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Household consumption patterns and income inequality in EU countries: Scenario analysis for a fair transition towards low-carbon economies

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ABSTRACT

The growing awareness of the current and future consequences of climate change has led to a range of international commitments aimed at ensuring sustainable development as part of the United Nations Framework Convention on Climate Change, and the Paris Agreement. These agreements reflect a concern of how to reduce carbon emissions and the pathway towards environmental improvement. Recent literature has pointed out the role of households as direct and indirect drivers of environmental impacts and as key agents in achieving low-carbon economies and climate-resilient development. Disparities in income distribution and lifestyles within and among countries, however, entail a different starting point for each country to reach sustainable pathways. The EU is fully committed to delivering on the United Nations 2030 Agenda and its implementation. Inequality continues to be a significant concern, reflected in the UN's Sustainable Development Goals. In this context, we explore the relationships between household consumption patterns in the EU, income inequality, and global carbon emissions trends, using an environmentally extended multiregional and multisectoral input-output model. We study the trends in global carbon emissions associated with the different household consumption patterns and income categories over 15 years, and evaluate the role of income distribution, consumption patterns, and technological conditions by country and income group. Additionally, we study, through certain scenarios, the potential achievement of double dividends, by alleviating poverty and reducing emissions.

1. Introduction

The growing awareness of the current and future consequences of climate change has led to a range of international commitments aimed at ensuring sustainable development, such as the United Nations Framework Convention on Climate Change (UNFCCC, 2015), and especially the Paris Agreement (PA). Specifically, the UNFCCC adopted a set of goals to end poverty, protect the planet, and ensure prosperity for all as part of a new sustainable development agenda. This agenda includes 17 goals of sustainable development, such as reducing inequality and poverty, responsible consumption and production, and climate action, among others. These goals must be inter-compatible and coincide with other deals established in the Paris Agreement (UNFCCC, 2016), which sets out a global action plan to put the world on track to avoiding dangerous climate change by limiting global warming to well below 2 °C.

In this context, the European Union (EU) has emerged as a crucial international agent in the fight against climate change. In fact, the European Commission has given this battle top priority, with the aim of achieving carbon neutrality in the EU by 2050. Additionally, reducing inequality is established as one of the UN's Sustainable Development Goals (SDG) by 2030, to achieve sustainable economic growth (Filauro, 2018), which is also part of the Paris Agreement to achieve environmental goals in a context of poverty reduction.

The EU Member States play a central role in implementing and coordinating policies for achieving sustainable development. In this transition, as acknowledged by the EEA (2012), there is a need to look beyond isolated efficiency improvements and instead address the production-consumption systems that fulfil societal functions. In other words, there is a need to put our production, distribution, and consumption patterns on a sustainable path (EC, 2019).

More specifically, EC (2019) notes that, although notable progress has been made towards ensuring sustainable consumption and production patterns (SDG12 objective), the global ranking of the EU-27 Member States has the second lowest average score in the UN's SDG. It is recognized that, despite positive progress and scores on SDG 1 (End poverty) and SDG 10 (Reduce inequality within and among countries), notable differences between the Member States persist. Moreover,

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European households present some of the most pollutant lifestyles (Ivanova et al., 2017). On a per-capita basis, global emissions therefore need to go down to 2.5–3.3 tCO2 per capita by 2030 or less (Girod et al., 2014; Ivanova et al., 2016).

Given the importance of household consumption in final demand, which is equivalent to 60% of greenhouse gas embodied emissions, worldwide and between 50% and 80% of global resource use (Hardadi et al., 2021), several studies have focused on the so-called carbon footprint of households and the dynamics of emissions in different economies, adopting a consumption-based approach that links final demand to the production needed to satisfy this demand throughout the whole supply chain (see, among others, Turner et al., 2007, Lenzen et al., 2007 and Minx et al., 2009). Under this approach, consumption patterns and lifestyles in each country drive atmospheric emissions embodied in the whole production chain. These are key elements of climate policy, as changes in demand at both national and international levels contribute to reduce emissions (Heerink et al., 2001; Minx et al., 2009; Duarte et al., 2012; Ivanova et al., 2017; Wiebe et al., 2018; Joyce et al., 2019).

One important and less well-studied issue is the role of household income and income inequality and their relationships with household environmental footprints (see, among others Hertwich and Peters, 2009 and Davis and Caldeira, 2010). Filauro (2018) claims that disparities in income distribution and lifestyles among and within countries, as well as differences in production technologies, entail a different starting point for each country to reach their objectives.

The carbon implications of income inequality in households lead to both indirect and direct emissions rising when income increases (Golley and Meng, 2012; Dai et al., 2012; Duarte et al., 2016; Sommer and Kratena, 2017). Overall, countries with high income consume more, although this consumption can be less intensive in CO_2 emissions (Kopidou and Diakoulaki, 2017). Understanding how the households in countries at different levels of development change their consumption patterns while income goes up along with their environmental impacts, is important (Bjelle et al., 2021).

Prior studies show that economic inequality provokes energy consumption inequality. Hubacek (2017) found that the top 10% of income earners in the world were responsible for 36% of global carbon emissions, while the poorest 12% of the global population contributed only 4% of global emissions. Fremstad and Paul (2019) also showed that wealthier households in the US economy pollute 5.5 times more than poorer households, with these differences being explained by the scale factor and consumption patterns. For the EU, Ivanova and Wood (2020) show that the top 10% of the population with the highest carbon footprint per capita represent 27% of the EU carbon footprint, which is a bigger contribution than 50% of the poorest population. This can be explained because households with differential purchasing power make differential use of goods and services (Oswald et al., 2020). However, the discussion of the effects of income inequality on emissions is still unresolved.

On the one hand, several studies confirm that a more equitable income distribution leads to decreasing environmental impacts (Qu and Zhang, 2011; Knight et al., 2017; Chen et al., 2020). Zhang and Zhao (2014) found this for the case of China, Baek and Gweisah (2013) for the U.S, and the relationship was also found in Sub-Saharan Africa, by Baloch et al. (2020). In this context, prior findings also show that a more equitable income distribution, in the long term, will allow investment in the improvement of environmental quality (Wiedenhofer et al., 2013; Liu et al., 2019), with the exceptional countries being those with good economic conditions (Wu and Xie, 2020). However, in the short and medium term, Heerink et al. (2001) claim that there is a trade-off between environmental conservation and income equality.

On the other hand, there is discussion throughout the literature that high income inequality can improve environmental impacts. Borghesi (2000), using the Gini Index, showed that in the poorest countries, inequality could contribute to pollution decline. This result is in line with Grunewald et al. (2017), who claim that the effect of income inequality on pollution depends on income level, with inequality in low- and middle-income countries reducing emissions. Also, Brännlund and Ghalwash (2008) found this same relationship between inequality and CO_2, SO_2, and nitrogen emissions in 1984, 1988, and 1996. However, Zhou and Li (2020) explain that this only holds when the inequality is relatively small.

Regarding the end of poverty, (Hubacek et al., 2017) also found that if extreme poverty were to be eliminated in China and India, carbon emissions would increase by 4% and 7%, respectively. Thus, large efforts would be required to reduce carbon emissions and poverty. López et al. (2020) also conclude that there is a difficulty in simultaneously achieving inequality reduction and a decrease of environmental impact; accomplishing that goal would require policies that modify the pattern of consumption to another, more sustainable process. In this context, understanding the relationships between income distribution, consumption patterns, and carbon-intensive lifestyles, it is necessary to evolve into a low-carbon society.

This paper builds on this literature and explores the trends in inequality in the carbon footprints of households in the EU27 + UK countries in a multiregional input-output framework, examining the role of income distribution, consumption patterns, and technological conditions. Moreover, via scenario analysis, we seek to shed light on measures and guidelines required for the compatibility of the aforementioned sustainable development goals. To the best of our knowledge, this is the first paper analysing this issue for EU countries within an MRIO framework.

