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ORIGINAL ARTICLE

Assessing the Economic Structure, Climate Change and Decarbonisation in Europe

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Abstract

Anthropogenic greenhouse gas (GHG) emissions coming mainly from fossil fuel combustion for energy use are causing air temperature increases resulting in climate change. This study employs an environmentally extended input–output model to conduct an economy-wide assessment of GHG emissions in the European Union (EU). Model results indicate that the assumed growth of economic activity by 2030 will lead to a large increase in GHG emissions by 89%, assuming no technological change and no additional policy mitigation efforts. The electricity sector and agriculture create the highest direct and indirect GHG emissions per unit of economic output across the 27 EU member states (EU-27); for every 1-million-euro-increase in the final demand for the products and services of the electricity sector and agriculture, 2198 and 1410 additional tons of GHG emit, respectively. Regional climate projections under a low-decarbonisation pathway (RCP8.5), in accordance with our economic analysis, indicate a further increase of regional warming, combined with pronounced changes in the hydrological cycle. Contrariwise, following a strong mitigation pathway (RCP2.6) will result in warming levels lower than 1.5 °C with respect to the 1986–2005 reference period. Our findings reveal the importance of both direct and indirect contribution of economic sectors in the generation of GHG emissions, taking into consideration the size of the sectors and the assumed growth rates. The design and implementation of sectoral emission reduction policies from the perspective of the whole production supply chain can effectively contribute to GHG emission reduction commitments.

Keywords Economic growth · Environmentally extended input–output analysis · GHG emissions · Climate change · Europe

1 Introduction

Economic and population growth have contributed to increasing demand for resources, including energy. Anthropogenic greenhouse gas (GHG) emissions, coming mainly from fossil fuel combustion for energy production (mainly coal and crude oil), are causing air temperature increases resulting in climate change (IPCC 2013). According to the Intergovernmental Panel on Climate Change (IPCC 2018), human-induced global warming, reached approximately 1.0 °C above pre-industrial levels in 2017 (with a likely range of 0.8 °C and 1.2 °C). In the absence of ambitious mitigation policies in the coming years that could lead to a sharp decline in GHG emissions by 2030, global warming is likely to surpass 1.5 °C sometime between 2030 and 2045 (IPCC 2018).

The Paris Agreement, achieved at the 21st United Nations Climate Change Conference (COP21) in Paris in 2015, aims to substantially reduce global GHG emissions and limit the temperature increase by the end of this century to well below 2 °C above the pre-industrial levels, while pursuing efforts to limit the global warming to less than 1.5 °C (UNFCCC 2021). In the European Union (EU), the Governance of the Energy Union and Climate Action Regulation sets out the legislative framework for achieving the 2030 energy and climate targets in line with the Paris Agreement (Reg. (EU) 2018/1999 2018). Member states are obliged to prepare and submit integrated National Energy and Climate Plans (NECPs). These plans aim to support the binding objective for an overall economy-wide reduction of at least 40% of

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GHG levels by 2030 compared to 1990 (European Council 2014). The European Commission has recently proposed an EU-wide net GHG emissions reduction target of at least 55% by 2030, compared to 1990 levels, to put the EU on a balanced pathway to reach climate neutrality by 2050 (European Commission 2020a). The EU Green Deal, the major initiative to move to a net-zero GHG emissions economy by 2050, aims to achieve decarbonisation in the EU within the coming years (European Commission 2020b).

Across the 27 EU countries (EU-27), there is a general downward trend of GHG emissions during the last 3 decades. In particular, emissions in the EU-27 declined by 16% between 1995 and 2018, while the gross domestic product (GDP) of the EU-27 economy increased by 48% (Fig. 1—left panel). This figure shows that the EU is on track to fulfil its commitments to meet the 2020 climate and energy package targets (European Commission 2009), i.e. to meet its 20% GHG emissions reduction target for 2020 compared to 1990 levels. Within the same period, the GHG emission intensity of the EU-27 economy has decreased by 43%, highlighting the efforts of the EU member states to decarbonise their economies (Fig. 1—right panel) (Eurostat 2021b; EEA 2021). The contribution of the individual production sectors to the GHG emission generation substantially varies in size and from year to year. The largest emitting sectors in the EU, that is, the electricity production and the manufacturing sectors, decreased their GHG emissions between 2008 and 2019 by 31% and 22%, respectively (Eurostat 2021a). On the other hand, the agriculture-related emissions (about 15% of the total GHG emissions) have decreased by only 3%, while in other sectors, such as air transport and health services, GHG emissions have increased by 19% and 10%, respectively.

The relationship between economic activity and GHG emissions has been widely studied. A large part of the literature focuses on investigating the relationship between economic growth, energy use and GHG emissions, testing the validity of the Environmental Kuznets Curve hypothesis that postulates an inverted U-shaped relationship between environmental degradation and per capita income (Acaravci and Ozturk 2010; Lee et al. 2015; Manta et al. 2020). Bottom-up studies examining alternative approaches for reducing GHG emissions, including specific technological and managerial options per sector (Neuhoff 2005; Worrell et al. 2001), typically provide detailed information about emission reduction potential within certain sectors, but they do not capture systemic effects (Mundaca et al. 2019). Less effort has been devoted in exploring the relationship between economic structure, climate change and GHG emissions. Capturing the sectoral-level emission effects is critical to identify the key emitters and so contribute to the overall reduction of GHG emissions.

