PAPER

Title: Technological change, consumption patterns and income distribution: strategies for a low-carbon EU transition

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Abstract:
In the fight against climate change, the European Union has been a leader, setting ambitious targets for 2020. Particularly, the European Union has created a complex set of goals concerning to the GHG with the aim to move towards a more sustainable life in 2050. The European Union pursues to diminish 40% of its emissions for 2030, 60% for 2040 and 80% for 2050, considering the levels of 1990.
The environmental impacts from different agents are analysed by many researchers. However, it is necessary to make this analysis considering not only the production side but also the demand side, due to the high percentage that households' environmental impacts represent. Also, it is important to take into account the disparities in income distribution and lifestyles between and within each country. So, analysing consumption pattern's impacts by income level is necessary to develop better policies to apply to achieve both goals, sustainable development and inequality reduction. Nevertheless, also it is relevant to consider the role of technological innovation.
This paper explores the trends in inequality in different environmental impacts of households in the EU27+UK countries in a multiregional input-output framework, examining the role of income distribution, consumption patterns, and technological conditions. We seek to shed light on measures and guidelines required for the compatibility of the aforementioned sustainable development goals. 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) and the associated global GHG emissions, land use and water consumption. We use a 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.

Keywords: input-output, environmental impacts, income inequality, technological change, consumption patterns
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Technological change, consumption patterns and income distribution: strategies for a low-carbon EU transition

1. INTRODUCTION

Since 1970, the different international commitments have set different goals in order to ensure natural resources, environmental quality and human health (Guerra & Sancho, 2018). This is not surprising if we consider that three planets are required to support energy and material consumption (Tukker et al., 2010)**.** In this fight against climate change, the European Union has been a leader, setting ambitious targets for 2020. In this way, the European Union has participated in the different agreements to limit pollution, such as The Convention on Climate Change (1997), the Kyoto Protocol (2002) and, it still does with the Paris Agreement (2015). Particularly, the European Union has created a complex set of goals concerning to the GHG (Green House Gases), with the aim to move towards a more sustainable life in 2050. The European Union pursues to diminish 40% of its emissions for 2030, 60% for 2040 and 80% for 2050, considering the levels of 1990 (Barisa et al., 2015).

The reduction of GHG emissions has been established as one of the policy priorities for the EU (Barisa et al., 2015). The study of the households could help to reduce the GHG emissions due to a better understood of their consumption behaviour (Lévay et al., 2021). This fact is not shocking considering that the households final consumption represents a high percentage of the GHG emissions (Song et al., 2019), being that some authors have found that households concentrate the 60-70% of the GHG (Hertwich & Peters, 2009; Ivanova et al., 2016; Harris et al., 2020; Bjelle et al., 2021).

The development of the nations has been accompanied by an increase in GHG emissions. So, in this way, the levels of CO_2, CH_4 and N_2O have significantly risen in the last decades due to climate change (Mohammed et al., 2021), being for that the important to focus on all the GHG emissions to reduce the effects of climate change (Y. Zhang et al., 2021).

In general, it is found that there are differences between nations when we refer to GHG emissions, and these differences mostly depend on the differences by income (Bjelle et al., 2021), being that usually, the emissions rise when income does. However, some studies that support the idea of the Environmental Kuznets Curve, such as Mohammed et al. (2021), who demonstrate that there is a point in which the economic growth reflects an environmental improvement.

Nevertheless, in general, it is found a positive relationship between income and environmental impacts (Zhang & Zhao, 2014; Lévay et al., 2021). However, this relation is less than proportional as some authors show in the literature (Girod & De Haan, 2010; Büchs & Schnepf, 2013), with exceptions for Brazil (Lenzen et al., 2006) and Norway (Steen-Olsen et al., 2016). However, as we see, income is one of the main drivers for the GHG footprint (Wiedenhofer et al., 2017; Hubacek et al., 2017a; Ivanova & Wood, 2020). In addition, if we refer to the emissions intensity, we find the opposite pattern than the income rise (Kerkhof et al., 2009; Golley & Meng, 2012). Finally, the increase of GHG emissions has been unequally distributed by different income households and countries (Wiedenhofer et al., 2017; Hubacek et al., 2017b).