To do this, we use an environmentally extended multiregional and multisectoral input-output model for the EU countries (EU27 + UK), plus the rest of the world. In particular, we assess the evolution of EU household consumption patterns by income category over recent decades (from 1999 to 2015)[1] and the associated global carbon emissions. We use structural decomposition analysis (SDA) to analyse the role of technology, as well as consumption patterns and the size and distribution of household income, by country and income group. Then, to identify the complementarities between the production and consumption perspectives, we focus on the formulation of different scenarios in the transition to a low-carbon society, entailing poverty alleviation, income redistribution, and changes in consumption patterns. Our research shows an emissions reduction associated with consumption in European countries in the last two decades. However, this reduction significantly comes from transformations in the production side, rather than changes in consumption patterns. In any case, these improvements are not unlimited, so exploring new possibilities on the consumption side is required.

Our findings indicate that cleaner technologies will prevent increases in emissions and, additionally, we suggest that there is room for compatibility between alleviating poverty and reducing emissions, through a proper formulation of economic policies to reduce inequality. Our outcomes also point out that a more equitable income distribution could contribute to reduce environmental impacts with cuts in emissions, although in all cases this will require changes in the productive technology of the economies.

Heterogeneity among countries and income groups is confirmed. Therefore, raising awareness of sustainable consumption becomes important in promoting the attention to consumption patterns, as well as scale factors.

The paper is organized as follows. Section 2 presents the methodology used, Section 3 describes the main results obtained, and our conclusions are set out in Section 4.

[1] This period is the latest that includes detailed information about household consumption obtained from Eurostat (2015a).

2. Methodology and data

As claimed in Turner et al. (2007) and Steen-Olsen et al. (2016), MRIO analysis is the most adequate tool to evaluate household consumption in environmental terms, as it makes explicit the relationship between the consumption and production sides. Our model is extended in two ways. First, the traditional economic model is environmentally extended with a vector of CO_2 emissions for productive sectors. Second, the final demand of households for all the European countries has been disaggregated into five groups, according to income quintiles, as is explained previously. We thus focus on the productive emissions associated with household consumption patterns.

Our starting point is the equilibrium equation in an MRIO framework with *m* countries and *n* industries

$$\mathbf{z} = \mathbf{Az} + \mathbf{y} \tag{1}$$

Let us denote by $\mathbf{z}$ the vector of gross production. We denote by $\mathbf{A} = (a_{ij}{}^{rs})$ the matrix of technical coefficients, whose representative element $a_{ij}{}^{rs}$ assigns the quantity of intermediate inputs *i* of country *r* needed to produce a unit of product *j* in country *s*. We denote as $\mathbf{Y} = (\mathbf{y}^{rs}) = (y_i{}^{rs})$ to the matrix (mxn)xm of total final demand, whose elements $y_i{}^{rs}$ show the demand of product *i* of country *r* to satisfy the final demand of country *s*, where $\mathbf{y}^{rs}$ is the vector nx1 of goods from *r* included in the final demand of *s*. We denominate $\mathbf{y} = (y_i^r) = \left(\sum_s y_i^{rs}\right)$ to the vector mxn of final world demand.

The equilibrium equation can be also expressed in terms of the well-known Leontief inverse, as follows:

$$\mathbf{z} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} = \mathbf{Ly} \tag{2}$$

The Leontief inverse allows us to link the production and the final demand categories (household consumption, public consumption, investment…), so we can evaluate for each final demand of a sector in a country, what is the total production in the world economy, that directly and indirectly satisfies it.

Let us consider a vector of direct CO_2 intensities, that is a vector of sectoral direct emissions per unit of production $\mathbf{c} = (c_i^r) = \left(C_i^r / z_i^r\right)$. We can obtain the associated *pollution values*, as $\boldsymbol{\lambda} = \mathbf{cL}$. The representative element in $\boldsymbol{\lambda} = \left(\lambda_j^s\right) = \left(\sum_{r,i} c_i^r \alpha_{ij}^{rs}\right)$ shows for each unit of final demand of product *j* in country *s* all the pollution generated in the economy, and directly and indirectly incorporated in the inputs needed to produce that unit of final demand. The term *pollution value* refers to the evaluation of all emissions directly and indirectly contained in each unit of final demand. Note that these pollution values synthetize the technological elements of the economies, capturing all CO_2 emissions produced elsewhere, and incorporated in the different steps of the production chains when producing each unit of final demand. In a second step, and with a focus on household consumption and its relationship to income, we split the household demand for each country into five groups, according to income quintiles.

Thus, using the extended MRIO we can obtain all the emissions generated worldwide, direct and embodied, to produce the final goods consumed by consumers in each country, by income category, as

$$\boldsymbol{\Omega}^s = \hat{\boldsymbol{\lambda}}\mathbf{H}^s = \hat{\boldsymbol{\lambda}}\mathbf{G}\hat{\mathbf{D}}\mathrm{T} \tag{3}$$

Denoting by $\mathbf{H}^s$the matrix of final consumption of households in country *s* by income categories, we can study this matrix as composed of three relevant factors:

-$\mathbf{G} = \left(G_i^{rh}\right) = \frac{H_i^{rh}}{\sum_{i,r} H_i^{rh}} = \frac{H_i^{rh}}{H^h}$ is the matrix representing each country and income category consumption patterns, referencing both domestic and imported products.

- $\hat{\mathbf{D}} = \left(\frac{H^h}{\sum_h H^h}\right)$ is a diagonal matrix capturing the distribution of consumption by income categories.

- $T = \sum_h H^h$ is the scale factor, representing the total household consumption expenditure of all households in the country.

Our research focuses on household consumption patterns in the EU countries and the associated world emissions through global value chains. In any case, in order to offer a better picture of the total emissions associated to household activity, we also calculate the household direct emissions from vehicle use and use of fuels at home.

In a second step, we are interested in explaining the role that changes in consumption patterns and income distribution have played in the observed evolution of global CO_2 emissions.[2] In order to examine this evolution, we employ a structural decomposition analysis (SDA). This technique allows us, in a growth-accounting vein, to decompose the changes observed in a variable into the contribution of changes in a group of driving forces that can act as accelerators or retardants (Dietzenbacher and Los, 1998). SDA analysis, unlike other techniques, takes into account both direct and indirect effects (Su and Ang, 2012). In addition, it differentiates between demand and technology effects (Cellura et al., 2012), and it is the most appropriate tool in final demand analysis (Cao et al., 2019). In our case, based on the equations above, we decompose the changes over time observed in global emissions associated with the final consumption of households, which are explained on the basis of the factors defined above. For each EU country *s*, we evaluate changes in these four components – technology (λ) consumption patterns (G), income distribution (D), and scale factors (T) over time, as described in the following equation:

$$\Delta\boldsymbol{\Omega}^s = \boldsymbol{\Omega}_1^s - \boldsymbol{\Omega}_0^s = \Delta\left(\hat{\boldsymbol{\lambda}}\mathbf{G}\hat{\mathbf{D}}\mathrm{T}\right) = \Delta\hat{\boldsymbol{\lambda}}\mathbf{G}\hat{\mathbf{D}}\mathrm{T} + \hat{\boldsymbol{\lambda}}\Delta\mathbf{G}\hat{\mathbf{D}}\mathrm{T} + \hat{\boldsymbol{\lambda}}\mathbf{G}\Delta\hat{\mathbf{D}}\mathrm{T} + \hat{\boldsymbol{\lambda}}\mathbf{G}\hat{\mathbf{D}}\Delta\mathrm{T} \tag{4}$$

