implications for human health through increases in heatwaves, and can greatly affect sectors such as agriculture, but also other outdoor economic activities.

Among the channels through which climate affects the day-to-day lives of individuals is the loss in labor productivity, and ultimately, the loss in the productive capacity of the entire economic system. Research on occupational health risk from increasing temperatures using changes in ambient temperature points to the reduction in labour productivity in higher temperatures as a result of natural human responses to avoid damages to health, e.g. workers slow down, take more breaks to re-hydrate, and cool down (Kjellstrom et al., 2009; Parsons, 2014; Dell et al., 2014; UNDP, 2016); or in cases of severe temperature increases, excessive body temperature and dehydration can cause, not only slower worker but also workers to make more mistakes and increased accidental injuries (Bouchama and Knochel, 2002; Schulte and Chun, 2009).

Europe has experienced more severe heatwaves in most recent years. According to the Copernicus Climate Change Programme data, in July 2019 European countries experienced temperatures that are already 1.2°C warmer than pre-industrial era, with France, Germany, Netherlands, the UK, and Belgium experiencing day temperatures of over 40°C. The recently launched PESETA III report (Gosling et al., 2018) highlights that, if climate change remains unmitigated, labour productivity in outdoor activities 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.

Among the three main economic sectors, the outputs of agriculture and to some extent industry sectors are most affected by rising temperatures, and only the services sector seems to be protected from weather and climatic shocks (Dell et al., 2012; Burke et al., 2015; IMF, 2017). While rising temperatures are seen to be detrimental to most economic activity and geographical areas, there may still be positive impacts on some sectors and regions. For instance, some crops that prosper in warmer conditions and summer tourism could benefit from this change (Bosello, et al., 2012; Grillakis, et al., 2016), especially in Northern EU countries. Barrios and Ibañez (2015) estimate a modest annual increase of 0.32% of GDP for Northern Europe, while Southern Europe could experience a reduction by 0.45% of GDP per year given current climate conditions.

Due to the EU's strong economic integration, it is important to look into the indirect effects of the climate change impacts and acknowledge the possibility and role of spillovers across different regions within Europe. Computable General Equilibrium (CGE) models reveal very useful to capture these indirect macro-economic effects because they are able to take into account inter-sectoral and inter-regional interactions via trade, investments and labour/capital reallocation. Recent CGE macro-economic assessments related to climate-induced impacts on labour for Europe include Ciscar et al. (2014), Orlov et al. (2020), Knitel et al (2020), and García-León et al. (2021). The aforementioned studies use the Wet Bulb Globe Temperature (WBGT) approach to estimate the effects of climate on labour productivity. The WBGT index is an experimental forecast tool to measure the effect of temperature, relative humidity, wind speed, and solar radiation on human body. In this research we use a different methodology in which we econometrically estimate the effects of temperature on worked hours at the sectoral level for the NUTS-2 European regions[1]. Then, we combine these econometric estimates with a multi-regional sub-national CGE model developed for Europe. We consider both socio-economic and climate uncertainty by including nine SSP-RCP scenario combinations.

[1] Nomenclature des Unités Territoriales Statistiques (NUTS) is a geocode standard used to classify the European regions for statistical purposes. NUTS0 corresponds to the country level. NUTS1, NUTS2, and NUTS3 are sub-national classifications with increasing levels of spatial details.

The results show that negative macro-economic effects can be substantial in Southern European regions, bigger than 1% of GDP in most of the scenarios by 2070. Moreover, negative economic effects propagate outside the agricultural and industrial sectors, which are directly impacted by the increasing temperatures. It is also interesting to note that regions belonging to the same country could be at the losing and winning end of climate change, which underlines the relevance of the sub-national detail. Italian regions are an example of this economic outcome.
The work develops as follows. In section 2 we describe the econometric framework used to estimate climate impacts on worked hours. Sections 3 briefly presents the CGE model and the database. In section 4 we provide information on the experiment design, i.e. the construction of the reference scenarios and the introduction of the econometrically-estimated impacts in the CGE model. Section 5 shows the results of the macro-economic assessment and section 6 concludes.

2. Econometric framework

2.1 Historical response of worked hours to climatic conditions

Historical data

We use information from 300 micro surveys from Integrated Public Use Microdata Series (IPUMS)-International, the world's largest archive of publicly available micro-survey data. The archive comprises data for more than 130 countries and 30 years, including the number of hours worked per week (defined as the number of hours an individual respondent worked per week at all jobs). We aggregated the data on worked hours to the annual level for two main sectors (agriculture and industry). We then extract mean temperature, maximum temperature, and near-surface relative humidity from ERA5 at a spatial resolution of 0·25° × 0·25° and hourly temporal resolution, which was overlaid on the subregional shapefile from IPUMS.

Benchmark econometric model

Following Burke et al. (2015) and Newell (2018), we apply a fixed-effects panel regression method linking the number of worked hours to temperature and squared temperature (Dasgupta et al., 2021). In Eq. [1] our dependent variable lny_{its} is the log of worked hours in region r, year t and sector i. *f(C)* includes the non-linear relationship between the temperature (*temp*) and dependent variable, controlled for by including both the linear and its squared-term; an acclimatization variable '$tdev$' that we introduce in this study, computed as the difference of the mean temperature from a rolling average of four periods prior[2]; total annual precipitation (and its second-degree polynomial), heat extremes represented by the Warm Spell Duration Index (WSDI)[3]. All our specifications include

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[2] The length of the rolling average is an arbitrary value and was guided by the observable length of a business cycle in EU regions.

[3] Annual count of days with at least 6 consecutive days when daily maximum is greater than 90th percentile. The 90th percentile was determined from months June-August in years 1981-2010 as the baseline years, and applied to summer months – May to October – for years 2000-2015 to count the number of days exceeding this threshold.

region α_r and year γ_t specific fixed-effects, and a quadratic time trend $\theta_{1i}t + \theta_{2i}t^2$ to capture non-linear technological changes.

$$lny_{rti} = f(C) + \alpha_r + \gamma_t + \theta_{1r}t + \theta_{2r}t^2 \qquad \text{Eq. [1]}$$

$$where\ f(C) = \beta_1 temp + \beta_2 temp^2 + \varphi tdev + \delta_1 prec + \delta_2 prec^2 + \sigma WSDI$$

Given existing findings on the non-linear and inverse U-shaped relationship of economic performance and temperatures, we expect for the set of coefficients of temperatures that $\beta_1 > 0, \beta_2 < 0$. In this case, the results indicate a non-linear relationship with an "optimal" value of the local temperature computed as $temp_s^{optimal} = |\beta_1/(2 * \beta_2)|$ for a given sector.
We find statistically significant climate effects on agricultural and industrial sectors which will be presented in section 4.2. The physiological basis of outdoor temperatures impacting productivity in the services whose activity is usually performed in temperature-controlled spaces is rather weak. Therefore, we assume that service sector in the CGE is not affected.

2.2 Impact Projections

The impact projections consider all the RCPs (2.6, 4.5, 6.0, and 8.5) and two time periods (2050 and 2070). In order to estimate the effect of future warming on sectoral, sub-national labour productivity, we use our spatial non-linear econometric estimates of temperature in Eq. [1] and gridded climate data from four different regional climate models (KNMI RACMO22E, IPSL-CM5A-MR, MPI-ESM-LR, and CNRM-CM5). Then, we follow the Delta method (Dasgupta, 2018) to combine the econometric estimates with future mean ensemble temperature projections to obtain percentage change of worked hours in 2050 and 2070 compared to the historical period according to the equation below:

$$\%\ change\ in\ worked\ hours = \left[\left(\frac{\exp\,(\hat{\beta}_1 \cdot Temp^{Fut.} + \hat{\beta}_2 \cdot Temp^{Fut.^2})}{exp\,(\hat{\beta}_1 \cdot Temp^{Hist.} + \hat{\beta}_2 \cdot Temp^{Hist.^2})}\right) - 1\right] \cdot 100 \qquad \text{Eq. [2]}$$

In Eq. [12] we have opted not to use any of the SSP scenarios because we want to isolate only the effect of temperature on the productive capacity of labour, the other socio-economic trends being already incorporated in the baseline scenarios of the macro-economic model.

3. CGE data and model

Concerning the data upon which the CGE model is calibrated, we start from the Global Trade Analysis Project (GTAP) 8 database (Narayanan et al., 2012). The national Social Accounting Matrices (SAMs) of the European Union in GTAP are regionalized using sub-national information coming from Eurostat (Economic Accounts for Agriculture; Structural Business Statistics; Gross value added at basic prices by NUTS 3 regions). We obtain mutually consistent and balanced SAMs for every NUTS region using the method of Bosello and Standardi (2018). At the end of the regionalization process, we have 138 EU NUTS regions displayed in Figure 1 plus 18 regions in the rest of the world[4]. We also consider 24 sectors in Table 2. It is worth noting that the model has been developed in the context of the Coacch H2020 project (https://www.coacch.eu/). The project analyses the macro-economic consequences of different climate impacts; from sea level rise to temperature-induced effects on energy demand and supply; from impacts on crop yields, forestry, and fishing to labour productivity and extreme events such as flood impacts on the transport sector. Therefore, in the CGE model we set a more detailed sectoral aggregation than only agriculture, industry and services. This is meant to match the single climate impact examined in the Coacch project.

The theoretical structure of the model is similar to that one of GTAP-E model (Burniaux and Truong, 2002), which allows the substitution between fossil fuels and capital. We also introduce renewables energy sources at the EU sub-country level to create additional opportunities to dercarbonise the economy and be consistent with the SSP-RCP combination in terms of emissions and SSP narrative. Our sub-national CGE is a fully-fledged model which includes bi-lateral trade flows across the sub-national units, i.e. intra-national trade. A Constant Ratios of Elasticities of Substitution Homothetic (CRESH) function (Pant, 2007) is used to model intra-national and inter-national trade (see Figure 2). Essentially, the CRESH function is implemented in the lower nest of the GTAP trade structure and gives more flexibility to the modelling because we may choose different levels of product substitutability via the bi-lateral CRESH Armington elasticity linking region s to region r. In practice, when trade relations refer to two sub-national units belonging to the same country, we increase the GTAP country-specified elasticity value by 50%. This modelling choice aims to capture the greater fluidity of intra-country trade, which is consistent with results from the trade literature about the border effect (Anderson and Wincoop, 2003; McCallum, 1995).

Given the nature of the climate impact experiment, it is important to clarify the theoretical assumptions about sectoral and spatial mobility of labour. In the model labour is perfectly mobile across different economic activities but it is immobile at the regional level. This means that labour can be relocated in different sectors of the economy but not in different regions even within the country. The model also assumes the possibility to substitute to some degree labour with capital, land, and natural resources. This is based on the default elasticity of GTAP 8 database (Narayanan et al., 2012). In general, labour can be more easily substituted with capital in industry and services while in agriculture, fishery, forestry and mining sectors this possibility is limited by the presence of the other primary factors, land and natural resources. Labour is also assumed to be fully employed in the region.