Apart from the role of the income, also it is important the size of the households, being other of the key factors from the demand perspective (Miehe et al., 2016). In addition, from a production perspective, there are differences caused by the production structure of a country. In this way, some sectors that are more pollutant, as can be the electricity or transport sector (Barisa et al., 2015; Ivanova et al., 2016). The technology effect, on the contrary of the income effect, can be a driver to mitigate GHG emissions (Salo et al., 2021). In addition, Duarte et al. (2016) have found that it is compatible to reduce GHG emissions and achieving economic and social goals such as economic growth or unemployment reduction.

Not only the GHG emissions is one of the problems against climate change, but also it is the land use and water consumption. In this way, the households represent two-thirds of the demand for materials and land (Bjelle et al., 2021).In the case of land use and water consumption, the food sectors are the most important to try to reduce this kind of environmental impacts (Usubiaga et al., 2018; Schmidt et al., 2019; Wilting et al., 2021). Particularly, for the land use, it is especially relevant the animal products, representing more than a half of the land use (de Ruiter et al., 2014), and also, we can find high percentage in shelter sector, textile sector and services sector (Ivanova et al., 2016). In the case of the water footprint, agriculture and livestock are the major contributors, following by the services sector (Ivanova et al., 2016)

As proof of the relevance of the land use, in 2007, it was needed 65 million km^2 to satisfy all the household demand. In these embodied requirements, the European Union contributed 15%. (Ivanova et al., 2016). Besides, in the literature, it is found that the per capita land use displays high disparities between the different European regions (Wilting et al., 2021). Although it could be thought that the small economies present a low land use impact, it could not be farther from the truth, causes they display high import impacts (Ivanova et al., 2016).

Also, water consumption has a huge role in climate change. In 2007, the blue water footprint associated with households was 1.386 km^3 (Ivanova et al., 2016). Ivanova et al., (2016) find that Russia, Canada, the United States and Norway highlight as the countries with the higher direct water footprint. As in the GHG emissions, it is also found the relationship between income and water consumption, being that the high-income groups provoke a high water footprint (Shan et al., 2015).

The literature has demonstrated that not only is important to pay attention to the development of new technologies or production process; the policies also have to focus on the role of the consumption in the fight against the global warming (Bjørn et al., 2018; Guerra and Sancho, 2018; Bjelle et al., 2021). For example, for the carbon footprint, it has been demonstrated that the emissions of each kind of consumption change over time due to shifts in the consumption behaviour, the economic structure or the consumption volume (Song et al., 2019). So, lifestyles and consumer behaviour have a relevant influence on the generation of pollution (Duarte et al., 2016; Ivanova and Wood, 2020). Besides, the mitigation policies need not also of an economic perspective, but also a social frame (Streimikiene & Volochovic, 2011).

The Sustainable Development Goals not only pursue to achieve sustainable growth, but also to end with the income inequality and the poverty. As an example of this problem, Hardoon (2015) shows that the wealth of the 80 richest individuals is equal to the wealth of the half of poor people. A country can achieve at the same time both goals, a reduction of income inequality and also, the mitigation of climate change (Chen et al., 2020). The income distribution is a driver in the generation of environmental impacts (Kasuga & Takaya, 2017; Mader, 2018; Bai et al., 2020). However, in the literature, we find a not solved discussion about the role of the income distribution in the climate change, finding different views. On the one hand, it is said that a more equality income distribution would lead to an increase of the environmental deterioration (Heerink et al., 2001, Hübler, 2017; Huang & Duan, 2020). One of the causes could be that the poorest display a higher Marginal Propensity to Emit, meaning that if the income inequality would be reduced, the environmental impact would rise (Ravallion et al. 2000). On the contrary, many researchers have found that the reduction of income inequality would drive to a mitigation of global warming, finding this relation for countries such as USA (Baek & Gweisah, 2013; Jorgenson et al., 2015), or China (Zhang & Zhao, 2014; Bai et al., 2020). This same conclusion is found for higher samples of countries (Qu & Zhang, 2011; Vona & Patriarca, 2011; Knight et al., 2017; Hailemariam et al., 2020). As we see, a higher understand of the link between income inequality and environmental impacts is essential for the design of policies that intend to achieve simultaneously, both goals (Chen et al., 2020).