A clear understanding of any economic structure requires a sectoral categorization and an analysis of the inter-industry commodity flows (Ghosh and Roy 1998). Input–output analysis (IOA) has been considered a valid approach for studying such interdependencies between the production sectors in an economy (Miller and Blair 2009), and it has been extensively applied for policy impact analysis, structural and technical change analysis (Giannakis and Bruggeman 2017; Taliotis et al. 2020). The environmental extension of IOA models has consequently become a valuable technique for analysing interdependency among industries and GHG emissions (Hawkins et al. 2015). Tracing the GHG emissions embodied in the flows of intermediates along production supply chains can provide a more thorough understanding of how GHG are driven through economic activity (Peters 2008) and an integrated assessment of the contribution of the production sectors in the generation of GHG emissions (Suh 2006).

Computable General Equilibrium (CGE) models have also been used in the literature to study the interrelationships of production sectors and their impact on climate change (Eboli et al 2010). CGE models, unlike IO models, capture supply-side effects and allow for more flexibility, due to their non-linearity, regarding substitution effects and relative price changes

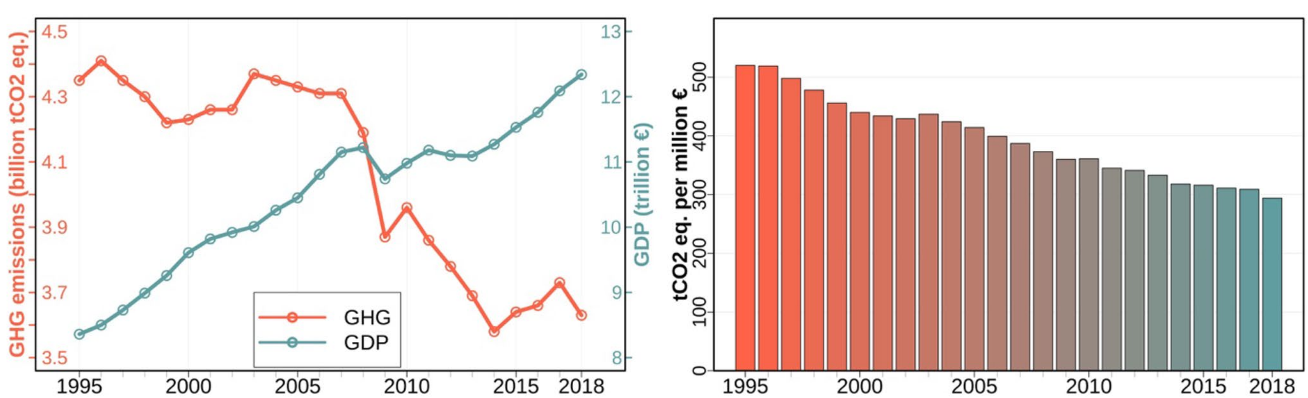

Fig. 1 GDP (trillion Euro at constant prices 2010) and GHG (billion tonnes CO_2 equivalent) emissions trends in EU-27, 1995–2018 (left panel) and GHG emission intensity (GHG emissions per GDP) of EU-27 economy (right panel). Source: Eurostat 2021b; EEA 2021

(Koks et al. 2016). Optimization models, such as the TIMES (The Integrated MARKAL-EFOM System) and the MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environmental Impacts), and accounting models, such as the LEAP (Long-range Energy Alternatives Planning system) and the GACMO (Greenhouse Gas Abatement Cost Model) have also been used for the development of the Nationally Determined Contributions (NDCs) worldwide (Haydock and McCullough 2017).

Given the highly uneven sectoral annual GHG emission generation and reduction potentials (Blok et al. 2020), an economy-wide assessment of the contribution of production sectors in the generation of GHG emissions is of major relevance. This paper aims to assess the direct and indirect contribution of economic sectors to GHG emissions, accounting for all monetary inter-sectoral transactions. Specifically, an environmentally extended input–output (EE-IOA) model is developed to explore the economy-wide effects of the growth of the production sectors on the GHG emissions generated in the EU-27. The paper is structured as follows: Sect. 2 outlines the methodology of the study, while Sect. 3 presents the results of the analysis. Section 4 presents complementary information on regional climate change projections for Europe under two concentration pathways for the future. The paper ends with a discussion of the results and conclusions drawn from the analysis.

2 Methods

2.1 Environmentally Extended Input–Output Analysis

The basic structure of an IOA model consists of a system of linear equations that account for the way in which the output of each sector i is distributed through sales to other sectors for intermediate use and final demand as follows (Miller and Blair 2009):

$$x_i = \sum_{j=1}^{n} x_{ij} + y_{i,} \tag{1}$$

where x_i is the total output of sector i $(i = 1, \dots, n)$; x_{ij} describes the inter-industry sales of sector i to all sectors $j (j = 1, \dots, n)$; y_i is the final demand for sector $i's$ product.

The technical coefficients $\left(a_{ij}\right)$ represent the value of the output from sector i that is required to produce one unit of output in sector j as follows:

$$a_{ij} = x_{ij}/x_{j.} \tag{2}$$

Equation (1) can then be rewritten in matrix notation as follows:

$$X = AX + Y, \tag{3}$$

where A is the technical coefficients matrix. Solving Eq. (3) for X, we obtain Eq. (4):

$$X = (I - A)^{-1} Y, \tag{4}$$

where $(I - A)^{-1} = L$ is the Leontief inverse or the total (direct and indirect) requirements matrix. The L matrix quantifies the direct and indirect impacts exerted by changes in final demand (ΔY) on the output of each sector (ΔX). The output multiplier for an individual sector j is defined as the column sums of the L matrix $\left(\sum_{i=1}^{n} l_{ij}\right)$.