[4] We report in the Appendix the mapping between the CGE model regions and the NUTS 2013 EU code (Table A1).

Country	Number of Regions	NUTS level
Austria	3	NUTS1
Belgium	3	NUTS1
Bulgaria	1	NUTS0
Cyprus	1	NUTS0
Czech Republic	8	NUTS2
Germany	16	NUTS1
Denmark	1	NUTS0
Estonia	1	NUTS0
Spain	17	NUTS2
Finland	1	NUTS0
France	22	NUTS2
Greece	4	NUTS1
Hungary	1	NUTS0
Croatia	1	NUTS0
Ireland	1	NUTS0
Italy	20	NUTS2
Lithuania	1	NUTS0
Luxembourg	1	NUTS0
Latvia	1	NUTS0
Malta	1	NUTS0
Netherlands	4	NUTS1
Poland	6	NUTS1
Portugal	5	NUTS2
Romania	1	NUTS0
Sweden	3	NUTS1
Slovenia	1	NUTS0
Slovakia	1	NUTS0
United Kingdom	12	NUTS1
Total	**138**	

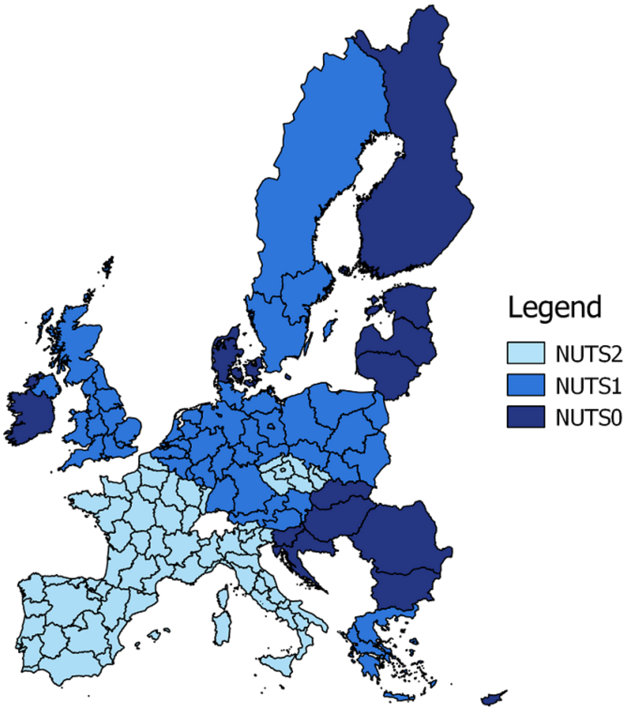

Figure 1: EU NUTS regions in the CGE

Table 1: Sectors in CGE model

	CGE sectors	Macro-sectors
1	Vegetables and_Fruits	Primary
2	Other Crops	
3	Livestock	
4	Timber	
5	Fishery	
6	Coal Extraction	Energy
7	Oil Extraction	
8	Gas Extraction	
9	Oil Products	
10	Transmission and Distribution	
11	Nuclear	
12	Electricity (Fossils)	
13	Wind	
14	Hydro	
15	Solar	
16	Other Electricity	
17	Light industry	Industry&Const
18	Heavy industry	
19	Construction	
20	Transport Road	Services
21	Transport_Water	
22	Transport Air	
23	Services	
24	Public Services	

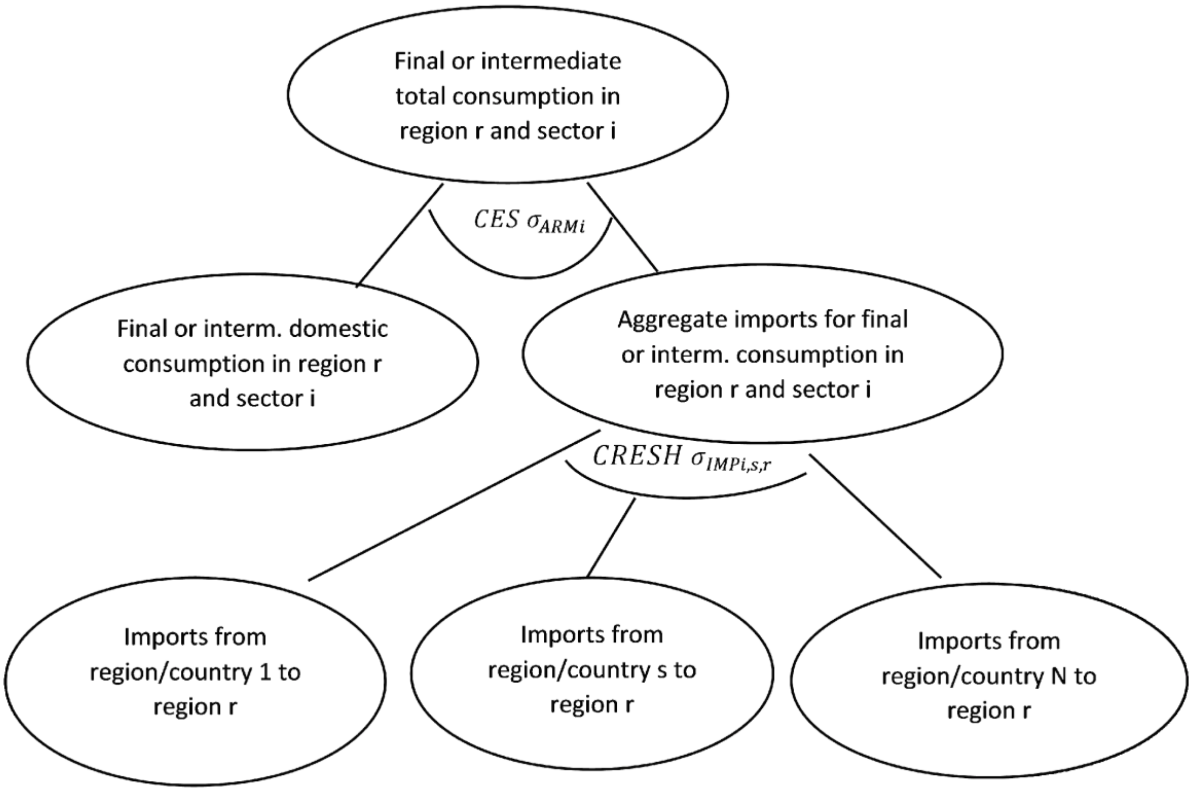

Figure 2: trade structure in the CGE model

4. Experiment design

4.1 Scenarios

To control for socio-economic and climate uncertainty in this assessment we consider nine SSP-RCP combinations as baseline scenarios: SSP1-RCP2.6, SSP1-RCP4.5, SSP2-RCP2.6, SSP2-RCP4.5, SSP2-RCP6.0, SSP3-RCP2.6, SSP3-RCP4.5, SSP5-RCP4.5, SSP5-RCP8.5. Population and GDP projections for the SSPs come from the IIASA database (Riahi et al., 2017). We assume that the sub-national regions follow the projections of the country they belong to. The baselines cover the period 2007-2070 in five-year time steps apart from the three initial years. GDP targets have been calibrated using the Total Factor Productivity (TFP) while stock of labour mimic population trends. We have also calibrated global Co2 emission corresponding to the different RCPs. This has been done using a mix of energy efficiency, elasticity of substitution in the energy nests and climate policy (global carbon tax). Finally, in SSP3, the Regional Rivalry scenario, we have assumed a more disrupted trade policy context and we have reduced the default values of the Armington elasticities by one quarter. Table 2 summarizes the main modelled features in our baseline scenarios.

Table 2. Main modelled features of the reference scenarios (SSPs-RCPs combinations)

	GDP calibration	**Stock of labour**	**Trade openness (Armington)**	**Elast. Substitut. between Kap&Energy**	**Climate policy (global carbon tax)**
SSP1-RCP2.6	Total Factor Productivity (TFP)	Follow SSP pop. projections	Default values	1.5	Yes
SSP1-RCP4.5	Total Factor Productivity (TFP)	Follow SSP pop. projections	Default values	0.75	No
SSP2-RCP2.6	Total Factor Productivity (TFP)	Follow SSP pop. projections	Default values	1.2	Yes
SSP2-RCP4.5	Total Factor Productivity (TFP)	Follow SSP pop. projections	Default values	1	No
SSP2-RCP6.0	Total Factor Productivity (TFP)	Follow SSP pop. projections	Default values	0.75	No
SSP3-RCP2.6	Total Factor Productivity (TFP)	Follow SSP pop. projections	Default values reduced by 25%	1	Yes
SSP3-RCP4.5	Total Factor Productivity (TFP)	Follow SSP pop. projections	Default values reduced by 25%	1	No
SSP5-RCP4.5	Total Factor Productivity (TFP)	Follow SSP pop. projections	Default values	1	Yes
SSP5-RCP8.5	Total Factor Productivity (TFP)	Follow SSP pop. projections	Default values	0.75	No

4.2 Introducing econometric impacts in the CGE model

In the CGE model, the changes in the worked hours coming from the econometric analysis and the climate projections are implemented directly as changes in the productivity of the labour production factor in the agricultural and industrial sectors. The econometric estimates measure the effect of temperature changes on the number of hours which a given amount of unit of labour can work, and therefore they give an indication on the productive capacity of those workers. However, it is also possible to see the changes in the worked hours as a change in the labour supply. In the context of the CGE model it is easier for us to implement this impact as an impact on the sectoral labour productivity. In our experiment agriculture sector includes vegetables and fruits, other crops, and livestock in Table 1. Industrial sectors include both heavy and light industry. The impacts are uniformly smoothed over the period 2015-2050 and 2015-2070, which are the two temporal windows of the climate projections. This simply means that in 2050 and 2070 we have the level of the shocks coming from the statistical estimation and in the previous five year time steps we also have shocks on labour productivity given by the linear interpolation in the period 2015-2050 and 2050-2070.

In modelling terms, we use the Agricultural Value Added (VA) equation of the CGE represented by a Constant Return to Scale (CRS) Constant Elasticity of Substitution (CES) function of land, capital, and labor as follows:

$$VA_{agr,i} = \left(Z_{agr,i}^{\frac{\sigma_{agr}-1}{\sigma_{agr}}} + K_{agr,i}^{\frac{\sigma_{agr}-1}{\sigma_{agr}}} + \psi_{agr,i} L_{agr,i}^{\frac{\sigma_{agr}-1}{\sigma_{agr}}} \right)^{\frac{\sigma_{agr}}{\sigma_{agr}-1}} \qquad \sigma_{agr} > 0 \qquad \text{Eq. [3]}$$

where land (Z), capital (K) and labor (L) are each endogenously determined by the demand of the cost-minimizing representative firm in region r; σ and ψ are respectively the elasticity of substitution between primary factors and the labour productivity in the agricultural sector.