In order to operationalize this decomposition avoiding residuals, we follow Dietzenbacher and Los (1998), who show that the average of the so-called polar solutions is a valid approximation to the average of the n! possible exact decompositions. In consequence:

$$\Delta\boldsymbol{\Omega}^s = \Delta\hat{\boldsymbol{\lambda}}\mathbf{G}_0\hat{\mathbf{D}}_0\mathrm{T}_0 + \hat{\boldsymbol{\lambda}}_1\Delta\mathbf{G}\hat{\mathbf{D}}_0\mathrm{T}_0 + \hat{\boldsymbol{\lambda}}_1\mathbf{G}_1\Delta\hat{\mathbf{D}}\mathrm{T}_0 + \hat{\boldsymbol{\lambda}}_1\mathbf{G}_1\hat{\mathbf{D}}_1\Delta\mathrm{T} = \mathbf{I_1} + \mathbf{P_1} + \mathbf{R_1} + \mathbf{T_1}$$

$$\Delta\boldsymbol{\Omega}^s = \Delta\hat{\boldsymbol{\lambda}}\mathbf{G}_1\hat{\mathbf{D}}_1\mathrm{T}_1 + \hat{\boldsymbol{\lambda}}_0\Delta\mathbf{G}\hat{\mathbf{D}}_1\mathrm{T}_1 + \hat{\boldsymbol{\lambda}}_0\mathbf{G}_0\Delta\hat{\mathbf{D}}\mathrm{T}_1 + \hat{\boldsymbol{\lambda}}_0\mathbf{G}_0\hat{\mathbf{D}}_0\Delta\mathrm{T} = \mathbf{I_2} + \mathbf{P_2} + \mathbf{R_2} + \mathbf{T_2}$$

$$\Delta\boldsymbol{\Omega}^s = \frac{(\mathbf{I_1} + \mathbf{I_2})}{\mathbf{2}} + \frac{(\mathbf{P_1} + \mathbf{P_2})}{\mathbf{2}} + \frac{(\mathbf{R_1} + \mathbf{R_2})}{\mathbf{2}} + \frac{(\mathbf{T_1} + \mathbf{T_2})}{\mathbf{2}} = \mathbf{I} + \mathbf{P} + \mathbf{R} + \mathbf{T} \tag{5}$$

By definition, the first component captures the effects on emissions of changes in technology (λ), while the second term refers to the contribution of changes in consumption patterns (G). The third component captures the contribution to total emissions of changes in income distribution (D), while the last factor accounts for the effect of consumption growth on the evolution of CO_2 emissions (T). The factors should be interpreted as contributions to the total change in $\boldsymbol{\Omega}$ or, in other words, the change in total emissions that would have happened

[2] According to European Commission (2015), carbon dioxide (CO_2) emissions represent around 80% of total CO_2 equivalent.

Table 1
Emissions, % change and sectoral decomposition of embodied EU27 + UK household emissions.

	CO_2 Emissions (Kt)				change 1999–2015	Decomposition			
	1999	%	2015	%		% Intensity	% Consumption Pattern	% Distributive	% Scale Factor
Products of agriculture, hunting and related services	77,474	*3.35*	57,528	*2.93*	**−25.75**	−28.00	−11.75	−0.12	14.12
Products of forestry, logging and related services	2937	*0.13*	2969	*0.15*	**1.07**	−61.69	41.98	0.18	20.59
Fish and other fishing products; aquaculture products;	7493	*0.32*	6652	*0.34*	**−11.22**	−17.11	−6.38	−0.48	12.76
Mining and quarrying	38,798	*1.68*	23,733	*1.21*	**−38.83**	−39.56	−23.40	−0.12	24.25
Food, beverages and tobacco products	234,421	*10.12*	174,204	*8.87*	**−25.69**	−33.66	−6.82	−0.54	15.32
Textiles, wearing apparel, leather and related products	125,241	*5.41*	89,345	*4.55*	**−28.66**	−47.73	8.34	0.21	10.51
Wood and of products of wood and cork, no furniture;	5254	*0.23*	4801	*0.24*	**−8.61**	−29.04	6.30	0.59	13.54
Paper and paper products, and printing	31,005	*1.34*	27,262	*1.39*	**−12.07**	−15.94	−9.45	−0.04	13.35
Coke and refined petroleum products	262,175	*11.32*	178,061	*9.07*	**−32.08**	−29.80	−13.80	0.00	11.52
Chemicals and chemical products	75,271	*3.25*	90,514	*4.61*	**20.25**	−8.66	13.39	0.10	15.43
Rubber and plastic products	12,105	*0.52*	12,167	*0.62*	**0.51**	−17.42	5.39	0.43	12.12
Other non-metallic mineral products	23,110	*1.00*	25,939	*1.32*	**12.24**	−7.59	3.00	0.51	16.33
Basic metals	6539	*0.28*	7831	*0.40*	**19.76**	−32.31	31.67	−0.10	20.50
Fabricated metal products, except machinery and equipment	17,248	*0.74*	13,709	*0.70*	**−20.52**	−40.57	7.93	0.20	11.92
Computer, electronic and optical products	16,220	*0.70*	46,518	*2.37*	**186.79**	−14.58	174.75	0.48	26.14
Electrical equipment	4577	*0.20*	9616	*0.49*	**110.10**	−17.25	105.56	0.42	21.37
Machinery and equipment n.e.c.	17,487	*0.76*	5109	*0.26*	**−70.79**	−6.97	−72.80	0.04	8.94
Motor vehicles, trailers and semi-trailers	76,821	*3.32*	61,600	*3.14*	**−19.81**	−18.41	−15.63	1.75	12.48
Other transport equipment	9604	*0.41*	9747	*0.50*	**1.49**	−32.93	20.37	1.60	12.45
Furniture and other manufactured goods	56,001	*2.42*	54,225	*2.76*	**−3.17**	−62.71	46.11	0.36	13.08
Electricity, gas, steam and air conditioning	440,844	*19.04*	367,978	*18.74*	**−16.53**	−33.51	4.26	−0.90	13.62
Natural water; water treatment and supply services	142,045	*6.13*	164,196	*8.36*	**15.59**	−28.25	20.79	0.08	22.98
Constructions and construction works	22,120	*0.96*	19,172	*0.98*	**−13.33**	−49.67	16.64	−0.03	19.72
Wholesale and retail trade	40,774	*1.76*	9866	*0.50*	**−75.80**	−67.38	−16.83	0.06	8.35
Land transport services and transport services via pipelines	53,976	*2.33*	33,954	*1.73*	**−37.09**	−42.14	−8.29	−0.13	13.46
Water transport services	68,074	*2.94*	61,515	*3.13*	**−9.64**	−12.29	−4.65	−0.02	7.33
Air transport services	98,009	*4.23*	108,623	*5.53*	**10.83**	−19.33	16.85	0.00	13.31
Warehousing and support services for transportation	24,193	*1.04*	18,296	*0.93*	**−24.37**	−29.95	−8.41	0.05	13.94
Post and Telecommunications	9861	*0.43*	18,146	*0.92*	**84.02**	−10.56	70.18	−0.12	24.53
Accommodation and food services	88,386	*3.82*	60,503	*3.08*	**−31.55**	−40.84	−1.72	0.03	10.98
Financial services, insurance and pension funding, services auxiliary	33,354	*1.44*	34,026	*1.73*	**2.01**	−23.18	9.52	0.25	15.42
Real estate services	95,250	*4.11*	73,745	*3.76*	**−22.58**	−46.96	−1.20	0.29	25.30
Renting of machinery, Computer and related activities	10,086	*0.44*	12,395	*0.63*	**22.89**	−30.43	35.27	0.37	17.68
Public administration and defence services, Education, Health	41,534	*1.79*	33,905	*1.73*	**−18.37**	−48.18	15.70	0.76	13.35
Other services	47,470	*2.05*	45,769	*2.33*	**−3.58**	−32.51	15.89	0.16	12.87
TOTAL	**2,315,756**	**100.00**	**1,963,617**	**100.00**	−15.21	**−32.45**	**2.86**	**−0.10**	**14.47**

Source: Authors' analysis. Note: Changes observed from 1999 to 2015 are decomposed in the intensity, consumption pattern, distributive, and scale factor effects, according to the SDA. The signs show their relationship to emissions - positive signs involve increases in emissions while negative signs represent falls in emissions.

(attributable to changes in the factor) all other things being constant.