The environmental extension of the basic IOA model can be obtained by introducing an exogenous vector of emission intensity, here denoted as $D = \left[d_i\right]$, that is, the amount of GHG emissions $\left(g_i\right)$ per unit output of each sector i $\left(x_i\right)$ as follows (Camanzi et al. 2017; Giannakis et al. 2019):

$$d_i = \frac{g_i}{x_i}. \tag{5}$$

The total (direct and indirect) GHG emissions (G) can be calculated as follows:

$$G = D(I - A)^{-1} Y. \tag{6}$$

2.2 Data

The EU-27 symmetric IOA table for the year 2019 was derived from the Eurostat database (Eurostat 2021c). The initial scheme of 65 sectors of economic activity (Appendix Table 2) was aggregated into 25 economic sectors (Appendix Table 3). The sectoral GHG emission data were obtained by the Eurostat (2021a). Sources of uncertainty typically associated with EE-IOA include: (a) the assumption of constant returns to scale, (b) the assumption of fixed input structure, (c) the assumption of homogenous prices, (d) the assumption that the imported goods are produced with the same domestic technology, (e) uncertainties in source data (Wiedmann 2009).

In this study, we used the long-term outlook of the EU Reference Scenario 2016, that is, one of the key modelling tools of the European Commission for projecting economic activity, to estimate sectoral growth rates in the EU (Capros et al. 2016). Specifically, we explore the direct and indirect impact of the increase in the final demand for the output of the individual production sectors in the GHG emissions in the EU-27 from 2019 to 2030.

Considering the rapid warming over the region and in addition to the input–output analysis presented in the previous sections, we analysed state-of-the-art regional climate projections for the twenty-first century to assess the importance of adopting timely mitigation measures and reducing GHG emissions and concentrations. Following the temporal horizon of the IOA, we focus on the near-term changes (2021–2040), while for comparison, we also present mid-twenty-first-century (2041–2060) projections for temperature and precipitation. These projections are based on a large ensemble of high-resolution regional simulations (0.11 × 0.11°) that is part of the EURO-CORDEX initiative (Jacob et al. 2020). Our model selection is similar to Cherif et al. (2020) and is presented in Table 4 (Appendix). Our analysis is complementary to Jacob et al. (2014) and is an update in terms of future scenarios and ensemble size.

In the present study, we have assessed two future scenarios. The first Representative Concentration Pathway (RCP), RCP2.6 (Van Vuuren et al. 2011), is representative of scenarios leading to low GHG concentration levels. It is a so-called 'peak' scenario, in the sense that its radiative forcing first reaches a value around 3.1 W/m^2 (mid-century), returning to 2.6 W/m^2 by 2100. To reach such radiative forcing levels, GHG emissions and concentrations have to be reduced substantially over time. According to the latest Assessment Report of IPCC (2013), global warming under RCP2.6 stays below 2 °C above 1850–1900 levels throughout the twenty-first century, clearly demonstrating the potential of mitigation policies. This pathway closely meets the main targets of the Paris Agreement, aiming at keeping global warming less than 2 °C above pre-industrial levels. The second pathway, RCP8.5 (Riahi et al. 2007), is representative of scenarios that lead to high GHG concentration levels. It is considered as a high-emission pathway, which, however, at least for parts of the region, is following the observed temperature trends (Zittis et al. 2019). Notably, the two pathways under investigation start to deviate significantly after the 2030s.

3 Results

The IOA multiplier analysis identified the most important sectors of economic activity in view of their capacity to generate economic output throughout the EU economy (Table 1). The food industry has the highest output multiplier (O-M: 2.42), that is, for every 1-million-euro-increase in the final demand for the industry's products, the total output of the economy will increase by 2.42 million euro. Similarly, the machinery and equipment sector (O-M: 2.17) also creates strong multiplier effects in the EU-27 economy, considering its high contribution to total economic output formation, that is, 10% (Fig. 2). On the other hand, service sectors such as real estate (O-M: 1.44) and education (O-M:

Table 1 Economic output multipliers and GHG multipliers for the EU-27 (2019)

Sectors of economic activity	Output multipliers (M€/M€)	Output share (%)	GHG multiplier (tn/M€)	GHG share (%)
Agriculture	2.06	1.6	1410	15.3
Forestry	1.88	0.2	141	0.1
Fisheries	1.88	0.1	537	0.2
Mining	2.30	0.3	756	1.8
Food manufacturing	2.42	3.9	342	1.9
Textile	2.10	0.8	70	0.2
Wood and paper	2.34	1.4	262	1.3
Chemical and plastic products	2.08	5.1	1210	9.3
Metal and non-metal products	2.24	3.8	757	11.7
Machinery and equipment	2.17	10.2	534	1.4
Electricity	2.15	2.3	2198	27.6
Water supply and waste management	1.99	1.1	709	4.8
Construction	2.13	6.9	273	1.8
Trade	1.82	10.3	743	2.8
Land transport	1.93	2.5	607	5.6
Water transport	2.04	0.5	1057	3.6
Air transport	2.15	0.5	1223	4.4
Transportation warehousing services	2.00	2.5	715	0.9
Accommodation and food services	1.89	2.8	113	0.5
Banking and financing	1.87	4.6	398	0.2
Real estate	1.44	7.1	215	0.2
Public administration	1.50	4.2	98	0.8
Education	1.33	2.8	62	0.5
Health	1.51	5.2	32	0.9
Other services	1.79	19.4	1656	2.1

1.33) create low backward linkages with the other economic sectors.