For the industrial sector we have a similar expression:

$$VA_{ind,i} = \left(K_{ind,i}^{\frac{\sigma_{ind}-1}{\sigma_{ind}}} + \psi_{ind,i} L_{agr,i}^{\frac{\sigma_{ind}-1}{\sigma_{ind}}} \right)^{\frac{\sigma_{ind}}{\sigma_{ind}-1}} \qquad \sigma_{ind} > 0 \qquad \text{Eq. [4]}$$

The industrial sectors do not use the land factor but only capital and labour[5]. In this case ψ is the labour productivity in the industrial sector. We assume that climate change impacts coming from the econometric analysis are applied in Eq. [2] and [3] according to the formula below:

$$\psi_{i,r}^{*} = \left(1 + \pi_{i,r}\right)\psi_{i,r} \qquad \text{Eq. [5]}$$

where $\psi^*$is the new sectoral productivity level in sector i and region r, and π is the climate-induced relative change in the worked hours.

Figures 3 and 4 show these percent changes in labour productivity applied in the agricultural and industrial sectors of the CGE over the period 2015-2070. From Figures 3 and 4 we can notice that the mildest impacts are in RCP2.6 in both agricultural and industrial sectors. Regions located in Southern Europe are more negatively affected while some Northern regions could experience some benefits, for example areas in Scandinavia. It is also interesting to signal that labour in the European Alpine regions can be positively affected by climate change. This is the consequence of the non-linear relationship between temperature and productivity, which implies the existence of an “optimal” temperature for a given economic activity. Therefore, mountainous regions may get closer to this optimal temperature because of global warming. This also means that regions within the same country can be affected quite differently according to their latitude but also their altitude, as it is the case for the Italian regions.

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[5] The heavy industry sector also uses a small fraction of natural resources, that are in the sub-sector of the other mining extraction (other than fossil fuels). We avoid reporting this in Eq. [3] to simplify the mathematical notation.

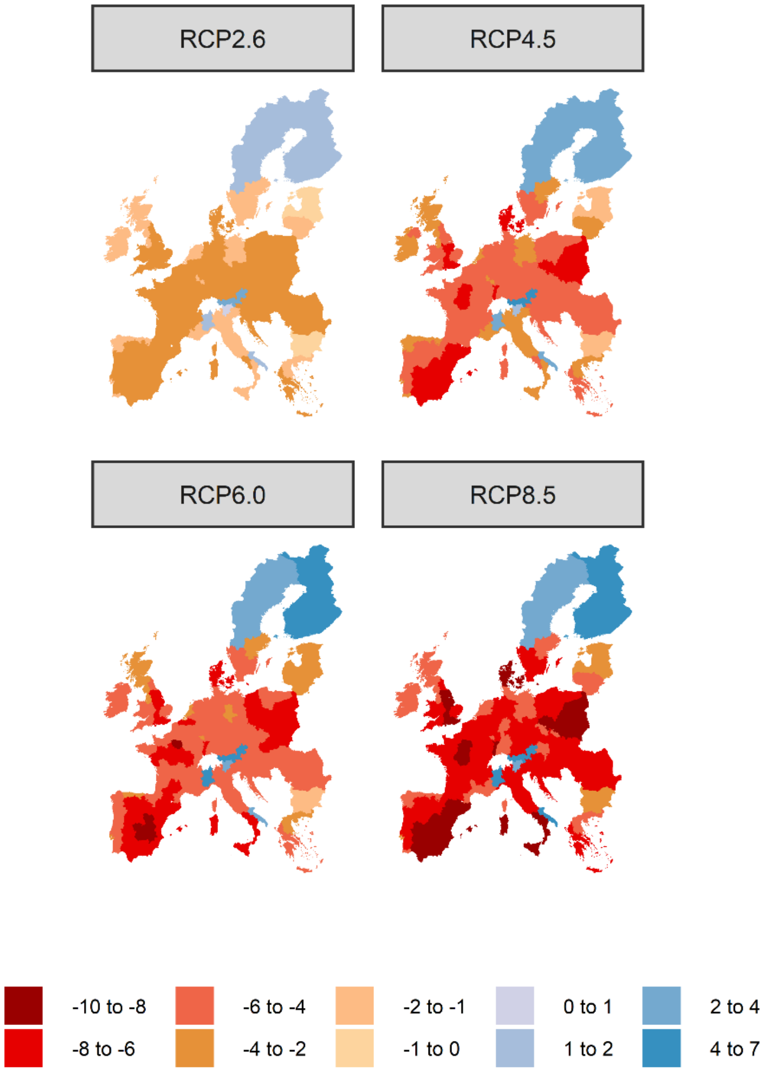

Figure 3. Climate change impacts on worked hours in the agricultural sector (% ch over the period 2015-2070)

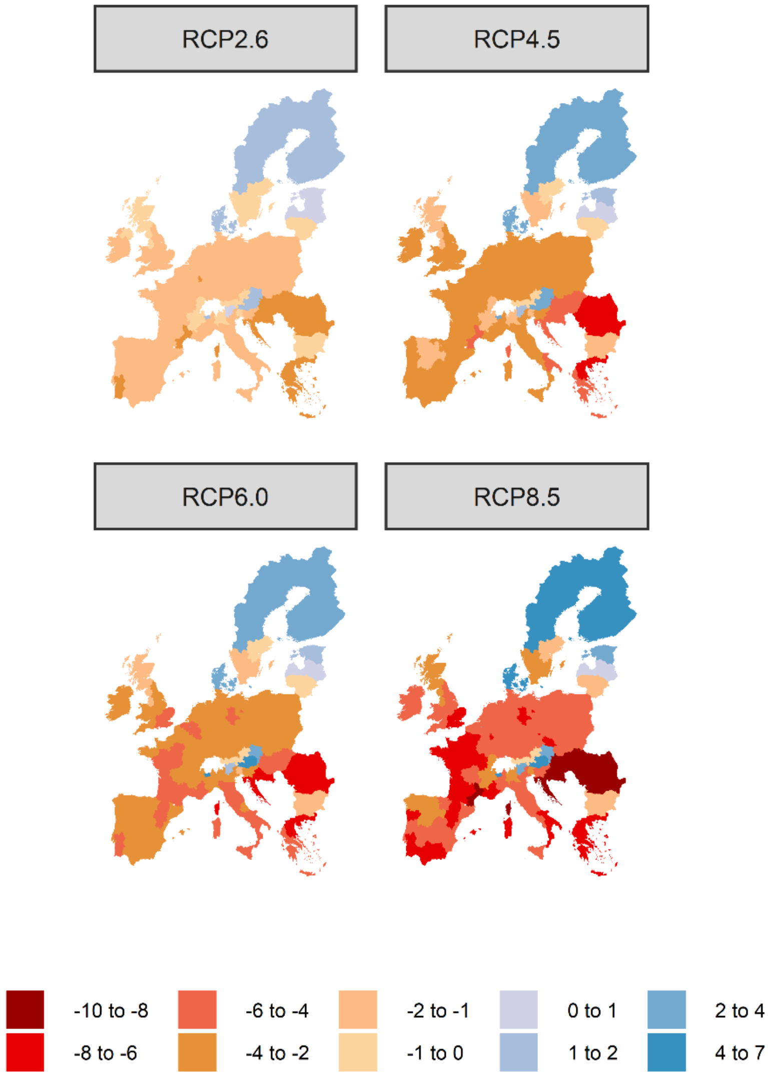

Figure 4: Climate change impacts on worked hours in the industrial sector (% change over the period 2015-2070)

5. Results of the macro-economic assessment

In Table 3 we have a quick overview of the macro-economic consequences coming from the labour productivity shocks implemented in the CGE. The table shows that negative GDP effects in Europe increase over time and are stronger in the higher RCPs (6.0 and 8.5). This is consistent with the econometric input data. The order of magnitude of the overall macro-economic loss in 2070 ranges from 0.24% in SSP1-RCP2.6 to 0.83% in SSP5-RCP8.5 compared to same year in the corresponding baseline scenario. It should be noted that the climate change scenario (RCP) exerts a larger importance than the social economic scenario in the determination of the final economic impact

(SSP). Still, the SSP3 scenario, featuring lower trade “flexibility”, tends to highlight, everything else equal, higher GDP losses than other SSPs.

Previous macro-economic assessments of climate change impacts on labour for Europe forecast a total household welfare loss of €190 billion or 2% of EU GDP by 2080s if current climate conditions persist, and no public adaptation occurs (Ciscar et al., 2014). Meeting the 2°C target alone significantly reduces the estimated impacts to the EU by €60 billion, or a reduction in GDP of 1.2% (Ciscar et al., 2014). According to García-León et al. (2021), in RCP 8.5 average GDP costs will pass from the current average of 0.21% over 1981–2010 to an expected annual average of 0.77% in 2035–2045, to beyond 1.14% in the 2060s. Orlov et al. (2020) find that between 2050 and 2100 in RCP8.5 EU GDP will experience economic losses in the range of 0.5-1% compared to the reference scenario.. All three studies use a CGE modelling approach and our results are within their range, being our outcomes in SSP5-RCP8.5 the most comparable.

Figures 5 and 6 show the spatial distribution of the GDP effects in the near future (2030) and far future (2070). We observe moderate effects in 2030, however, the winner/loser geographical pattern starts to appear already in 2030 with Scandinavian and Alpine regions experiencing economic benefits and Southern Mediterranean and Eastern regions more negatively affected. The pattern becomes evident in 2070 where the winner/loser divide amplifies and the macro-economic losses are substantial, close to 3% in Southern Europe and higher RCPs. We should mention that in the long term the GDP total loss is not only the consequence of the reduced labour productivity but also the result of the decreased capital accumulation taking place because of the previous shocks on labour. Indeed, regions decrease their productive capacity, which implies a reduced real income and savings, and finally less investments over the years.

Declines in labour productivity transmit through the overall economic system outside the directly impacted sectors, agriculture and industry. This is possible via the input-output interconnections and the regional bi-lateral trade relationships. For this reason, it is important to examine the variations in sectoral production of the four macro-sectors: primary, industry, services, and energy[6].