The environmental impacts are unequally distributed by income quintiles. In this way, Wiedenhofer et al. (2017) find that the consumption of high-income group provokes between 40-51% of the GHG emissions, while the poorest households emit between 10-13%. These authors also described that due to the high inequality income found in China, the 4% of the richest population displays a carbon footprint that is almost four times the average of the rest of population. In line with these results, Hubacek et al. (2017b), find that the top 10% causes more than a third of the GHG global emissions, while the 50% of the bottom is responsible just about 15% (a similar result is found in Hubacek et al., 2017a). Hubacek et al (2017b) also find that the carbon footprint of the richest is 11 times higher than the carbon footprint of the poorest population, being that the per capita emissions move from a 1.6 t CO_{2e} from the low-quintile group, to 17.9t CO_{2e} for the high-income group. To move the poorest population to the next income level, it would be necessary to assume a 66% of the available carbon emissions to reach the objective of not overcome the 2ºC (Hubacek et al., 2017b), being require that the annual rate of decarbonization would be higher than the 4% (Hubacek et al., 2017a).

This paper builds on this literature and explores the trends in inequality in different environmental impacts of households in the EU27+UK countries in a multiregional input-output framework, examining the role of income distribution, consumption patterns, and technological conditions. 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 GHG emissions, land use and water consumption. 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.

Our results display an environmental reduction of all our environmental indicators, especially for GHG emissions and land use, associated with consumption in European countries in the last decades. These reductions come mainly from transformations in the production side, rather than changes in consumption patterns, being, for example, that we are moving towards more water intensive lifestyles. Consequently, these improvements are not unlimited, being necessary the exploration of new policies on the consumption framework. Our outcomes also point out that a more equitable income distribution could mitigate climate change with cuts in GHG emissions, water consumption and land use.

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.

2. METHODOLOGY

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, as claimed in Turner et al. (2007) and Steen-Olsen et al. (2016) Our model is extended in two ways. First, the traditional economic model is environmentally extended with a vector of GHG emissions, land use and water consumption 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 environmental impacts associated with household consumption patterns.

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

$$\mathbf{z} = \mathbf{A}\mathbf{z} + \mathbf{y} \quad (1)$$

Let us denote by **z** the vector of gross production. We denote by **A**= $\left(a_{ij}^{rs}\right)$ 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 $\mathbf{y} = (y_i^r) = (\sum_s y_i^{rs})$ 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:

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

[1] This period is the latest that includes detailed information about household consumption obtained from Eurostat (2010).

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.

Our total environmental impacts take into account both household direct GHG emissions, land use and water consumption, and environmental impacts from production activities associated with household final demand (embodied). Let us consider a vector of direct environmental impact intensities, that is a vector of sectoral direct pollution per unit of production $\mathbf{c} = \left(c_i^r\right) = \left(C_i^r / z_i^r\right)$. 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 environmental impacts directly and indirectly contained in each unit of final demand. Note that these pollution values synthetize the technological elements of the economies, capturing all GHG emissions, land use and water footprint 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 environmental impacts generated worldwide, direct and embodied, to produce the final goods consumed by consumers in each country, by income category, as

$$\boldsymbol{\Omega}^{s} = \hat{\boldsymbol{\lambda}}\mathbf{H}^{s} = \hat{\boldsymbol{\lambda}}\mathbf{G}\hat{\mathbf{D}}T \qquad (3)$$

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:

- $\mathbf{G} = \left(G_i^{rh}\right) = \dfrac{H_i^{rh}}{\sum_{i,r} H_i^{rh}} = \dfrac{H_i^{rh}}{H^h}$ is the matrix representing each country and income category consumption patterns, referencing both domestic and imported products.
- $\hat{\mathbf{D}} = \left(\dfrac{H^h}{\sum_h H^h}\right)$ 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 pollution. We are interested in explaining the role that changes in consumption patterns and income distribution have played in the observed evolution of global GHG emissions, land use and water consumption. 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 considers both direct and indirect effects (Su & Ang, 2012). In addition, it differentiates between technology and demand 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 environmental impacts associated with the final consumption of households, which are explained on the basis of the four 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:

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

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:

$$\begin{aligned}
\Delta\mathbf{\Omega}^{\mathbf{s}} &= \Delta\hat{\boldsymbol{\lambda}}\mathbf{G}_0\hat{\mathbf{D}}_0 T_0 + \hat{\boldsymbol{\lambda}}_1\Delta\mathbf{G}\hat{\mathbf{D}}_0 T_0 + \hat{\boldsymbol{\lambda}}_1\mathbf{G}_1\Delta\hat{\mathbf{D}} T_0 + \hat{\boldsymbol{\lambda}}_1\mathbf{G}_1\hat{\mathbf{D}}_1\Delta T = \mathbf{I_1} + \mathbf{P_1} + \mathbf{R_1} + \mathbf{T_1} \\
\Delta\mathbf{\Omega}^{\mathbf{s}} &= \Delta\hat{\boldsymbol{\lambda}}\mathbf{G}_1\hat{\mathbf{D}}_1 T_1 + \hat{\boldsymbol{\lambda}}_0\Delta\mathbf{G}\hat{\mathbf{D}}_1 T_1 + \hat{\boldsymbol{\lambda}}_0\mathbf{G}_0\Delta\hat{\mathbf{D}} T_1 + \hat{\boldsymbol{\lambda}}_0\mathbf{G}_0\hat{\mathbf{D}}_0\Delta T = \mathbf{I}_2 + \mathbf{P}_2 + \mathbf{R}_2 + \mathbf{T}_2 \\
\Delta\mathbf{\Omega}^{\mathbf{s}} &= \frac{\left(\mathbf{I_1} + \mathbf{I_2}\right)}{\mathbf{2}} + \frac{\left(\mathbf{P_1} + \mathbf{P_2}\right)}{\mathbf{2}} + \frac{\left(\mathbf{R_1} + \mathbf{R_2}\right)}{\mathbf{2}} + \frac{\left(\mathbf{T_1} + \mathbf{T_2}\right)}{\mathbf{2}} = \mathbf{I} + \mathbf{P} + \mathbf{R} + \mathbf{T}
\end{aligned} \quad (5)$$

By definition, the first component captures the effects on environmental impacts 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 GHG emissions, land use and water consumption (T). The factors should be interpreted as contributions to the total change in $\mathbf{\Omega}$ or, in other words, the change in total environmental impacts that would have happened, 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)2. In order to analyse changes in consumption patterns and the associated impacts, we consider the years 1999

[2] 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.

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, 2015), 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 (Eursostat, 2015), with the information on income distribution by quintiles also provided by Eurostat. 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 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.[3]

Regarding the environmental data, we consider the different components of the GHG emissions (CO_2, methane, nitrous oxide and sulphur hexafluoride) and turn them into equivalent amounts of CO_2 by weighting their radioactive properties for a horizon of 10 years. In the case of land use, this environmental impact covers the use of cropland, pastureland, and forest land. Finally, the water consumption includes blue, fresh surface and groundwater, water footprint embodied in the agriculture and livestock sectors, electricity, manufacturing sectors, and direct household demand.

3. RESULTS

In this work, we 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. We focus our attention on the households due to its relevance in the emissions associated to the final demand, as we have mentioned in the introduction.

3.1 Structural decomposition analysis for the environmental impacts associated to households.

European households develop a relevant role to reduce the environmental impacts and accomplish the targets that the European Union has set in the last decades. However, there are many differences between the different regions of the European Union, in per capita and total environmental impacts. Contributing to the literature, we have made an SDA for all the environmental impacts, getting some interesting facts.