The EE-IOA multiplier analysis identified the contribution of the twenty-five economic sectors in the generation of GHG emissions (Table 1). The electricity sector has the highest GHG multiplier (GHG-M: 2198 tn/M€) in the EU, that is, for every 1-million-euro-increase in the final demand for the products and services of the sector, 2198 additional tons of GHG emit. Agriculture (GHG-M: 1410 tn/M€), air transport (GHG-M: 1223 tn/M€), chemical and plastic products (GHG-M: 1210 tn/M€) and shipping (GHG-M: 1057 tn/M€) are also significant (direct and indirect) GHG emitters. Similar to the IOA analysis, service sectors, such as education (GHG-M: 62 tn/M€) and health (GHG-M: 32 tn/M€), generate low GHG emissions.

In 2019, the EU-27's sectors emitted 3049 megatons of GHG (CO_2 equivalent). The assumed growth of EU economic sectors by 2030, assuming no change in technology $\left(a_{ij}\right)$ and no explicit policies and measures to reduce GHG emissions, results in a total (direct and indirect) increase of GHG emissions by 89% relative to 2019. Significant increases in the emissions of GHG are presented in the industrial sectors of machinery and equipment (332%) and chemical and plastic products (69%), which emit about 10.7% of the total GHG emissions in the EU-27. Several service sectors also exhibit large increases in their GHG emissions, such as trade (427%) and transportation warehousing services (259%); however, their share in the generation of GHG emissions is less than 3.7%. The relatively low increase of GHG emissions of agriculture (4%) and electricity (11%) sectors, i.e. the largest GHG emitters in absolute terms (Fig. 2), is mainly due to the assumed low growth rates by 2030.

4 Climate Change in Europe with and Without Decarbonisation

The regional implications of anthropogenic warming have been widely observed in Europe, and these are most profound over the last 3 decades (Kovats et al. 2014). These manifestations include an overall warming, faster than the global mean rates (Fig. 3). Particularly in the last four decades, the warming trend is 0.41 °C/decade, or 1.5 times higher than the global average (0.27 °C/decade). This regional temperature increase is mainly driven by the global concentration levels of greenhouse gases (mainly CO_2). These gases have a long lifetime and are, therefore, well-mixed in the atmosphere. Besides some decarbonization efforts in Europe, global GHG concentrations have increased substantially (Olivier and Peters 2020), contributing to the observed warming trend, in addition to further positive climatic feedbacks. Past precipitation changes are

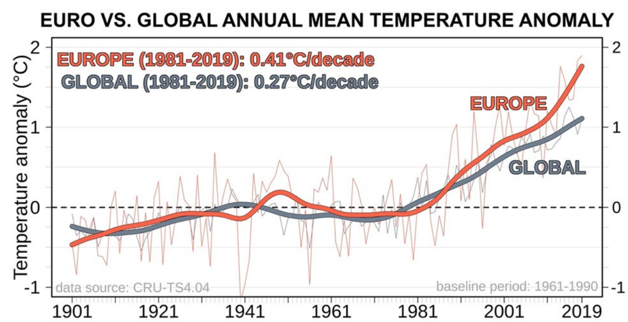

Fig. 3 Observed global and European temperature anomalies with respect to the 1961–1990 historical reference period based on CRU-TS4.04 data (Harris et al. 2020). Linear trends for the last four decades (1981–2019) are also indicated

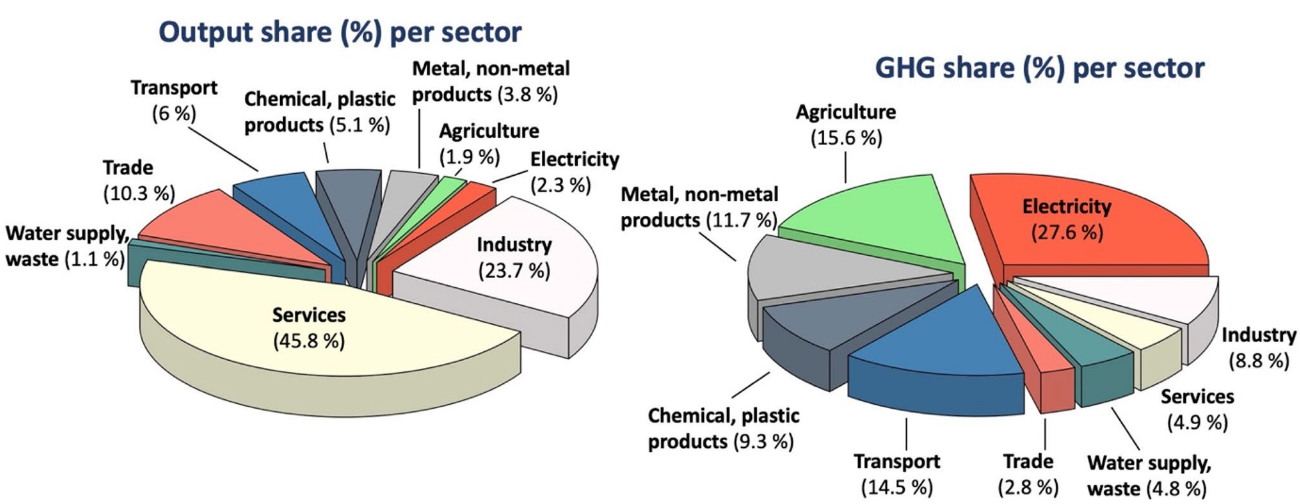

Fig. 2 Sectoral economic output and greenhouse gas (GHG) emission shares (%)

mostly driven by natural climate variability (e.g. Zittis 2018), however, the role of anthropogenic climate change and external forcing is projected to become more evident, as drier (wetter) conditions are expected for southern (northern) Europe (Zittis et al. 2019; Coppola et al. 2021).