Figures 7 and 8 show the macro-economic consequences for the primary sector. Not surprisingly, the effects in 2030 are milder than in 2070, where negative effects get stronger in Southern Europe in the two scenario combinations SSP5-RCP8.5 and SSP3-RCP4.5. Figures 9 and 10 display the same results for the industrial sector plus construction. It is interesting to note that macro-economic impacts are more spatially asymmetric in the latter macro-sector compared to the primary sector, especially in the long run. A reasonable explanation for this economic outcome are the higher Armington elasticities in the industrial sectors, which allow a more pronounced economic specialization across European regions.

The economic effects in the not directly impacted macro-sectors (energy and services) are also not negligible (Figures 11-14). Negative spillovers in 2070 become substantial, in particular in the services, suggesting a greater reliance of this macro-sector on agriculture and industry. The results on energy production are more fragmented with more benefits, probably linked to the substitution of labour with more capital-intensive technologies.

[6] The mapping between the 24 CGE sectors and the four macro-sectors is displayed in Table 1.

Table 2: GDP % Changes with respect to baseline in EU28

	2030	2050	2070
SSP1-RCP2.6	-0.09	-0.22	-0.24
SSP1-RCP4.5	-0.15	-0.36	-0.51
SSP2-RCP2.6	-0.09	-0.22	-0.25
SSP2-RCP4.5	-0.15	-0.37	-0.52
SSP2-RCP6.0	-0.16	-0.40	-0.64
SSP3-RCP2.6	-0.09	-0.24	-0.30
SSP3-RCP4.5	-0.15	-0.40	-0.63
SSP5-RCP4.5	-0.15	-0.37	-0.49
SSP5-RCP8.5	-0.22	-0.54	-0.83

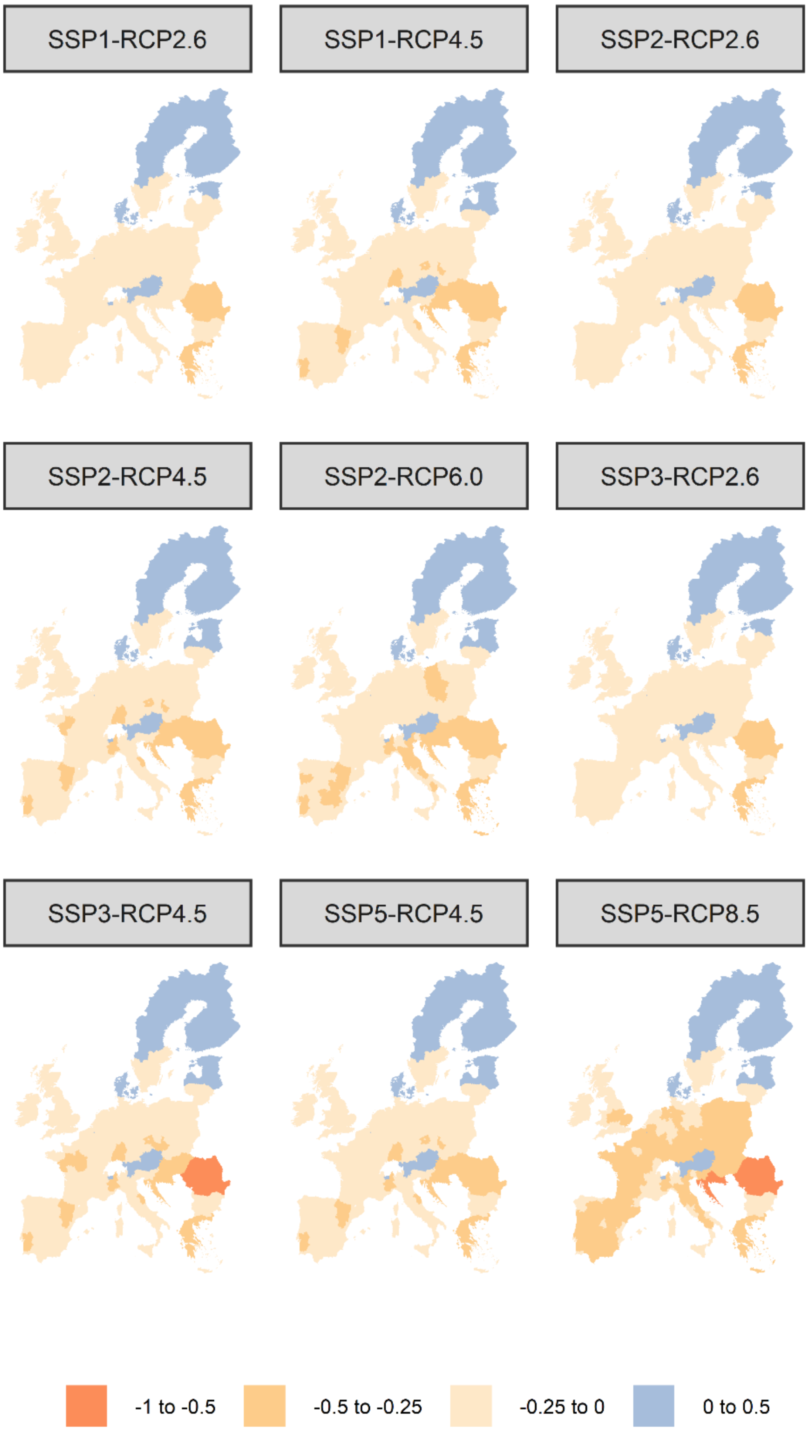

Figure 5: GDP impacts in 2030 (% changes compared to the baseline)

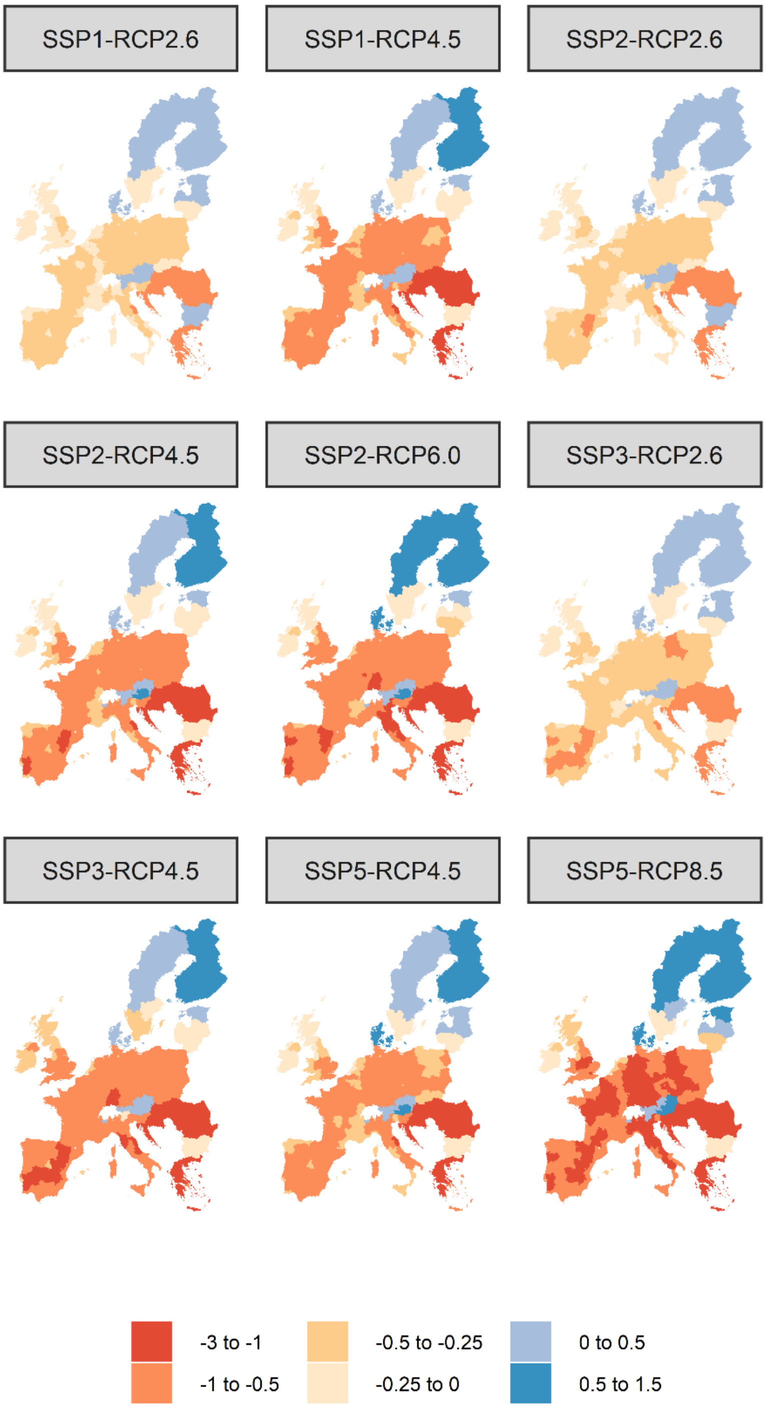

Figure 6: GDP impacts in 2070 (% changes compared to the baseline)

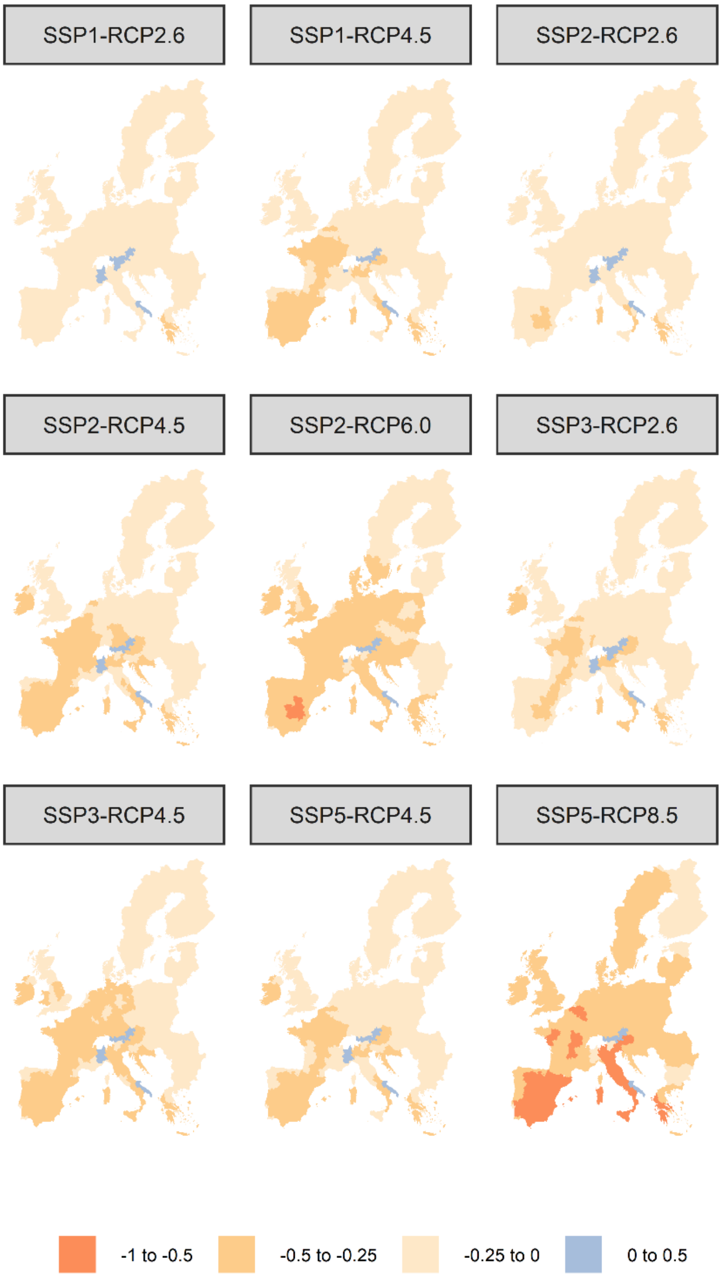

Figure 7: Impacts on primary production in 2030 (% changes compared to the baseline). Primary production includes crop production, livestock, fishery, and forestry.