Empirically, we use the EXIOBASE 3.0 database that provides a broad picture environmental pressures for 44 countries (28 EU members plus 16 major economies) and five rest-of-the-world regions. Each of them accounts for 163 industries and 200 commodities (see Koslowski et al., 2020, and Wood et al., 2020).[3] In order to analyse changes in consumption patterns and the associated impacts, we consider the years 1999 and 2015, a temporal span of more than 15 years, allowing us to perceive important changes. The MRIO table is extended to disaggregate household consumption into five income groups of households for each European country. In order to disaggregate the corresponding household consumption vector for each EU country, three information sources provided by Eurostat are used: the *consumption expenditure structure, by income quintiles* for the years studied (Eurostat, 2015a), as well as information on *distribution of income by quantiles* - EU-SILC and ECHP surveys of Eurostat, and *aggregate propensity to consume by income quintile*, with the information on income distribution by quintiles also provided by Eurostat.[4] Moreover, shares based on the bridge matrices by Cai and Vandyck (2020) for all EU countries have been used to match COICOP and CPA product shares in the household consumption vector

[3] The EXIOBASE database offers a high disaggregation of products and sectors, especially for the transport sectors, and distributes emissions across industries and consumers. As our goal is focused on the behaviour of households, this database meets our objectives. Additionally, we make use of product- and country-specific deflators obtained from WIOD, to avoid price volatility of consumption products.

[4] Note that we do not specifically depart from the individual microdata of Household Budget Surveys (HBS), but the associated Eurostat country summaries for consumption structures. Therefore, these statistics can be subject to evident under-reporting.

Table 2
Emissions and % change by country region and income level, and decomposition of household embodied emissions.

		CO_2 Emissions (Kt)				% change 1999–2015	% Intensity	% Consumption Pattern	% Distributive	% Scale Factor
		1999	%	2015	%					
	H1	353,626	*15.27*	260,119	*13.25*	**−26.44**	−29.74	−3.02	−7.30	13.62
	H2	391,258	*16.90*	320,760	*16.34*	**−18.02**	−32.14	0.91	−1.43	14.64
	H3	437,177	*18.88*	374,067	*19.05*	**−14.44**	−32.61	2.91	0.76	14.51
	H4	493,145	*21.30*	426,264	*21.71*	**−13.56**	−32.83	4.08	0.64	14.54
EU27+ UK total	H5	640,551	*27.66*	582,408	*29.66*	**−9.08**	−33.72	6.34	3.55	14.76
	TOTAL	**2,315,756**		**1,963,617**		**−15.21**	**−32.45**	**2.86**	**−0.10**	**14.47**
	H1	19,871	*15.31*	14,625	*15.01*	**−26.40**	−48.18	−8.19	−1.41	31.38
	H2	23,483	*18.09*	17,444	*17.90*	**−25.72**	−48.53	−9.62	−0.13	32.57
	H3	25,853	*19.92*	19,035	*19.54*	**−26.37**	−47.75	−10.79	0.62	31.55
	H4	27,395	*21.11*	20,764	*21.31*	**−24.20**	−48.23	−7.74	−0.04	31.81
Central Europe	H5	33,190	*25.57*	25,570	*26.24*	**−22.96**	−48.26	−6.04	0.36	30.98
	TOTAL	**129,793**	***5.60***	**97,438**	***4.96***	**−24.93**	**−48.19**	**−8.32**	**−0.03**	**31.62**
	H1	15,682	*15.23*	13,434	*14.32*	**−14.34**	−28.71	2.51	−6.94	18.80
	H2	18,532	*18.00*	16,351	*17.43*	**−11.77**	−30.46	3.96	−4.28	19.02
	H3	20,197	*19.62*	18,166	*19.36*	**−10.06**	−31.41	2.52	−0.27	19.11
	H4	21,846	*21.22*	20,118	*21.44*	**−7.91**	−32.08	3.34	1.20	19.62
Nordic countries	H5	26,686	*25.92*	25,753	*27.45*	**−3.50**	−33.08	2.59	6.62	20.37
	TOTAL	**102,943**	***4.45***	**93,822**	***4.78***	**−8.86**	**−31.40**	**2.97**	**0.09**	**19.48**
	H1	211,669	*16.56*	144,304	*13.22*	**−31.83**	−26.38	−7.23	−9.15	10.93
	H2	215,425	*16.85*	172,432	*15.80*	**−19.96**	−29.16	0.30	−2.97	11.87
	H3	237,033	*18.54*	205,425	*18.82*	**−13.33**	−30.46	4.34	0.47	12.31
	H4	267,294	*20.91*	238,051	*21.81*	**−10.94**	−31.20	6.72	0.83	12.71
Atlantic countries	H5	347,151	*27.15*	331,452	*30.36*	**−4.52**	−32.30	9.09	5.64	13.05
	TOTAL	**1,278,573**	***55.21***	**1,091,665**	***55.59***	**−14.62**	**−30.22**	**3.53**	**−0.22**	**12.29**
	H1	30,481	*11.68*	33,374	*14.41*	**9.49**	−63.84	16.90	12.07	44.36
	H2	43,956	*16.85*	40,746	*17.59*	**−7.30**	−57.47	8.57	3.02	38.58
	H3	50,153	*19.22*	44,880	*19.37*	**−10.51**	−55.73	7.53	1.55	36.14
	H4	56,553	*21.68*	48,395	*20.89*	**−14.43**	−54.67	5.81	−0.87	35.30
Eastern Europe	H5	79,730	*30.56*	64,252	*27.74*	**−19.41**	−53.29	5.02	−5.08	33.93
	TOTAL	**260,872**	***11.27***	**231,647**	***11.80***	**−11.20**	**−55.99**	**7.66**	**0.48**	**36.65**
	H1	75,923	*13.97*	54,382	*12.11*	**−28.37**	−20.82	0.94	−11.57	3.07
	H2	89,861	*16.53*	73,785	*16.43*	**−17.89**	−22.95	0.75	0.34	3.96
	H3	103,941	*19.12*	86,562	*19.28*	**−16.72**	−22.83	0.89	1.28	3.94
Mediterranean countries	H4	120,057	*22.09*	98,935	*22.03*	**−17.59**	−22.79	0.23	0.98	3.98
	H5	153,794	*28.29*	135,381	*30.15*	**−11.97**	−23.75	4.12	3.45	4.21
	TOTAL	**543,576**	**23.47**	**449,045**	**22.87**	**−17.39**	**−22.82**	**1.64**	**−0.12**	**3.91**

Source: Authors' analysis. Note: Country regions: Central Europe (Austria, Czech Republic, Hungary, Slovakia) Nordic Countries (Denmark, Finland, Sweden), Atlantic Countries (Belgium, France, Germany, Ireland, Luxembourg, Netherlands, United Kingdom), Eastern Europe (Bulgaria, Estonia, Latvia, Lithuania, Poland, Romania), Mediterranean Countries (Croatia, Cyprus, Greece, Italy, Malta, Portugal, Slovenia, Spain). Income groups: H1: low-income, H2: middle-low-income, H3: middle-income; H4: middle-high income, H5: high-income.

by country. A final RAS adjustment is used to achieve full consistency between the EXIOBASE household consumption vectors by sector, and the associated shares by income quintiles and CPA classifications. A final disaggregation level of 36 sectors, for the structure of consumption obtained from Eurostat and for the MRIO data obtained from EXIOBASE, is considered. Finally, we apply product- and country-specific deflators obtained from WIOD (Timmer et al., 2015), adapting the database released in July of 2014 to November of 2016.[5]

3. Results

We first analyse the environmental impacts of EU27 + UK consumption patterns, regarding the relationship between the changes observed in household demands, income distribution, consumption patterns, and technological conditions. Then, alternative scenarios are formulated to evaluate the role of these elements in the definition of paths to low-carbon economies and the compatibility of objectives to alleviate poverty and reduce inequality, along with reducing emissions. An analysis of consumption patterns by country and sector from 1999 to 2015 is summarized in the Supplementary Information (SI) (Table SI1 and Figure SI1). The outcome shows that inequality in consumption patterns within income groups in the EU27 + UK seems to be advancing, slowly, towards more equal patterns in food sectors, electricity, construction, and the remaining industry and services sectors. More interestingly, the share of consumption in most sectors of high-income groups is even greater in 2015 than in 1999, while low-income groups reduce their shares, increasing differences among the extreme income groups.

3.1. Environmental impacts of EU27 + UK consumption patterns

Household emissions play a significant role in embodied emissions, constituting more than half of embodied emissions associated with final demand, in both 1999 and 2015, and being the most polluting component of final demand (see Table SI2 of the SI). The relevance of emissions associated to households through the global supply chain is commonly found in the literature, where household emissions are the most important final demand category, followed by investment emissions (Palm et al., 2019). As the main household emissions are embodied, with a small share of household direct emissions, we now focus on the analysis of household embodied emissions. Table 1 displays sectoral

[5] For all countries, we have used the deflators of the corresponding year. However, due to the lack of data for Croatia, for 1999 we used deflators for the year 2000.