Mean annual temperature projections, with respect to the 1986–2005 historical reference period, are presented in the maps of Fig. 4. Under the strong mitigation pathway (RCP2.6), the projected changes for temperature will likely not exceed 1.5 °C (Fig. 4—left panels). This is the case for both time horizons under investigation. Exceptions are the northern parts of Scandinavia, where due to positive climate feedbacks, the projected warming is somehow higher (up to 3 °C in mid-century). In contrast, a high-emission pathway of low decarbonization rates (RCP8.5) indicates a much stronger European warming, particularly for the middle of the twenty-first century (Fig. 4—right panels). For the hot-spot areas (for example, the Alps and Scandinavia), the temperature increase could reach levels of 4–5 °C. Such warming levels and reduced snow cover imply severe impacts in a range of critical socio-economic sectors, including tourism, agriculture, hydropower and more (Gobiet et al. 2014; Jacob et al. 2018). The snow-albedo positive feedback (Winter et al. 2017) is likely dominant in these areas since, in a warmer future, smaller areas are expected

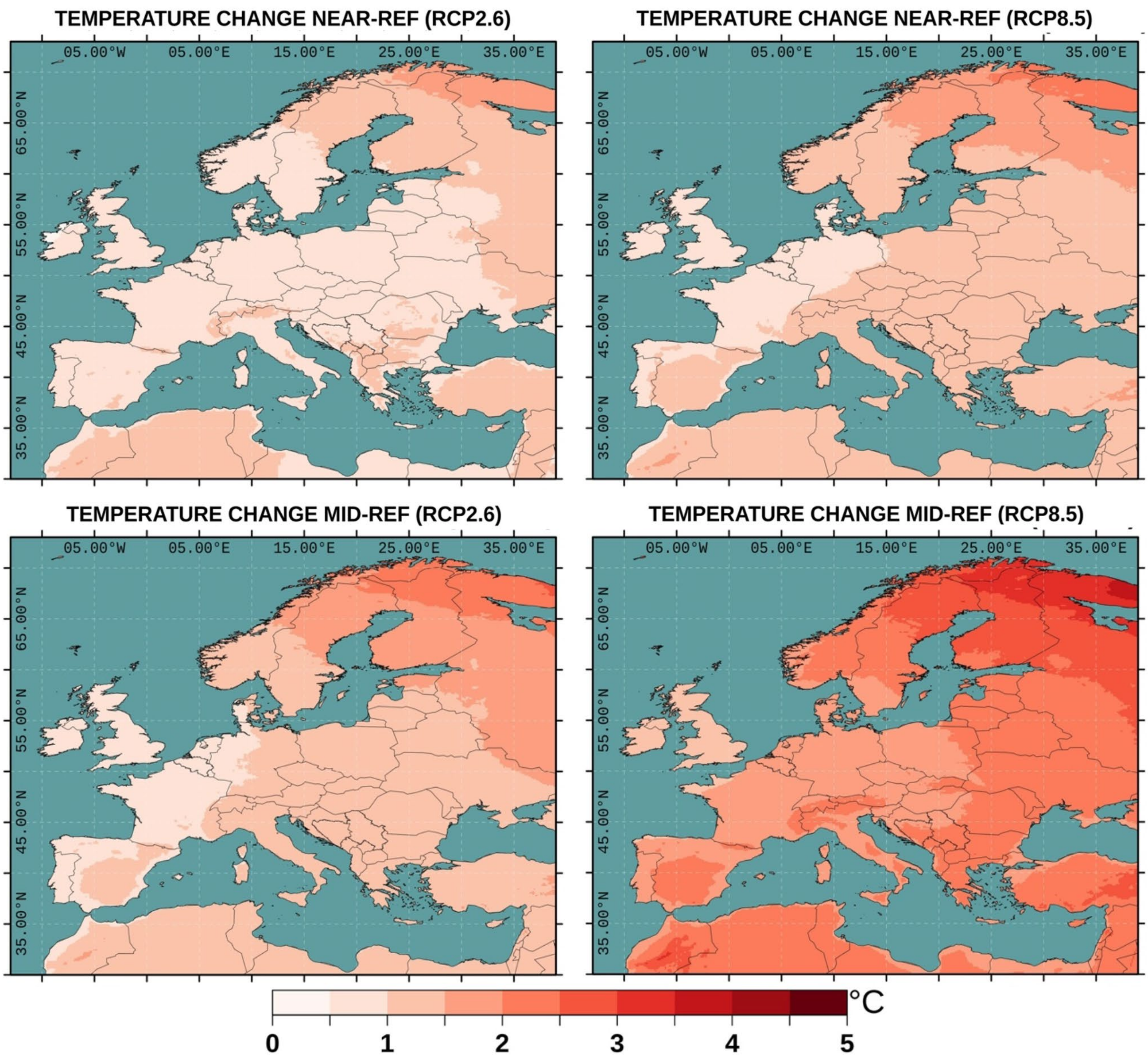

Fig. 4 Projected annual temperature change for the near future (NEAR: 2021–2040) and the middle of the twenty-first century (MID: 2041–2060) with respect to the historical reference period (REF: 1986–2005), based on the EURO-CORDEX ensemble of regional climate projections. Pathway RCP2.6 is presented in the left panels and pathway RCP8.5 in the right panels

to be covered by snow during the winter and spring seasons. Since we have used a relatively recent reference period, about 0.6–0.7 °C should be added to these projections to approximate the regional warming levels with respect to the pre-industrial era. This comparison highlights the need for timely decarbonization at the European and global scales. For specific hot-spot areas (for example, Scandinavia, Iberia, East Europe, Anatolia, North Africa), the milder warming (about 0.5 °C less), projected under a more sustainable pathway (i.e. RCP2.6), is already evident in the next 2 decades.