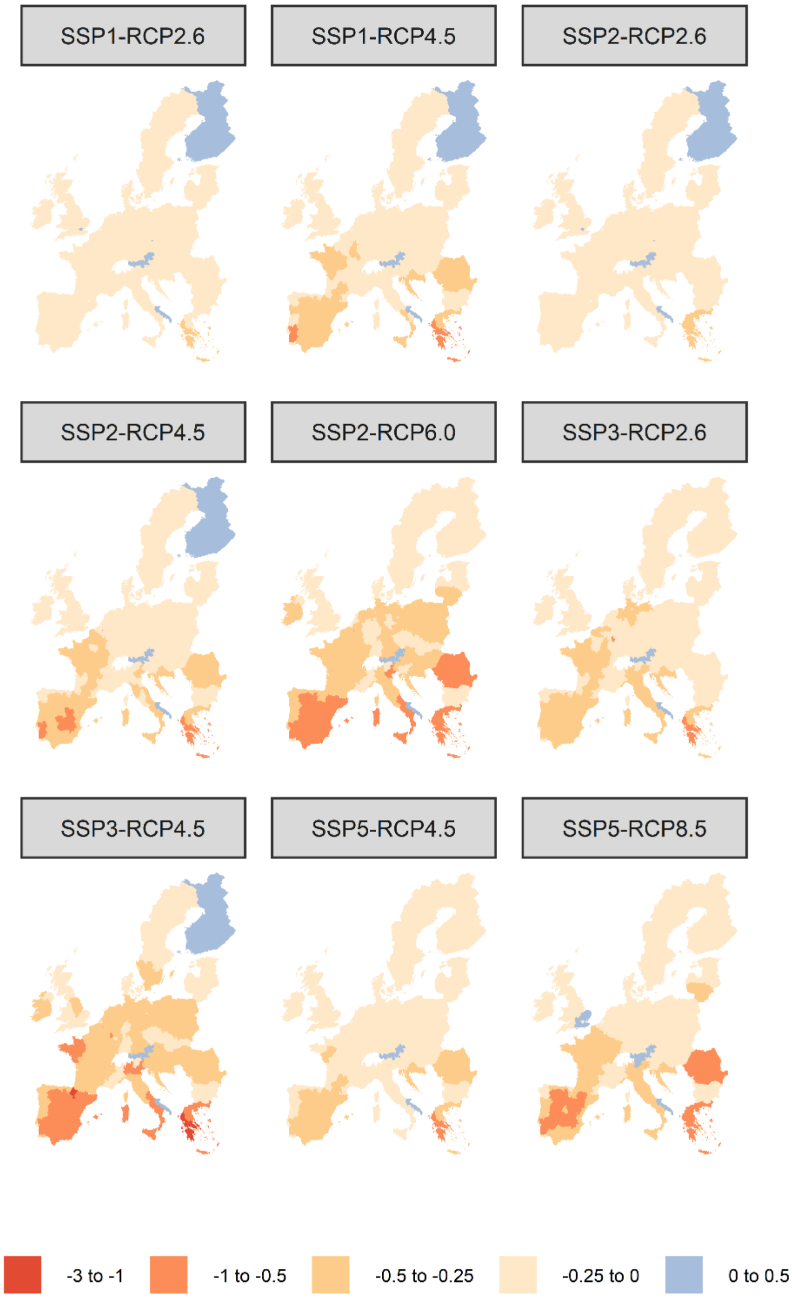

Figure 8: Impacts on primary production in 2070 (% changes compared to the baseline). Primary production includes crop production, livestock, fishery, and forestry.

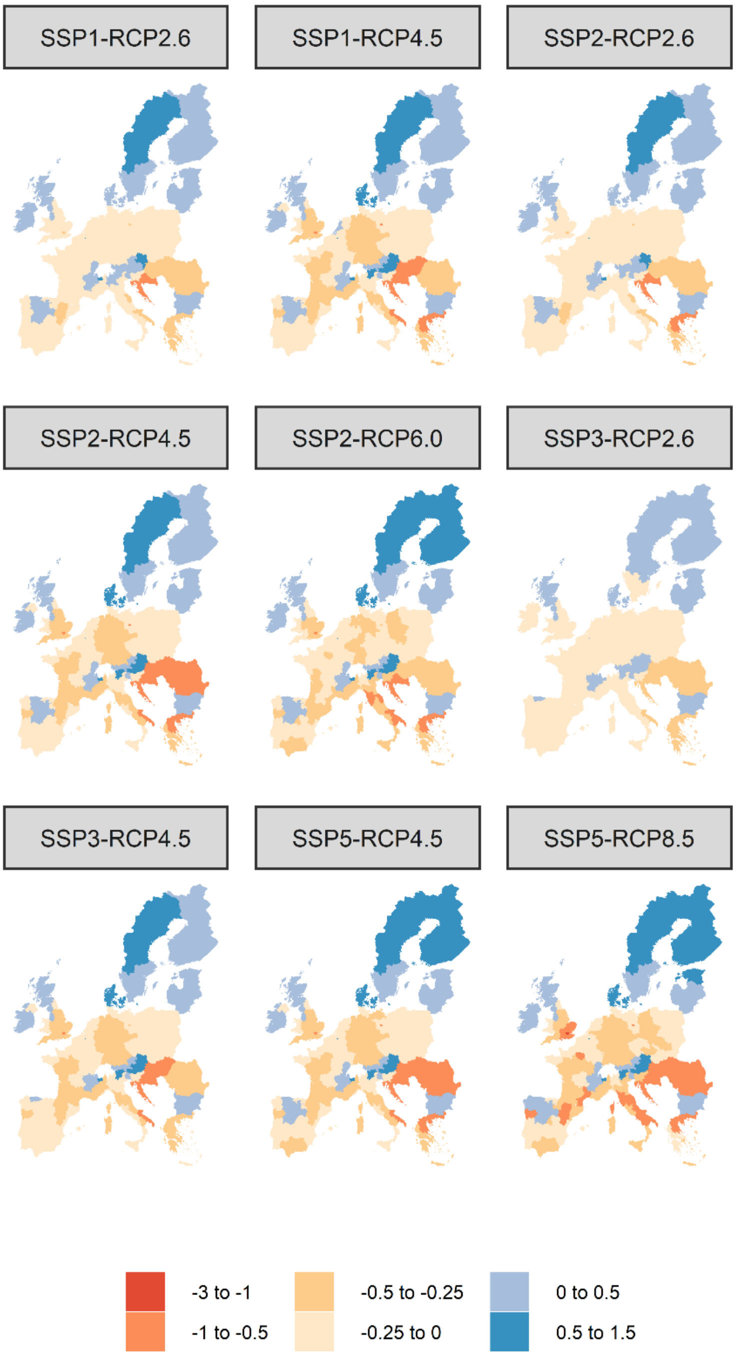

Figure 9: Impacts on industrial production plus construction in 2030 (% changes compared to the baseline).

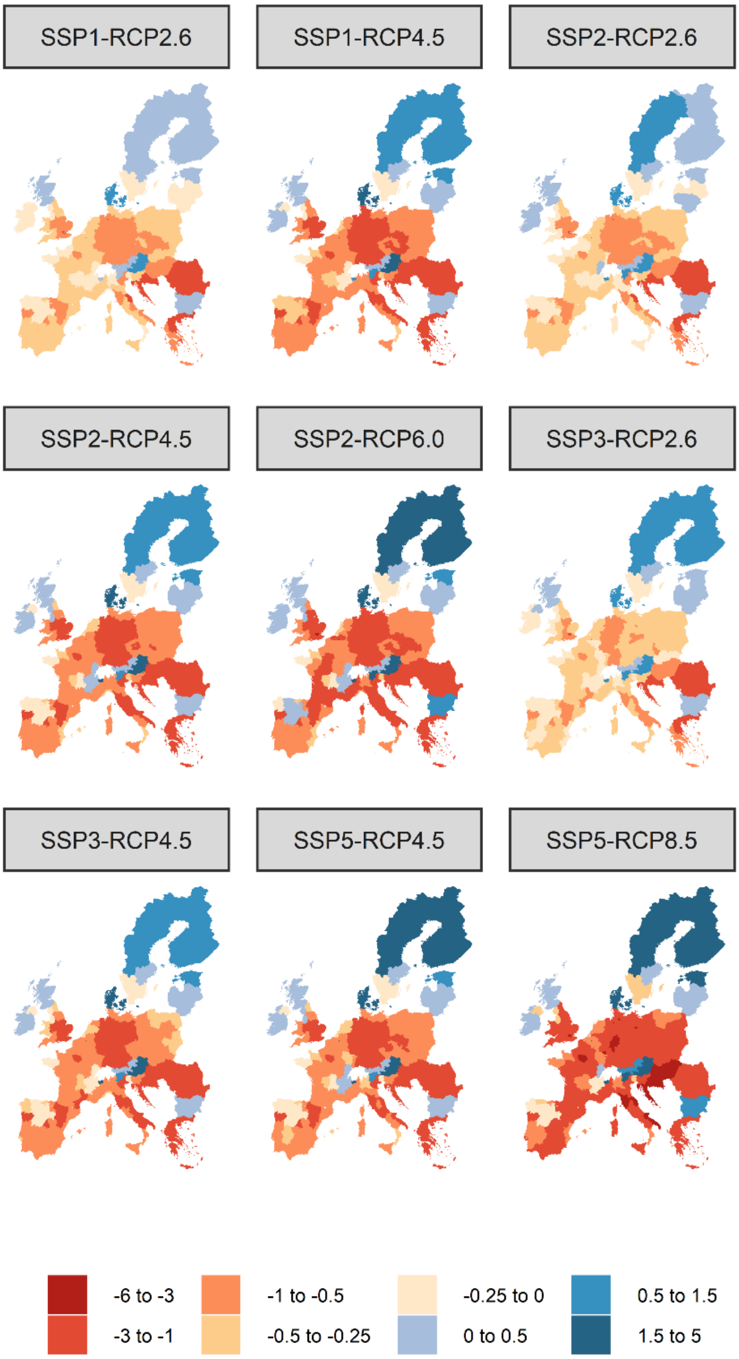

Figure 10: Impacts on industrial production plus construction in 2070 (% changes compared to the baseline).