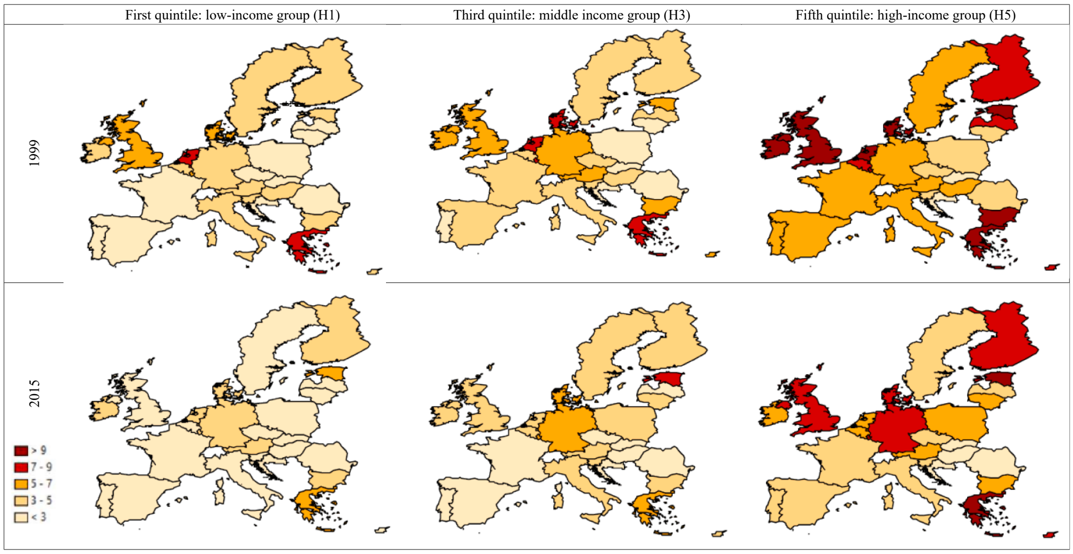

Fig. 1. Per capita household embodied emissions by income level in 1999 and 2015 (t per capita). (Source: Authors' analysis.)

results of emissions embodied in household consumption, the changes between 1999 and 2015, and the results of the SDA addressed.[6] For the whole of the EU27 + UK, a first remarkable feature is a 15.21% fall in CO_2 embodied emissions in household consumption. In both 1999 and 2015, the largest carbon embodied emissions associated with the EU27 + UK consumption correspond to *"Electricity, gas, steam, and air conditioning", "Coke and refined petroleum products", and "Food, beverages, and tobacco products"*. Despite that these sectors show significant declines in their emissions from 1999 (for example, there is a reduction of 16.53% in "*Electricity, gas, steam, and air conditioning*"), they are still the most polluting sectors in 2015.

When we decompose these changes in emissions, the total fall in embodied emissions in EU27 + UK household consumption is driven by a decline in the intensity effect in all sectors. Thus, technological and structural changes in the supply chains providing EU27 + UK products, as well as reductions in direct emissions intensities, have been the main driving force in reducing emissions during this period, in line with the prior literature (see among others Zhao et al., 2010; Su and Ang, 2012; Zhu et al., 2012; Das and Paul, 2014). The opposite is found in the scale effect. Thus, for the whole period, the increase in household consumption from 1999 to 2015, other factors held constant, has acted as an accelerator for increasing emissions. To a lesser extent, changes in consumption patterns over the period triggered larger emissions for the whole economy. In most sectors, the distributive effect by income level has some responsibility for the increase in emissions, as happens with the consumption pattern in most industrial sectors. However, consumption patterns also helped to reduce emissions in some important sectors, such as "*Coke and refined petroleum products", and "Food, beverages, and tobacco products"*, for the EU27 + UK.

Reading by groups of countries and household income level, Table 2 presents changes in emissions by income group. Detailed results by country are shown in Table SI3 of the SI. First, as expected, for the whole of EU27 + UK, the consumption of the high-income groups involves larger emissions than that of the low-income groups (see also Fig. 3 below). Second, the largest relative decline in emissions is attributed to the low-income groups. Moreover, as income increases, declines in emissions are lower. These falls in emissions are achieved thanks to improvements in technology, which contribute to prevent increases in the emissions provoked by the growth of the economy, and the consumption patterns for all income groups. Thus, technological improvements have been the main driver in reducing emissions, while scale factors and consumption pattern effects have contributed to increase emissions. These findings are not observed in Eastern Europe, which presents increases in emissions for the low-income group and, as income increases, declines in emissions are greater. However, the contribution of consumption pattern effects differs in some groups of countries, such as Central Europe and the Atlantic countries, and for low-income groups, all with a positive effect on the environment. More interestingly, the responsibility of the distributive effect also differs by income group. At the extreme intervals of low-income, this effect contributes to reduce emissions, while in middle and middle-high income groups it provokes the opposite effect, with the exception of high-income groups in the Atlantic countries, the Mediterranean countries and Central Europe.

Our findings also reveal peculiarities by country (see detailed results in Table SI3 of the SI). The largest cuts in emissions are not always associated with low-income groups (with the exception also of Eastern countries) but are larger in high-income groups in countries such as Belgium, Ireland, and France, due to the distributive effect in these countries.

Regarding the largest and smallest changes in emissions by group of countries, we see that the largest percentage in emissions reduction linked to consumption correspond to Central Europe, while the smallest percentage falls in emissions are observed in Nordic countries, as these countries represent the smallest percentage of emissions of the EU27 + UK (4.78%). The Atlantic countries represent half of the emissions within the EU27 + UK, followed by Mediterranean countries.

Despite these reductions in emissions in all the areas, significant efforts to reduce emissions are still required in all the EU27 + UK countries. This battle should be primarily led by those households with greater incomes, not forgetting that all income groups should modify their behaviour. Additionally, we should note the peculiarities of each country and their relationships between income distribution and carbon intensive lifestyles, as the impact can differ substantially from one country to another. More interestingly, technological improvements are essential to offset economic growth, while the role of consumption patterns and distributive effects is not negligible, especially in high income groups. Actions to modify such impacts could achieve reductions in household embodied emissions.

Fig. 1 shows per capita household embodied emissions by country in

[6] Note that we study the consumption patterns associated with the different income levels by quintiles, which are mediated by the propensity to consume corresponding to each income group. In this regard, potential emissions associated to the non-directly consumed income (*household savings*) are not considered in the analysis.

Table 3
Emissions (Kt) and changes in emissions (percentage change) by countries compared to emissions in 2015 in all scenarios.