Future precipitation projections for Europe are presented in Fig. 5. Under pathway RCP2.6, mild changes (± 10%) are expected throughout the region (Fig. 5—left panels). In this scenario, with respect to the reference period (1986–2005), most of Europe is expected to become wetter, except for some Mediterranean countries. The high-emission pathway RCP8.5 implies similar precipitation changes for the near-future period (2021–2040). By the middle of the current century (2041–2060), the projected signal is expected to intensify with increased precipitation (10–20%) in north-east Europe and Scandinavia and strong drying (decreases of 10–30%) for Mediterranean Europe (Fig. 5—right panels).

The projected precipitation changes for southern and northern Europe are mainly attributed to changes in atmospheric

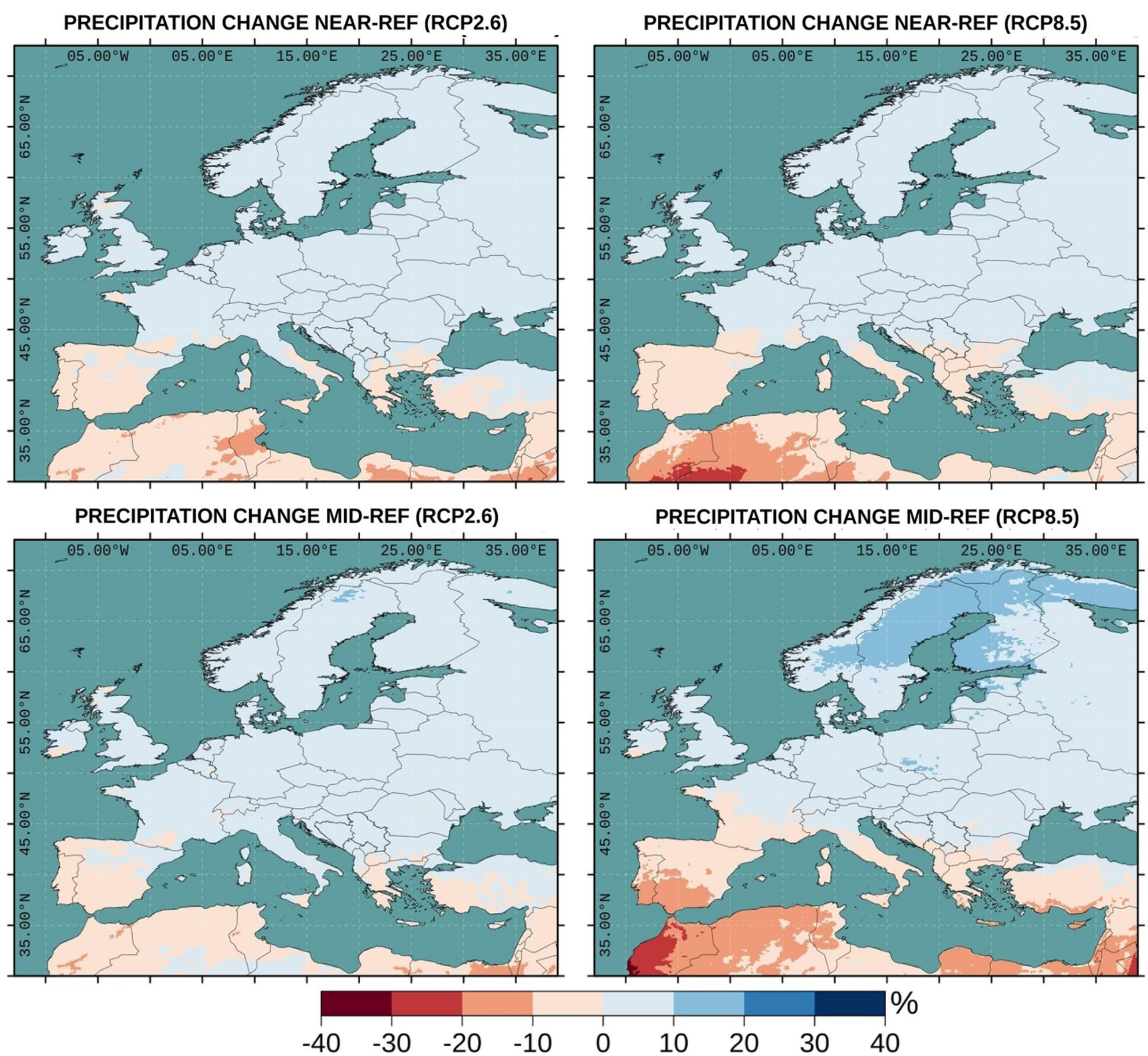

Fig. 5 Projected annual precipitation change for the near future (NEAR: 2021–2040) and the middle of the twenty-first century (MID: 2041–2060) with respect to the historical reference period (REF: 1986–2005), based on the EURO-CORDEX ensemble of regional climate projections. Pathway RCP2.6 is presented in the left panels and pathway RCP8.5 in the right panels

circulation and thermodynamics. Under rising greenhouse gas concentrations, climate models project that the Hadley Cell circulation will change, the tropics will expand, and the mid-latitude westerlies and associated storm tracks will likely shift poleward (Cherif et al. 2020). This is expected to enhance subsidence and reduce storminess at the latitudes of southern Europe and the Mediterranean region, with a resulting reduction in precipitation (Fig. 5). This poleward shift of storm tracks, in addition to changes in thermodynamics, can explain the projected precipitation increase in northern Europe. For example, the Clausius–Clapeyron relationship predicts an increase in the water holding capacity of air (the saturation water vapor pressure) of approximately 7%/°C rise in temperature (Held and Soden 2006).