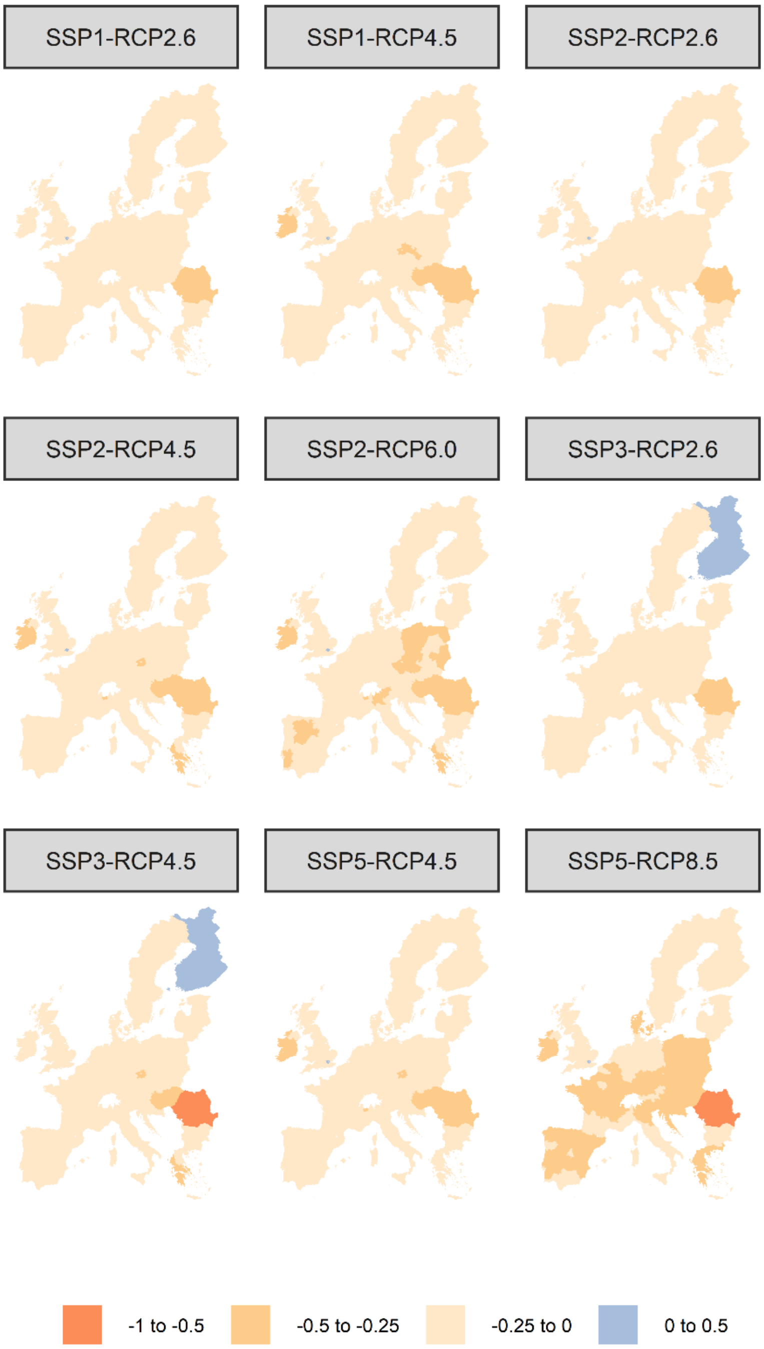

Figure 11: Impacts on services production in 2030 (% changes compared to the baseline). Services include private and public services, and transport.

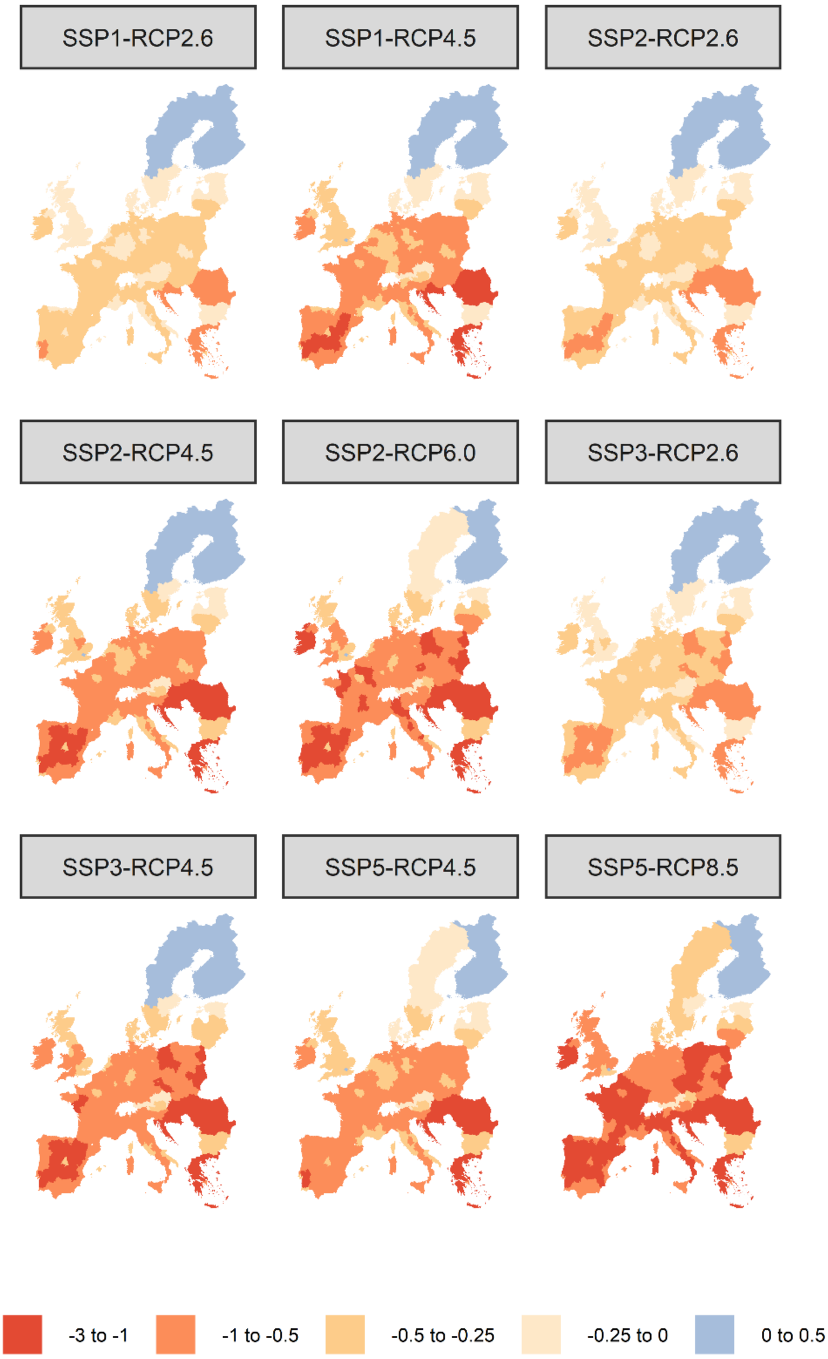

Figure 12: Impacts on services production in 2070 (% changes compared to the baseline). Services include private and public services, and transport.

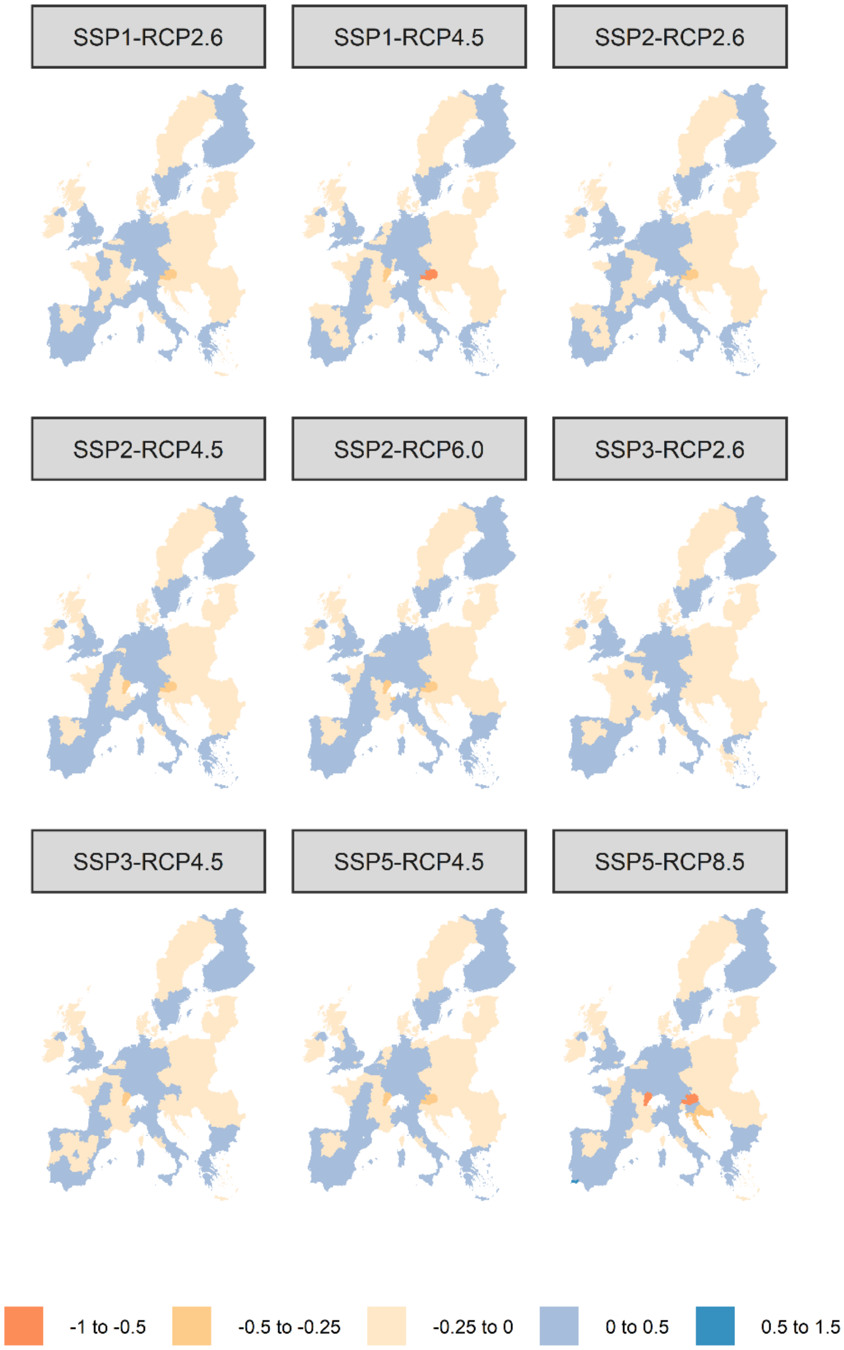

Figure 13: Impacts on energy production in 2030 (% changes compared to the baseline). Energy includes electricity, fossil fuels extraction, and petroleum products.