	Scenario 1			Scenario 2			Scenario 3a			Scenario 3b		
	Total Kt	%	% Change	Total Kt	%	% Change	Total Kt	%	% Change	Total Kt	%	% Change
Austria	36,515	1.80	*0.64*	35,172	1.81	*−2.30*	34,441	1.84	*−4.33*	34,441	1.84	*−4.33*
Belgium	47,041	2.32	*2.53*	45,602	2.35	*1.37*	44,145	2.36	*−1.86*	44,145	2.36	*−1.86*
Bulgaria	30,155	1.49	*1.55*	28,966	1.49	*0.03*	29,360	1.57	*1.39*	28,958	1.55	*0.00*
Croatia	6900	0.34	*1.61*	6619	0.34	*−0.88*	7048	0.38	*5.53*	6678	0.36	*0.00*
Cyprus	5862	0.29	*−20.62*	5703	0.29	*0.72*	5147	0.28	*−9.10*	5147	0.28	*−9.10*
Czech Republic	31,658	1.56	*−29.71*	30,616	1.58	*0.66*	29,759	1.59	*−2.16*	29,759	1.59	*−2.16*
Denmark	31,988	1.58	*5.66*	30,191	1.56	*−2.61*	30,834	1.65	*−0.53*	30,834	1.65	*−0.53*
Estonia	9820	0.49	*4.17*	9471	0.49	*−1.21*	9229	0.49	*−3.74*	9229	0.49	*−3.74*
Finland	27,914	1.38	*−15.44*	26,789	1.38	*−0.66*	25,535	1.37	*−5.31*	25,535	1.37	*−5.31*
France	184,403	9.11	*3.80*	179,525	9.25	*−0.53*	161,809	8.65	*−10.35*	161,809	8.66	*−10.35*
Germany	441,281	21.80	*3.27*	422,569	21.78	*−1.54*	410,102	21.93	*−4.45*	410,102	21.95	*−4.45*
Greece	80,850	3.99	*4.78*	76,786	3.96	*−3.57*	72,139	3.86	*−9.41*	72,139	3.86	*−9.41*
Hungary	17,620	0.87	*−0.62*	16,852	0.87	*−1.05*	16,417	0.88	*−3.61*	16,417	0.88	*−3.61*
Ireland	18,873	0.93	*−14.03*	18,268	0.94	*−1.31*	17,309	0.93	*−6.50*	17,309	0.93	*−6.50*
Italy	209,526	10.35	*1.63*	199,760	10.29	*−0.12*	198,134	10.59	*−0.93*	198,134	10.61	*−0.93*
Latvia	5160	0.25	*2.95*	4953	0.26	*0.48*	4714	0.25	*−4.36*	4714	0.25	*−4.36*
Lithuania	11,082	0.55	*12.50*	10,625	0.55	*−0.92*	10,000	0.53	*−6.75*	10,000	0.54	*−6.75*
Luxembourg	3834	0.19	*1.23*	3702	0.19	*−1.87*	3674	0.20	*−2.61*	3674	0.20	*−2.61*
Malta	1783	0.09	*3.73*	1715	0.09	*−0.31*	1749	0.09	*1.65*	1720	0.09	*0.00*
Netherlands	85,567	4.23	*3.22*	82,895	4.27	*−2.57*	82,060	4.39	*−3.55*	82,060	4.39	*−3.55*
Poland	151,126	7.47	*4.53*	144,267	7.43	*−2.28*	140,555	7.51	*−4.80*	140,555	7.52	*−4.80*
Portugal	27,955	1.38	*3.82*	26,808	1.38	*0.04*	24,050	1.29	*−10.25*	24,050	1.29	*−10.25*
Romania	31,676	1.56	*0.28*	30,080	1.55	*0.90*	30,542	1.63	*2.45*	29,812	1.60	*0.00*
Slovakia	14,465	0.71	*4.28*	13,861	0.71	*−0.94*	14,557	0.78	*4.04*	13,992	0.75	*0.00*
Slovenia	6963	0.34	*0.30*	6707	0.35	*−2.04*	6576	0.35	*−3.95*	6576	0.35	*−3.95*
Spain	128,610	6.35	*10.42*	122,538	6.31	*0.67*	117,965	6.31	*−3.08*	117,965	6.31	*−3.08*
Sweden	36,837	1.82	*5.68*	35,416	1.83	*−1.22*	34,459	1.84	*−3.89*	34,459	1.84	*−3.89*
United Kingdom	338,794	16.74	*0.20*	324,101	16.70	*−1.68*	308,028	16.47	*−6.56*	308,028	16.49	*−6.56*
EU 27	**1,685,464**	***83.26***	***3.15***	**1,616,457**	***83.30***	***−1.07***	**1,562,309**	***83.53***	***−4.39***	**1,560,214**	***83.51***	***−4.51***
EU 27 + UK	**2,024,258**	***100.00***	***3.09***	**1,940,558**	***100.00***	***−1.17***	**1,870,336**	***100.00***	***−4.75***	**1,868,241**	***100.00***	***−4.86***

Source:Authors' analysis.

both 1999 and 2015, by income groups. Detailed results by country are shown in Table SI4 of the SI. A slight reduction in per capita household embodied emissions is observed from 1999 to 2015 in most countries. All the income groups present, in 1999, an average value above that of the EU27 + UK average in 2015. Per-capita emissions in Greece, Luxembourg, Denmark, Ireland, the Netherlands, and the UK were significantly above the average levels in 1999, and despite that they reduced their emissions in 2015, they remain over the EU27 + UK average, and even with increases in population in the UK, Greece, and Denmark. The largest reductions in emissions in these countries are in the low-income groups, while the smallest decreases appear in middle and high-middle income groups (except Ireland). Greece is the country with the largest per capita household emissions (despite a 20.53% decline in per capita emissions). The lowest per capita emissions are found in Croatia, Slovakia, and Romania, who represent low percentages of population in the EU27 + UK.

Thus, the Atlantic countries - the UK, the Netherlands, Germany, and Luxembourg present large per-capita household emissions, in both 1999 and 2015, although they have slightly reduced their emissions in the low-income group especially. Central countries show the greatest reductions in emissions, mainly in the middle- and low-income groups, followed by Mediterranean countries, who exhibit a reduction of 23.54% in their per capita emissions between 1999 and 2015.

The analysis of emissions per capita cannot be dissociated from the evolution of total household emissions (Figure SI2 in the SI). Large economies, such as Germany and the UK, present notable cuts in emissions from 1999 to 2015 linked to households. They are the most polluting countries, whose total emissions represent a larger share in the EU27 + UK than their shares of population (see Table SI4 of the SI). Other large economies with large shares of total household embodied emissions are France, Italy, Spain, and Poland, for all income groups. The Nordic countries are the least polluting, together with countries in Central Europe and Eastern Europe. The former results for Eastern Europe are in line with results obtained in Moutinho et al. (2015) and recently in Duarte and Serrano (2021). A similar result is found in de Araújo et al. (2020), who show that New European Union members (most of them, Eastern countries) present emissions reductions during the period from the 1990s to the 2000s. This reduction could be caused by the intensity effect, as our results indicate. However, this intensity effect has not been enough to beat the demand and consumption pattern effects for the low-income group.

In summary, the Atlantic countries stand out because of their population (48.44% of the EU27 + UK), total household embodied emissions (55.59% of the EU27 + UK) and per capita emissions. Mediterranean countries, which are the second most populated region (26.73% of the EU27 + UK), present lower values of per capita emissions despite that they contribute 22.87% of the total household embodied emissions. In these two regions, the largest cuts in emissions are generated in the lowest income groups. The Nordics present the lowest household embodied emissions, although their per capita emissions are above the EU27 + UK average. Their largest declines in emissions are observed in the low and middle-low income groups. Countries in Eastern Europe also decrease their emissions over the period studied.

3.2. *Scenario analysis*

3.2.1. *Description of scenarios*

Once the main features of CO_2 emissions linked to EU27 + UK household patterns, and the evolution over time, have been analysed, we examine how different scenarios on the demand side can contribute to reduced emissions. More specifically, we now formulate different scenarios to analyse the compatibility of the objectives to reduce emissions, alleviate poverty, and reduce inequality in the EU27 + UK countries. The following scenarios are designed to take into account consumption patterns and marginal propensity to consume in the different groups and countries.[7]

-**Scenario 1**: This scenario analyses the environmental effects of alleviating poverty by ***increasing*** income of those at the risk-of-poverty threshold, following the estimations in Eurostat (2015b), set at 60% of the national median equivalent disposable income. This involves raising income in all countries in the low-income group (H1) to the middle-low income group (H2). The marginal propensity and consumption pattern are assumed to change after the increase in income, following the EU27 + UK aggregate propensity to consume by income quintile, from Eurostat (2015c).

- Scenario 2: This scenario alleviates the environmental effects of increasing income by a ***redistribution*** of per capita disposable income from the high-income group (H5) to the low-income group (H1), in the same quantity as in Scenario 1, for all countries. Again, we assume that after this redistribution, marginal propensity to consume changes. Note that Scenarios 1 and 2 are thus not identical.

-**Scenario 3**: This scenario examines the effects of a convergence in the EU27 + UK consumption patterns. We seek to simulate the effects of modifying consumer behaviours after potential changes for instance in environmental awareness, education, and policy measures. We evaluate two strategies. To simplify, in a first Scenario 3a, we assume that all income groups adopt the consumption pattern of the middle-income group (H3). Then, in a second Scenario 3b, we implement an average consumption pattern of all income groups for those countries where this middle-income group is more polluting than the average.[8]

3.2.2. Results of scenarios

Table 3 presents the results of the different scenarios, in comparison with emissions in 2015. Table 4 displays sectoral details of these scenarios. Fig. 2 also shows changes in per-capita emissions between countries and scenarios, which can be compared with the baseline situation shown in Fig. 1.