5 Discussion and Conclusions

In this study, we empirically analysed the relationship between the production activities of the EU-27's economic system and GHG emissions at the macroeconomic level. Our analysis shows the level of GHG emissions that would occur in the EU-27 by 2030 in the absence of any further policy mitigation effort and without any technological progress. In particular, the results of the EE-IOA model indicate that the assumed growth of economic activity will lead to a large increase in GHG emissions, that is, around 89%.

Our regional climate projections under a high-emission pathway of low decarbonisation (RCP8.5), in accordance with our economic analysis, indicate a considerable increase of European warming levels while for a strong mitigation pathway (RCP2.6), warming will not surpass 1.5 °C, with respect to our reference period (or about 2–2.5 °C since pre-industrial levels). Near and mid-term climate projections for precipitation indicate changes of the range of $\pm$ 10% for both pathways. These ranges agree with previous assessments for the region (Gobiet et al. 2014; Jacob et al. 2018; Zittis et al. 2019; Coppola et al. 2021). Moreover, the identified hot-spot areas (for example, northeast Europe and parts of the Mediterranean) corroborate previous studies (Giorgi 2006; Giorgi and Lionello 2008). Both analyses highlight the crucial role of sectoral climate change mitigation policies and decarbonisation technologies to ameliorate the negative effects of economic growth in the generation of GHG emissions and to meet EU GHG emission reduction targets.

The results of the EE-IOA multiplier analysis revealed that the electricity and the agricultural sectors create the highest direct and indirect GHG emissions in the EU-27 per unit (million euro) of economic output produced. Electricity, agriculture and the industrial sectors of metal and non-metal products and chemical and plastic products are also the largest GHG emitters in absolute terms (tons). Our analysis reveals the importance of both direct and indirect contribution of economic sectors in the generation of GHG emissions, taking into consideration the size of the sector in terms of economic output formation and GHG emissions generation, and the assumed growth rates.

Our findings are aligned with the results of Liu et al. (2020), who found with the use of EE-IOA models that agriculture and electric power generation sectors have high-emission intensities and a strong effect on other industries in Canada. The electricity, the metal and non-metal products and the land transport sectors are the most important CO_2 emitters in Cyprus (Giannakis et al. 2020). Morán and González (2007) found that the largest CO_2 emitters in Spain are the electricity and the metal and non-metal products sectors. Alcántara and Padilla (2020) showed that the sectors inducing more GHG emissions from other sectors in the Spanish economy are food manufacturing, wholesale and retail trade and construction. The metal products, the chemical products and the coal mining and petroleum processing products are the key GHG-emitting sectors in China (Guo et al. 2018; Shen et al. 2018; Yuan et al. 2020).

Identifying key GHG-emitting sectors, including both direct and indirect emissions, is, thus, crucial for formulating effective energy and environmental policies. Our findings stress the importance of an effective enforcement regime for reducing GHG emissions to counterbalance the adverse effects of economic growth. Moreover, they highlight the need for deploying advanced technologies to reduce sectoral emission intensities and contribute to the EU's medium- and long-term ambitious decarbonization targets. A broad portfolio of clean energy technologies will be needed to decarbonize all sectors of the economy, including further advancements in renewables, energy efficiency and storage and hydrogen-producing electrolyzers (IEA 2020).

Sectoral emission intensities are expected to vary greatly in the near future. Thus, if the focus is on individual GHG-emitting sectors, ignoring the complicated relations and linkages between different GHG-emitting sectors, the effectiveness of mitigation policies will be limited as less attention will be paid to sectors with low direct GHG emissions but high indirect linkages that drive other sectors to release emissions. The formulation and implementation of industrial emission reduction policies from the perspective of the whole industrial chain can be more efficient than policies focusing on specific individual sectors (Xie et al. 2016). Future research could analyse the emission intensities of the production sectors with their associated GHG abatement costs to explore the cost-effectiveness of abatement options within certain sectors to meet GHG emission reduction targets.

Appendix

See Tables 2, 3 and 4.

Table 2 NACE (statistical classification of economic activities in the European Union) codes of the 65 sectors of economic activity included in the symmetric input–output table for EU-27 (2019)

n/n	Sector	Description NACE
1	Products of agriculture, hunting and related services	A01
2	Products of forestry, logging and related services	A02
3	Fish and other fishing products; aquaculture products; support services to fishing	A03
4	Mining and quarrying	B
5	Food, beverages and tobacco products	C10-12
6	Textiles, wearing apparel, leather and related products	C13-15
7	Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials	C16
8	Paper and paper products	C17
9	Printing and recording services	C18
10	Coke and refined petroleum products	C19
11	Chemicals and chemical products	C20
12	Basic pharmaceutical products and pharmaceutical preparations	C21
13	Rubber and plastic products	C22
14	Other non-metallic mineral products	C23
15	Basic metals	C24
16	Fabricated metal products, except machinery and equipment	C25
17	Computer, electronic and optical products	C26
18	Electrical equipment	C27
19	Machinery and equipment	C28
20	Motor vehicles, trailers and semi-trailers	C29
21	Other transport equipment	C30
22	Furniture and other manufactured goods	C31-32
23	Repair and installation services of machinery and equipment	C33
24	Electricity, gas, steam and air conditioning	D
25	Natural water; water treatment and supply services	E36
26	Sewerage services; sewage sludge; waste collection, treatment and disposal services; materials recovery services; remediation services and other waste management services	C37-39
27	Constructions and construction works	F
28	Wholesale and retail trade and repair services of motor vehicles and motorcycles	G45
29	Wholesale trade services, except of motor vehicles and motorcycles	G46
30	Retail trade services, except of motor vehicles and motorcycles	G47
31	Land transport services and transport services via pipelines	H49
32	Water transport services	H50
33	Air transport services	H51
34	Warehousing and support services for transportation	H52
35	Postal and courier services	H53
36	Accommodation and food services	I
37	Publishing services	J58
38	Motion picture, video and television programme production services, sound recording and music publishing; programming and broadcasting services	J59-60
39	Telecommunications services	J61
40	Computer programming, consultancy and related services; Information services	J62-63
41	Financial services, except insurance and pension funding	K64
42	Insurance, reinsurance and pension funding services, except compulsory social security	K65
43	Services auxiliary to financial services and insurance services	K66
44	Real estate services excluding imputed rents	L68B
45	Imputed rents of owner-occupied dwellings	L68A
46	Legal and accounting services; services of head offices; management consultancy services	M69-70
47	Architectural and engineering services; technical testing and analysis services	M71