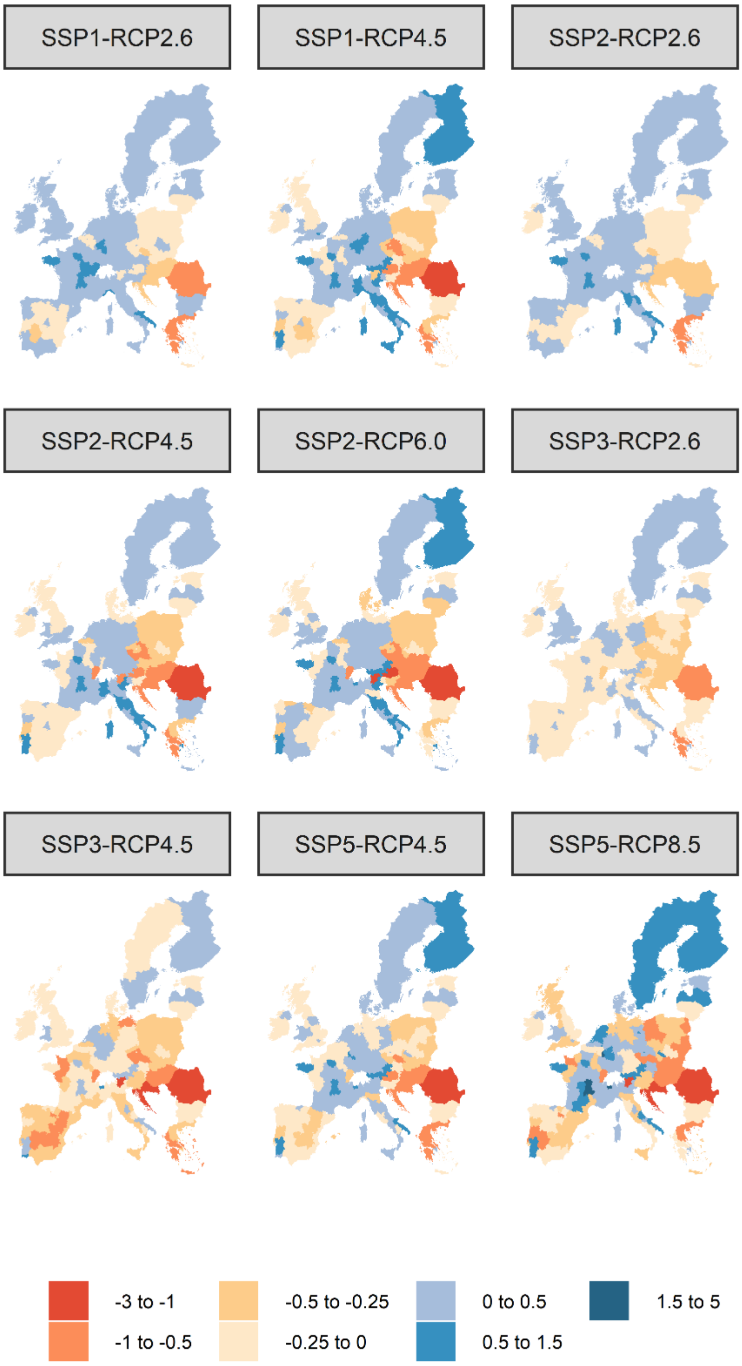

Figure 14: Impacts on energy production in 2070 (% changes compared to the baseline). Energy includes electricity, fossil fuels extraction, and petroleum products.

6. Conclusions

In this paper we have examined the macro-economic consequences of climate-induced impacts on labour productivity in the European sub-national regions. The econometric analysis has confirmed a non-linear relationship between temperature and worked hours in line with Burke et al. (2015), suggesting the existence of an “optimal temperature” for agriculture and industry. The link between services and climate is still uncertain. Econometric estimates have been combined with future temperature projections to feed a multi-regional sub-national CGE model calibrated for Europe.
The macro-economic results have shown the importance of the sub-national detail because we have observed that regions within the same country can be affected quite differently. This is evident for Italy, where Alpine regions may experience economic benefits while the rest of the country is badly impacted by global warming. In general, we also notice that Southern Mediterranean and Eastern regions are more subject to macro-economic losses while Scandinavian regions may experience some economic gains.
Another interesting outcome is the propagation of the macro-economic effects outside agriculture and industry through the economic channels of inter-sectoral connections and inter- and intra-national trade. We signal negative spillovers especially in the service sector.
We also make clear the limitations of this work. The first one is related to the fact that labour cannot move outside the region where it is located. We have kept this conservative approach to avoid the appearance of excessive outflows and inflows of labour across regions, which could create too disruptive economic results. However, the analysis of spatial labour reallocation would deserve a deeper investigation. The other point refers to the assumption of full employment of labour. Relaxing this assumption would provide additional insight to the overall macro-economic picture concerning the climate-induced labour impacts. Increasing the sectoral detail of the econometric analysis is another aspect that should be further developed. Finally, we should contrast our results with those obtained using WBGT and different types of exposure-response functions to compute inputs for the sub-national CGE.
Looking at the policy implications of this study, it is important to stress the importance of implementing appropriate mitigation policies to reduce the economic damages of climate change on labour. Indeed, we have seen that higher RCPs are associated with bigger economic losses. Preserving the European economic integration is another relevant policy issue as we have noted that the trade frictions in SSP3 are *ceteris paribus* detrimental to the economic performance of the European regions.

References

Anderson, J. E., Wincoop, E. van. (2003). Gravity with Gravitas: A Solution to the Border Puzzie. The American Economic Review, 93(1), 170–192. https://doi.org/10.1257/000282803321455214

Barrios, S., and Ibañez, J. N. (2015). Time is of the essence: adaptation of tourism demand to climate change in Europe. Climatic Change, 132(4), 645–660. https://doi.org/10.1007/ s10584-015-1431-1

Bednar-Friedl, B., R. Biesbroek, D.N. Schmidt, P. Alexander, K.Y. Børsheim, J. Carnicer, E. Georgopoulou, M. Haasnoot, G. Le Cozannet, P. Lionello, O. Lipka, C. Möllmann, V. Muccione, T. Mustonen, D. Piepenburg, and L. Whitmarsh, 2022: Europe. In: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1817-1927, doi:10.1017/9781009325844.015

Bosello, F., Eboli, F., and Pierfederici, R. (2012). Assessing the Economic Impacts of Climate Change. Retrieved from http://papers.ssrn.com/abstract=2030223

Bosello, F., Standardi, G. (2018). A Sub-national CGE Model for the European Mediterranean Countries, in F. Perali and P. L. Scandizzo (eds.), The New Generation of Computable General Equilibrium Models, Springer International.

Bouchama, A., and Knochel, J. (2002). Heat Stroke. The New England Journal of Medicine, 346, 1978–1988. https://doi.org/10.1056/NEJMra011089

Burke, M., Hsiang, S. M., and Miguel, E. (2015). Global non-linear effect of temperature on economic production. Nature, (1), 1–16. https://doi.org/10.1038/nature15725

Burke, M., S. Hsiang, and E. Miguel. (2015). Global non-linear effect of temperature on economic production. Nature; 527,235–239, doi:10.1038/nature15725.

Burniaux J.-M., Truong T. P. (2002). GTAP-E: An energy environmental version of the GTAP model. GTAP Technical Paper n. 16.

Ciscar, J., Feyen, L., Soria, A., Lavalle, C., Raes, F., Perry, M., Ibarreta, D. (2014). Climate Impacts in Europe. The JRC PESETA II Project (JRC Scientific and Policy Reports No. EUR 26586EN). Seville, Spain. https://doi.org/10.2791/7409

Dasgupta, S. (2018). Burden of Climate Change on Malaria Mortality. International Journal of Hygiene and Environmental Health. https://doi.org/10.1016/j.ijheh.2018.04.003

Dasgupta, S., et al. (2021). Effects of climate change on combined labour productivity and supply: an empirical, multi-model study. The Lancet Planetary Health. https://doi.org/10.1016/S2542-5196(21)00170-4

Dell, M., Jones, B. F., and Olken, B. A. (2014). What Do We Learn from the Weather. The New Climate- Economy Literature. Journal of Economic Literature, 52(3), 740–798. https: //doi.org/10.3386/w19578

Eurostat (2018). Gross value added at basic prices by NUTS 3 regions. http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nama_10r_3gva&lang=en

Eurostat. Economic Accounts for Agriculture (2018). http://appsso.eurostat.ec.europa.eu/nui/show.do

Eurostat. Structural business statistics (2018). http://ec.europa.eu/eurostat/web/structuralbusiness-statistics/data/database

García-León D, Casanueva A, Standardi G et al (2021). Current and projected regional economic impacts of heatwaves in Europe. Nat Commun 12:5807. https://doi. org/ 10. 1038/ s41467-021- 26050-z

Gosling S.N., Zaherpour J., Ibarreta D., PESETA III: Climate change impacts on labour productivity, EUR 29423 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79- 96912-6, doi:10.2760/07911, JRC113740. https://ec.europa.eu/jrc/en/publication/peseta-iii-climate-change-impacts-labour-productivity

Grillakis, M. G., Koutroulis, A. G., Seiradakis, K. D., and Tsanis, I. K. (2016). Implications of 2°C global warming in European summer tourism. Climate Services, 1, 30–38. https://doi. org/10.1016/j.cliser.2016.01.002

IMF. (2017). The effects of weather shocks on economic activity. How can low income countries cope (Chapter 3). Global Economic Outlook: Seeking sustainable growth. Retrieved from https: //www.imf.org/en/Publications/WEO/Issues/2017/09/19/world-economic-outlook-october- 2017#Chapter3

Kjellstrom, T., Kovats, R. S., Lloyd, S. J., Holt, T., and Tol, R. S. J. (2009). The direct impact of climate change on regional labour productivity. Archives of Environmental and Occupational Health, 64(4), 217–227. https://doi.org/10.1080/19338240903352776

Knittel, N., Jury, M. W., Bednar-Friedl, B., Bachner, G. & Steiner, A. K. (2020). A global analysis of heat-related labour productivity losses under climate change —implications for Germany's foreign trade. Climatic Change 160, 251–269

McCallum, J. (1995). National Borders Matter: Canada-U.S. Regional Trade Patterns. The American Economic Review, 85(3), 615–623. https://doi.org/10.1111/0008-4085.00055

Narayanan, B., Aguiar, A. & McDougall, R. (2012). Global Trade, Assistance, and Production: The GTAP 8 Data Base. Center for Global Trade Analysis, Purdue University.