[3] 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.

In Table 1, we have the results of the SDA for European. The first thing to notice is that land use and GHG Emissions are the environmental impacts with the highest reduction between 1999 to 2015. This reduction is mainly produced by the Intensity Effect, confirming what is said in the literature that the technology effect is one of the main drivers to the reduction of environmental impacts. This intensity effect we see that provokes higher reduction when income rises for all the environmental impacts. The scale factor, on the contrary, increases the pollution for all the environmental impacts for the European Union. Most interesting is the analysis of consumption pattern effect. In this way, we see that, in general, this effect contributes to increase the environmental impacts. However, it is remarkable the role that it plays in water consumption. In this environmental impact, we see that this effect is higher than in the others, meaning that we are going towards a more water intensive consumption pattern in the European Union. Also, we can highlight that for lower income groups, for GHG emissions and land use, this effect allows to diminish these environmental impacts. Finally, the distributive effect presents a neutral effect in the explication of the change of the environmental impacts in the European Union. Nevertheless, as in consumption pattern effect, this effect contributes to reduce the impacts when we refer to low-income groups.

Table 1. SDA by Environmental Impacts for all the European Union

		% change 1999-2015	Intensity	Consumptio n Pattern	Distributiv e	Scale Factor
GHG Emissions	**H1**	-25.63	-29.04	-3.04	-7.28	13.72
	H2	-17.27	-31.43	0.87	-1.42	14.71
	H3	-13.75	-31.94	2.87	0.77	14.56
	H4	-12.91	-32.18	4.05	0.63	14.58
	H5	-8.47	-33.08	6.29	3.52	14.79
	TOTAL	**-14.51**	**-31.78**	**2.83**	**-0.09**	**14.53**
Water Consumption	**H1**	-15.49	-19.65	1.04	-8.50	11.62
	H2	-4.25	-21.90	6.34	-1.21	12.52
	H3	0.28	-23.82	10.36	1.12	12.61
	H4	2.93	-25.80	14.81	1.12	12.80
	H5	4.08	-29.68	17.63	3.16	12.96
	TOTAL	**-1.42**	**-24.80**	**11.06**	**-0.26**	**12.57**
Lan d Use	**H1**	-25.17	-23.82	-7.91	-6.87	13.43

H2	-17.36	-26.85	-3.44	-1.19	14.12
H3	-13.30	-28.82	0.42	0.91	14.19
H4	-11.34	-30.85	4.44	0.77	14.30
H5	-10.91	-34.66	6.45	2.86	14.44
TOTAL	**-14.77**	**-29.71**	**0.94**	**-0.16**	**14.15**

Source: Own Elaboration

In Table 2, we have the SDA for each of the Environmental Impacts. As we see, in most of regions, the three environmental impacts have decreased between 1999 to 2015, being the intensity effect, the main driver of this reduction for all of them. For GHG emissions and water consumption, the Central Europe is positioned as the region with the greatest reduction, while in land use, it would be the Mediterranean Countries, with a total reduction of 30.46%. However, not all regions have diminished these environmental impacts. This is the case of Eastern Europe, that present an increase of 12.67%, 12.02% and 3.84% for low-income group in GHG emissions, water consumption and land use, respectively. In most cases, these increases would be the product of the sum of the distributive effect and the scale factor effect. In addition, the consumption pattern effect would contribute to this increase in GHG emissions. For water consumption, both, the Nordic countries and Atlantic countries, present an increase of their water footprint of 10.56% and 12.02% respectively, for all the quintile income groups (with the only exception of the low-income group for Atlantic Countries, caused mainly due to intensity and distributive effects). The Atlantic Countries also present increases in the high-middle and high-income groups, due to a higher land intensive consumption pattern. As in the European Union, the intensity effect has contributed to reduce the environmental impacts while the scale factor effect would increase the same. Again, the more interesting issues are found in pattern consumption effect.