Table 2 (continued)

n/n	Sector	Description NACE
48	Scientific research and development services	M72
49	Advertising and market research services	M73
50	Other professional, scientific and technical services and veterinary services	M74-75
51	Rental and leasing services	N77
52	Employment services	N78
53	Travel agency, tour operator and other reservation services and related services	N79
54	Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services	N80-82
55	Public administration and defence services; compulsory social security services	O
56	Education services	P
57	Human health services	Q86
58	Residential care services; social work services without accommodation	Q87-88
59	Creative, arts, entertainment, library, archive, museum, other cultural services; gambling and betting services	R90-92
60	Sporting services and amusement and recreation services	R93
61	Services furnished by membership organisations	S94
62	Repair services of computers and personal and household goods	S95
63	Other personal services	S96
64	Services of households as employers; undifferentiated goods and services produced by households for own use	T
65	Services provided by extraterritorial organisations and bodies	U

Table 3 NACE (statistical classification of economic activities in the European Union) codes of the sectors of economic activity that make up the 25 sectors for the input–output analysis for EU-27 (2019) Source: Eurostat (2008)

n/n	Sector	Description NACE
1	Agriculture	A01
2	Forestry	A02
3	Fisheries	A03
4	Mining	B
5	Food Manufacturing	C10, C11, C12
6	Textile	C13, C14, C15
7	Wood and Paper	C16, C17, C18
8	Chemical and Plastic Products	C19, C20, C21, C22
9	Metal and Non-metal Products	C23, C24, C25
10	Machinery and Equipment	C26, C27, C28, C29, C30, C31, C32, C33
11	Electricity	D
12	Water Supply and Waste Management	E
13	Construction	F
14	Trade	G
15	Land Transport	H49
16	Water Transport	H50
17	Air Transport	H51
18	Transportation Warehousing Services	H52, H53
19	Accommodation and Food Services	I
20	Banking and Financing	K
21	Real Estate	L
22	Public Administration	O
23	Education	P
24	Health	Q
25	Other Services	J, M, N, R, S, T, U

Table 4 List of EURO-CORDEX simulations considered in the present study

Global Climate Model (GCM)	Regional Climate Model (RCM)	Temperature			Precipitation		
		Historical	RCP2.6	RCP8.5	Historical	RCP2.6	RCP8.5
CNRM-CM5	ALADIN53	✓	✓	✓			
CNRM-CM5	ALADIN63	✓		✓			
CNRM-CM5	ALARO-0	✓	✓	✓	✓	✓	✓
CNRM-CM5	CCLM4	✓		✓	✓		✓
CNRM-CM5	HIRHAM5	✓		✓	✓		✓
CNRM-CM5	RACMO22E	✓	✓	✓	✓	✓	✓
CNRM-CM5	RCA4	✓		✓	✓		✓
EC-EARTH	CCLM4	✓	✓	✓	✓	✓	✓
EC-EARTH	HIRHAM5	✓		✓	✓		✓
EC-EARTH	RACMO22E	✓	✓	✓	✓	✓	✓
EC-EARTH	RCA4	✓		✓	✓	✓	✓
EC-EARTH (r3)	RACMO22E	✓		✓	✓		✓
EC-EARTH (r3)	RCA4	✓	✓	✓	✓		✓
IPSL-CM5A	RCA4	✓	✓	✓	✓	✓	✓
HadGEM2-ES	CCLM4	✓		✓	✓		✓
HadGEM2-ES	HIRHAM5	✓		✓	✓		✓
HadGEM2-ES	RACMO22E	✓	✓	✓	✓	✓	✓
HadGEM2-ES	RCA4	✓	✓	✓	✓	✓	✓
MPI-ESM-LR	CCLM4	✓		✓	✓		✓
MPI-ESM-LR	RCA4	✓	✓	✓	✓		✓
MPI-ESM-LR	REMO	✓	✓	✓	✓		✓
NorESM1-M	HIRHAM5	✓		✓	✓		✓
NorESM1-M	RACMO22E	✓		✓			
NorESM1-M	REMO	✓		✓	✓		✓
NorESM1-M	RCA4	✓	✓	✓	✓	✓	✓
GFDL-ESM2G	REMO	✓	✓		✓	✓	

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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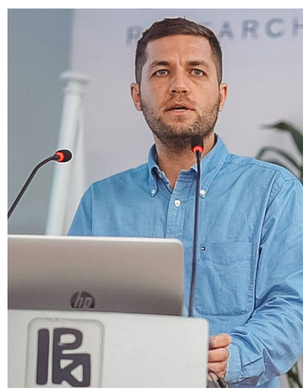

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