Newell, R.G., Prest, B.C. and Sexton, S.E. (2018). The GDP Temperature Relationship: Im- plications for Climate Change Damages. RFF Working Paper Series, WP 18-17 REV. Available at http://www.rff.org/research/publications/gdp-temperature-relationship-implications-climate-change-damages

Orlov, A., Sillman, J., Aunan, K., Kjellstrom, T. & Aaheim, A. (2020). Economic costs of heat-induced reductions in worker productivity due to global warming. Glob. Environ. Change 63, 102087

Pant, H. (2007). GTEM: Global Trade and Environment Model. ABARE Technical Report. Canberra: Australian Bureau of Agricultural and Resource Economics and Sciences.

Parsons, K. C. (2014). Human Thermal Environment. The Effects of Hot, Moderate, and Cold Environments on Human Health, Comfort, and Performance (3rd editio). New York: CRC Press. https://doi.org/10.4324/9780203302620

Riahi, K., van Vuuren D. P., Kriegler E. et al. (2017). The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview, Global Environmental Change, Volume 42, Pages 153-168. https://doi.org/10.1016/j.gloenvcha.2016.05.009

Schleypen, J.R., Dasgupta, S., Borsky, S., Jury, M., Ščasný, M., Bezhanishvili, L. (2019). D2.4 Impacts on Industry, Energy, Services, and Trade. Deliverable of the H2020 COACCH project.

Schulte, P. a, and Chun, H. (2009). Climate change and occupational safety and health: establishing a preliminary framework. Journal of Occupational and Environmental Hygiene, 6(April 2015), 542–554. https://doi.org/10.1080/15459620903066008

UNDP (2016). Climate Change and Labour: Impacts of heat in the workplace. Retrieved from https://www.undp.org/publications/climate-change-and-labor-impacts-heat-workplace

Table A1: mapping between EU regions of the CGE model and NUTS 2013 EU code

No.	ICES EU regions	NUTS Level (from level 0 country to level 2)	NUTS 2013 code	Country
1	EastAustria	NUTS1	AT1	Austria
2	SouthAustria	NUTS1	AT2	Austria
3	WestAustria	NUTS1	AT3	Austria
4	Brussels	NUTS1	BE1	Belgium
5	Flanders	NUTS1	BE2	Belgium
6	Wallonia	NUTS1	BE3	Belgium
7	Cyprus	NUTS0	CY	Cyprus
8	Prague	NUTS2	CZ01	Czech Rep.
9	CentBoemia	NUTS2	CZ02	Czech Rep.
10	Souwestcze	NUTS2	CZ03	Czech Rep.
11	Norwestcze	NUTS2	CZ04	Czech Rep.
12	Noreastcze	NUTS2	CZ05	Czech Rep.
13	Soueastcze	NUTS2	CZ06	Czech Rep.
14	CentMoravia	NUTS2	CZ07	Czech Rep.
15	MoraviaSil	NUTS2	CZ08	Czech Rep.
16	Denmark	NUTS0	DK	Denmark
17	Estonia	NUTS0	EE	Estonia
18	Finland	NUTS0	FI	Finland
19	IleFrance	NUTS2	FR10	France
20	ChamArde	NUTS2	FR21	France
21	Picardie	NUTS2	FR22	France
22	HautNorm	NUTS2	FR23	France
23	Centre	NUTS2	FR24	France
24	BasseNorm	NUTS2	FR25	France
25	Bourgogne	NUTS2	FR26	France
26	NordPCalais	NUTS2	FR30	France
27	Lorraine	NUTS2	FR41	France
28	Alsace	NUTS2	FR42	France
29	FranComte	NUTS2	FR43	France

30	PaysLoire	NUTS2	FR51	France
31	Bretagne	NUTS2	FR52	France
32	PoitouChar	NUTS2	FR53	France
33	Aquitaine	NUTS2	FR61	France
34	MidiPyren	NUTS2	FR62	France
35	Limousin	NUTS2	FR63	France
36	RhoneAlp	NUTS2	FR71	France
37	Auvergne	NUTS2	FR72	France
38	LangRouss	NUTS2	FR81	France
39	Provence	NUTS2	FR82	France
40	Corse	NUTS2	FR83	France
41	BadenWur	NUTS1	DE1	Germany
42	Bavaria	NUTS1	DE2	Germany
43	Berlin	NUTS1	DE3	Germany
44	Branden	NUTS1	DE4	Germany
45	Bremen	NUTS1	DE5	Germany
46	Hamburg	NUTS1	DE6	Germany
47	Hessen	NUTS1	DE7	Germany
48	MeklenVor	NUTS1	DE8	Germany
49	LowSaxony	NUTS1	DE9	Germany
50	NorRenoWes	NUTS1	DEA	Germany
51	RenoPala	NUTS1	DEB	Germany
52	Saarland	NUTS1	DEC	Germany
53	Saxony	NUTS1	DED	Germany
54	SaxonyAnh	NUTS1	DEE	Germany
55	SchHol	NUTS1	DEF	Germany
56	Turingia	NUTS1	DEG	Germany
57	Voreia	NUTS1	EL1 (NUTS 2010 code)	Greece
58	Kentriki	NUTS1	EL2 (NUTS 2010 code)	Greece
59	Attiki	NUTS1	EL3	Greece
60	Nisia	NUTS1	EL4	Greece
61	Hungary	NUTS0	HU	Hungary
62	Ireland	NUTS0	IE	Ireland
63	Piemonte	NUTS2	ITC1	Italy
64	ValAosta	NUTS2	ITC2	Italy
65	Lombardia	NUTS2	ITC4	Italy
66	TrentAdige*	NUTS2	ITH1-ITH2	Italy
67	Veneto	NUTS2	ITH3	Italy
68	FriuliGiulia	NUTS2	ITH4	Italy
69	Liguria	NUTS2	ITC3	Italy
70	EmiRom	NUTS2	ITH5	Italy
71	Toscana	NUTS2	ITI1	Italy
72	Umbria	NUTS2	ITI2	Italy
73	Marche	NUTS2	ITI3	Italy
74	Lazio	NUTS2	ITI4	Italy
75	Abruzzo	NUTS2	ITF1	Italy
76	Molise	NUTS2	ITF2	Italy
77	Campania	NUTS2	ITF3	Italy
78	Puglia	NUTS2	ITF4	Italy
79	Basilicata	NUTS2	ITF5	Italy
80	Calabria	NUTS2	ITF6	Italy
81	Sicilia	NUTS2	ITG1	Italy
82	Sardegna	NUTS2	ITG2	Italy
83	Latvia	NUTS0	LV	Latvia
84	Lithuania	NUTS0	LT	Lithuania
85	Luxembourg	NUTS0	LU	Luxembourg
86	Malta	NUTS0	MT	Malta
87	NorthNether	NUTS1	NL1	Netherlands
88	EastNether	NUTS1	NL2	Netherlands
89	WestNether	NUTS1	NL3	Netherlands
90	SouthNether	NUTS1	NL4	Netherlands
91	CentPol	NUTS1	PL1	Poland

92	SouthPol	NUTS1	PL2	Poland
93	EastPol	NUTS1	PL3	Poland
94	NorWestPol	NUTS1	PL4	Poland
95	SouWestPol	NUTS1	PL5	Poland
96	NorthPol	NUTS1	PL6	Poland
97	Norte	NUTS2	PT11	Portugal
98	Algarve	NUTS2	PT15	Portugal
99	Centro	NUTS2	PT16	Portugal
100	Lisboa	NUTS2	PT17	Portugal
101	Alentejo	NUTS2	PT18	Portugal
102	Slovakia	NUTS0	SK	Slovakia
103	Slovenia	NUTS0	SI	Slovenia
104	Galicia	NUTS2	ES11	Spain
105	Asturias	NUTS2	ES12	Spain
106	Cantabria	NUTS2	ES13	Spain
107	PaisVasco	NUTS2	ES21	Spain
108	Navarra	NUTS2	ES22	Spain
109	LaRioja	NUTS2	ES23	Spain
110	Aragon	NUTS2	ES24	Spain
111	Madrid	NUTS2	ES30	Spain
112	CastLeon	NUTS2	ES41	Spain
113	CastMancha	NUTS2	ES42	Spain
114	Extremadura	NUTS2	ES43	Spain
115	Cataluna	NUTS2	ES51	Spain
116	Valencia	NUTS2	ES52	Spain
117	Balears	NUTS2	ES53	Spain
118	Andalucia**	NUTS2	ES61-ES63-ES64	Spain
119	Murcia	NUTS2	ES62	Spain
120	Canarias	NUTS2	ES70	Spain
121	EastSweden	NUTS1	SE1	Sweden
122	SouthSweden	NUTS1	SE2	Sweden
123	NorthSweden	NUTS1	SE3	Sweden
124	NorEastEng	NUTS1	UKC	UK
125	NorWestEng	NUTS1	UKD	UK
126	YorkHumber	NUTS1	UKE	UK
127	EastMidEng	NUTS1	UKF	UK
128	WestMidEng	NUTS1	UKG	UK
129	EastofEng	NUTS1	UKH	UK
130	London	NUTS1	UKI	UK
131	SouEastEng	NUTS1	UKJ	UK
132	SouWestEng	NUTS1	UKK	UK
133	Wales	NUTS1	UKL	UK
134	Scotland	NUTS1	UKM	UK
135	NorthIre	NUTS1	UKN	UK
136	Bulgaria	NUTS0	BG	Bulgaria
137	Croatia	NUTS0	HR	Croatia
138	Romania	NUTS0	RO	Romania

* It includes two Italian Nuts2 regions: Provincia Autonoma di Bolzano (ITH1) and Provincia Autonoma di Trento (ITH2).
** It includes three Nuts2 Spanish regions: Andalucia (ES61), Ceuta (ES63) and Melilla (ES64).