As we can see, alleviating poverty in all EU countries increases emissions by 3.09% in the EU27 + UK (Scenario 1), as expected. By country, the largest increases take place in Lithuania (12.50%), Spain (10.42%), Sweden (5.68%), and Denmark (5.66%). The increase in income of those at risk of poverty leads to increased emissions from the polluting sectors, such as "*Wholesale and retail trade", "Machinery and equipment n.e.c.*" and "*Motor vehicles, trailers and semi-trailers*" (Table 4), with more polluting consumption patterns. We can observe an increase in all of the transport sectors. However, other countries with low shares of emissions, such as Czech Republic and Cyprus, reduce their emissions. This is because these countries present, to a certain extent, a less emission-intensive consumption pattern in the low-middle income group, in addition to the reduction in the marginal propensity to consume. Thus, complementary measures to boost sustainable consumption patterns, such as the use of public transport, would be required.

Reducing inequality and poverty through a redistribution of per-capita disposable income from the high-income group to the low-income group (Scenario 2) leads to reduced emissions associated to the EU27 + UK (1.17%). This scenario would suggest the possibility of achieving a double dividend by reducing emissions and poverty. Most countries present declines in emissions, with the largest ones being Greece (3.57%), Denmark (2.61%), Netherlands (2.57%), Austria (2.30%) and Poland (2.28%) thanks to declines from the income redistribution with reductions in the high-income groups (see Fig. 2). Falls in emissions from *Food* sectors, "*Electricity, gas, steam and air conditioning*"

Table 4
Percentage changes in emissions by sectors.

	Scenario 1	Scenario 2	Scenario 3a	Scenario 3b
Products of agriculture, hunting and related services	3.37	−1.01	−1.01	−1.24
Products of forestry, logging and related services	3.63	−1.10	−1.50	−2.04
Fish and other fishing products; aquaculture products; support services to fishing	3.75	−0.86	0.34	0.28
Mining and quarrying	3.43	−1.13	−1.42	−1.86
Food, beverages and tobacco products	2.46	−1.72	0.51	0.19
Textiles, wearing apparel, leather and related products	4.27	−0.07	−8.50	−8.44
Wood and of products of wood and cork, except furniture	4.61	0.09	−5.54	−5.56
Paper and paper products, and printing	3.67	−0.78	−5.35	−5.33
Coke and refined petroleum products	4.86	−0.01	−3.30	−3.15
Chemicals and chemical products	4.08	−0.57	−1.83	−1.97
Rubber and plastic products	4.76	0.16	−5.98	−5.91
Other non-metallic mineral products	4.36	0.00	−7.45	−7.40
Basic metals	3.51	−1.00	−4.97	−5.02
Fabricated metal products, except machinery and equipment	4.62	−0.06	−2.41	−2.33
Computer, electronic and optical products	3.61	−0.56	−6.17	−6.24
Electrical equipment	5.02	0.22	2.00	1.98
Machinery and equipment n.e.c.	5.15	0.30	1.67	2.10
Motor vehicles, trailers and semi-trailers	5.04	0.90	−21.56	−21.15
Other transport equipment	4.97	0.83	−18.92	−18.79
Furniture and other manufactured goods	4.39	−0.16	−5.98	−5.96
Electricity, gas, steam and air conditioning	1.50	−2.52	0.22	−0.24
Natural water; water treatment and supply services	3.46	−1.45	−0.54	−0.84
Constructions and construction works	4.33	0.09	−8.30	−7.91
Wholesale and retail trade	6.19	0.88	0.71	−1.36
Land transport services and transport services via pipelines	1.37	−1.90	−15.15	−15.10
Water transport services	1.65	−2.20	−13.94	−13.92
Air transport services	2.17	−1.29	−15.21	−15.19
Warehousing and support services for transportation	4.53	0.10	−4.55	−4.33
Post and Telecommunications	3.54	−1.09	−1.29	−1.33
Accommodation and food services	0.00	0.00	0.00	−10.43
Financial services, insurance and pension funding, services auxiliary	4.51	−0.18	−4.29	−4.09
Real estate services	0.42	−3.24	−3.20	−3.25
Renting of machinery, Computer and related activities,Research and development	4.03	−0.18	−7.53	−6.98
Public administration and defence services, Education, Health and Social work	3.03	−0.53	−14.44	−14.16
Other services	4.06	−0.38	−6.49	−6.38
Total	**3.09**	**−1.17**	**−4.75**	**−4.86**

[7] Note that, until now, we have focused on household consumption by income level. However, in order to formulate scenarios affecting income and income distribution, household consumption cannot be considered as equivalent to disposable income, as consumption in the different income groups depends on marginal propensity to consume.

[8] This is applied in Bulgaria, Croatia, Malta, Romania and Slovakia.

Source: Authors' analysis.

and *Transport* sectors are the most relevant in most countries (Table 4). However, small increases in emissions are observed in small countries, like Cyprus (0.72%) and Latvia (0.48%), and others like Belgium (1.37%) and Spain (0.67%), where high-middle income groups could lead to even more polluting consumption patterns. In this way, the results offer some initial insights where the objectives of reducing inequality and poverty could be compatible with reducing emissions associated to that consumption. Moreover, a proper formulation of income redistribution by country, and measures to boost sustainable consumption patterns, could achieve much larger declines in emissions.

Finally, a convergence in the EU27 + UK consumption pattern, as simulated in Scenario 3a, involves a redistribution of emissions among countries, pointing to a decrease in emissions in the EU27 + UK (4.75%) and in the EU27 (4.39%) if the convergence in consumption patterns is implemented, and even a higher reduction considering the peculiarities of the countries (Scenario 3b). The largest declines in emissions are found in France, Portugal, and Greece, mainly due to cuts in emissions from high income groups, who adopt a less polluting consumption pattern in this scenario (see Fig. 2). However, we observe increases in emissions in countries like Croatia, Slovakia, and Romania. The consumption pattern in these countries in the middle-income group is more polluting than an average consumption pattern of all income groups.

As noted previously, the EU27 + UK includes countries with different characteristics, levels of income inequality, wealth disparity, and consumption patterns. Thus, if we assume an average consumption pattern in these countries (Scenario 3b), this convergence in consumption patterns could lead to reductions in emissions. Specific policies towards more sustainable consumption patterns by meeting the singularities of each country could achieve reductions in emissions, thereby achieving larger declines in emissions from the change in high-income groups, and larger falls from low-income groups. Moreover, this strategy would be complementary with the previous redistribution of income studied in Scenario 2.

This convergence in consumption patterns could lead to increased emissions in Scenario 3a, mainly from the consumption of "*Electrical equipment*", "*Machinery and equipment*" and "*Wholesale and retail trade*", which are important sectors associated with the consumption of the middle-income group, and reduced embodied emissions in the

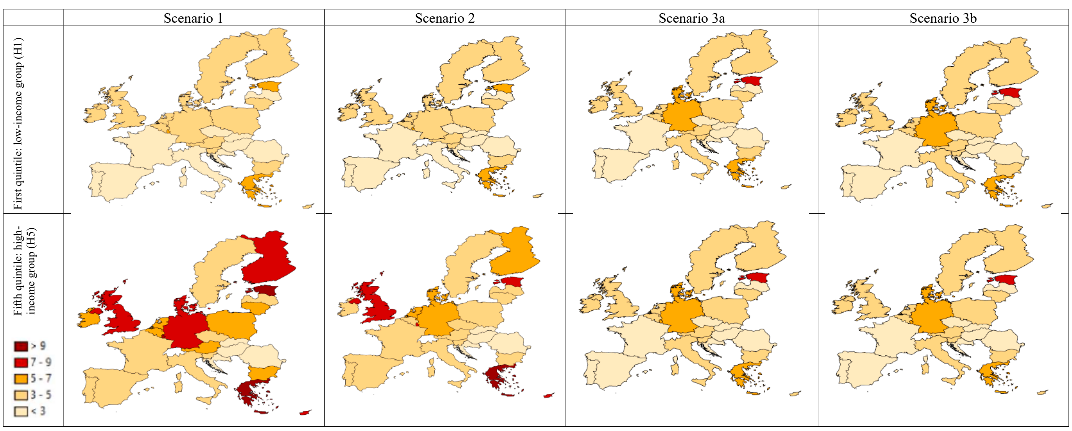

Fig. 2. Per capita household embodied emissions by income level in Scenarios 1, 2 and 3 (t per capita). (Source: Authors' analysis)