In GHG emissions, we find that for most regions, this effect would increase emissions, meaning that most of the European consumption patterns go towards more emission’s intensive patterns. The most remarkable case would be Eastern Europe, as we have mentioned before, but also it is relevant the consumption pattern of the high-income group of Atlantic Countries. However, there is a region that is reducing its emissions intense in consumption pattern terms. This is Central Europe. Central Europe shows a less emissions intense patterns, especially in the case of middle and low-income groups. A different frame is displayed for water consumption. Also, in most regions, we are also going towards more water intensive consumption pattern, there are some exceptions, highlighting the case of Eastern Europe, with a reduction of 10.94%. However, regions

Table 2. SDA of Environmental Impacts for the European Regions

		GHG Emissions					Water Consumption					Land Use				
		% change 1999-2015	Intensity	Consumption Pattern	Distributive	Scale Factor	% change 1999-2015	Intensity	Consumption Pattern	Distributive	Scale Factor	% change 1999-2015	Intensity	Consumption Pattern	Distributive	Scale Factor
Central Europe	H1	-25.20	-47.33	-8.13	-1.42	31.46	-29.73	-44.94	-5.30	-2.57	23.08	-32.12	-38.63	-14.09	-2.62	23.22
	H2	-24.83	-47.74	-9.58	-0.14	32.70	-26.33	-45.48	-4.14	-0.87	24.16	-29.65	-40.03	-12.96	-0.89	24.22
	H3	-25.25	-46.92	-10.73	0.62	31.64	-24.51	-46.50	-2.36	0.39	23.96	-27.91	-40.72	-11.56	0.40	23.97
	H4	-23.34	-47.46	-7.70	-0.04	31.94	-23.29	-47.73	-0.11	0.45	24.11	-26.50	-41.76	-9.29	0.52	24.02
	H5	-22.13	-47.51	-6.00	0.37	31.12	-20.62	-49.64	3.98	1.02	24.03	-23.53	-43.87	-4.62	0.98	23.99
	TOTAL	**-23.97**	**-47.40**	**-8.27**	**-0.03**	**31.74**	**-24.41**	**-47.13**	**-1.06**	**-0.13**	**23.91**	**-27.51**	**-41.26**	**-10.02**	**-0.14**	**23.91**
Nordic Countries	H1	-12.88	-27.61	2.47	-6.96	18.93	-3.12	-32.15	15.70	-8.13	21.46	-24.47	-41.92	2.10	-6.62	21.98
	H2	-10.66	-29.35	3.91	-4.31	19.20	3.46	-32.73	19.01	-4.80	21.97	-21.25	-42.82	3.75	-4.36	22.19
	H3	-8.51	-30.22	2.49	-0.27	19.26	10.60	-34.14	22.08	-0.12	22.78	-13.63	-44.73	7.84	0.24	23.02
	H4	-6.70	-30.92	3.34	1.21	19.81	15.89	-35.72	26.62	1.57	23.42	-9.31	-46.17	12.44	0.88	23.54
	H5	-2.31	-31.92	2.56	6.66	20.57	20.65	-39.82	28.20	7.73	24.53	-7.37	-49.32	11.56	6.34	24.04
	TOTAL	**-7.57**	**-30.26**	**2.94**	**0.09**	**19.65**	**10.56**	**-35.27**	**22.89**	**-0.04**	**22.97**	**-14.26**	**-45.40**	**8.08**	**-0.02**	**23.07**
Atlantic Countries	H1	-31.14	-25.94	-7.21	-9.16	10.94	-7.39	-16.11	5.10	-8.51	12.14	-22.37	-20.65	-5.51	-7.79	11.58
	H2	-19.55	-28.72	0.33	-2.98	11.91	10.55	-17.98	17.46	-2.30	13.37	-9.24	-23.63	3.86	-1.98	12.52
	H3	-12.59	-29.94	4.37	0.47	12.33	19.66	-19.30	24.24	0.70	14.02	-1.82	-25.40	9.89	0.61	13.07
	H4	-10.49	-30.74	6.76	0.83	12.76	27.03	-20.42	31.88	0.89	14.67	3.74	-26.69	16.11	0.72	13.60
	H5	-4.06	-31.84	9.13	5.66	13.11	31.71	-22.20	34.03	4.98	14.90	6.93	-28.99	17.81	4.39	13.72
	TOTAL	**-14.08**	**-29.75**	**3.56**	**-0.22**	**12.33**	**18.27**	**-19.53**	**24.04**	**-0.19**	**13.96**	**-2.92**	**-25.56**	**9.78**	**-0.16**	**13.02**
n Europe	H1	12.67	-57.99	15.70	11.86	43.32	12.02	-14.05	-19.06	11.67	33.46	3.84	-8.31	-34.93	10.30	36.78
	H2	-5.10	-54.54	7.92	3.06	38.36	-6.84	-20.24	-16.51	3.15	26.76	-8.82	-10.90	-31.88	2.59	31.38