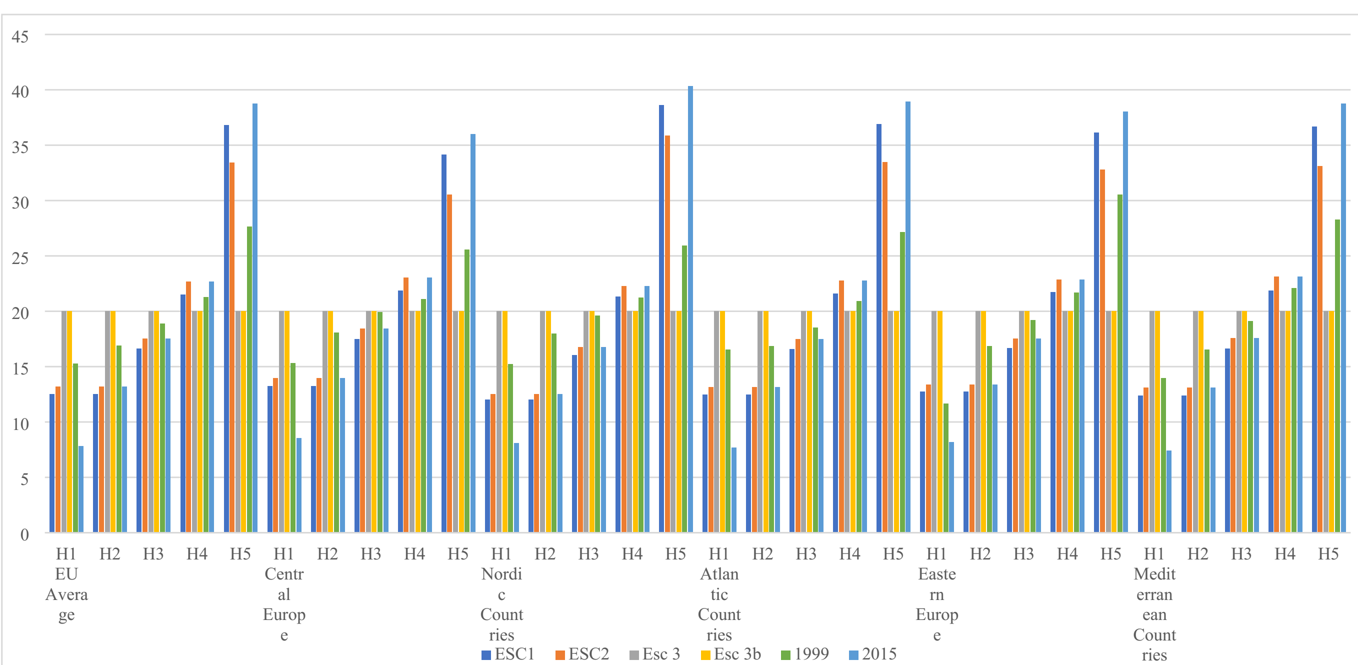

Fig. 3. Distribution of embodied emissions by income group in scenarios, 1999 and 2015 (Source: Authors' analysis.)

consumption of "*Transport sectors*" and "*Public administration and defence services, Education, Health and Social work*". In Scenario 3b, when the peculiarities of the countries are accounted for, a significant reduction is found in "*Accommodation and food services*".

Regarding changes in per capita emissions (Fig. 2), alleviating poverty, as studied in Scenarios 1 and 2, leads to increased emissions associated to the consumption of low-income groups, which worsens the level of global per capita emissions in economies, such as Belgium. On the other hand, a proper consumption pattern for each country could again reduce per capita emissions in high-income groups in Poland and Germany.

Finally, as we see in Fig. 3, the distribution of emissions among income groups is more equitable in all scenarios, in comparison with the situation in 2015, which exhibits significant reductions in the inequal distribution of emissions for all groups of countries. Therefore, these results show that more equitable distribution in emissions, obtained from a more equitable income distribution, may help to reduce environmental impacts with cuts in emissions.

4. Conclusions

The fight against climate change should be coupled with other objectives, such as ending poverty and reducing inequality, to ensure sustainable development. The consumption of households, directly through their consumption and indirectly through the whole production chain, involves a key role of climate change, as households are responsible for more than half of total emissions, as shown in this paper.

In this study, we evaluate the environmental impacts of the consumption patterns in all EU Member States from 1999 to 2015, distinguishing five income categories by country. The role of income distribution, consumption patterns, and technological conditions are studied through a SDA. The EU27 + UK achieved a reduction in emissions associated with household consumption, from 1999 to 2015, which is mainly associated to structural and technological factors. This shows the importance of the incorporation of cleaner technologies in the different stages of the EU supply chains. However, there is no clear impact over the period associated with changes in consumption patterns and income distribution, which could lead to more sustainable modes of consumption. Consequently, there is still considerable room for exploring improvements in consumption patterns, mainly related to changes in diet, shorter food-supply chains, sustainable transport, etc.

In line with the Paris Agreement and the UN's Sustainable Development Goals, we simulate a range of scenarios to study the impacts of the compatibility of the sustainable development goals regarding ending poverty and reducing inequality, which are priority aims for the EU27 + UK, with their potential environmental effects. We have considered consumption patterns and income, but also propensities to consume, for each income group.

Our findings show that alleviating poverty in all EU27 + UK countries by increasing income in low-income groups would lead to increased emissions, due to changes in consumption patterns and the high marginal propensity to consume of these income groups. Thus, complementary measures to boost sustainable consumption patterns would be required jointly. However, these are small increases in emissions that could be offset with technological improvements. Nevertheless, our results suggest that reducing inequality and poverty through a redistribution of income would lead to reduced emissions in the EU27 + UK. This finding shows a more optimistic decoupling. Moreover, our findings suggest that a convergence in consumption patterns could help to reduce total household emissions by around 5%.

The results by country and income category reveal a large heterogeneity among and within the EU countries. Therefore, our paper shows that a proper formulation of income redistribution by country could achieve much larger declines in emissions. In this sense, a convergence in the EU27 + UK consumption patterns related to the peculiarities of the countries could achieve cuts in emissions for the whole of the EU. Moreover, despite a convergence in the pathways is expected, this heterogeneity complicates to have similar end points in the medium term. Thus, policy efforts to promote sustainable consumption patterns are critical for reaching sustainable pathways towards low-carbon societies. Additionally, a more equitable income distribution could also contribute to alleviate environmental pressures. We can conclude that a more equitable economy could be achieved with reduced environmental impacts, although in all cases this will require changes in the productive technology of the economies. Besides, policymaking would require considering impacts in other pollutants and pressures such as water and land.

This study shows the suitability of the consumption-based approach that links final demand with all the production needed to satisfy demand throughout the global supply chain, through the use of an environmentally extended multiregional input-output model. However, we are aware of uncertainties that can affect the strategies studied, regarding the design of behavioural consumption functions for households, sustainability in the consumption of products, production functions, and elasticities. Thus, the extension of these analyses to a more flexible framework, such as a Computable General Equilibrium model, would be the next step in this work, to provide a wider view of the impacts for all economic, social, and environmental variables.

Inclusion and diversity

While citing references scientifically relevant for this work, we also actively worked to promote gender balance in our reference list.

Authorship statement

All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript. Furthermore, each author certifies that this material or similar material has not been and will not be submitted to or published in any other publication before its appearance in *Energy Economics*.

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This statement is signed by Sara Miranda-Buetas, the corresponding author (on behalf of myself, Rosa Duarte and Cristina Sarasa).

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Appendix A. Supplementary data

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