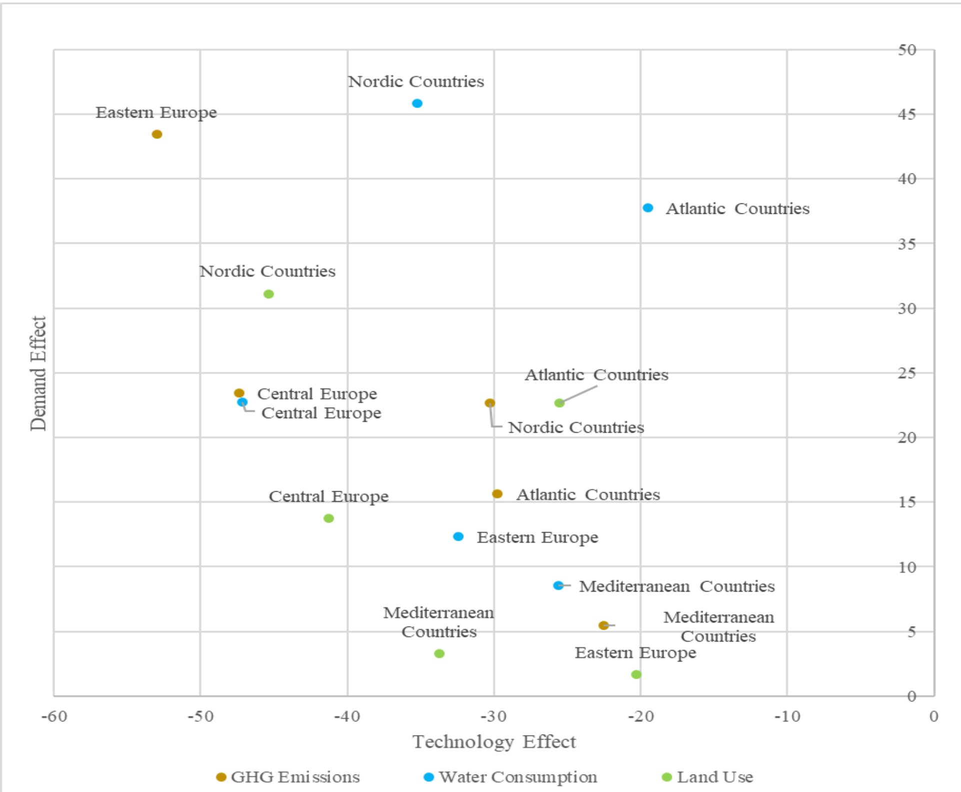
	H3	-8.30	-52.11	6.74	1.53	34.96	-14.55	-26.93	-12.83	1.48	23.73	-13.59	-14.88	-29.44	1.56	29.18
	H4	-13.15	-52.30	5.26	-0.88	34.72	-22.72	-34.06	-9.51	-0.82	21.67	-21.18	-21.93	-26.06	-0.60	27.41
	H5	-18.77	-51.27	4.62	-5.11	33.36	-37.45	-45.68	-5.72	-4.20	18.15	-33.36	-31.80	-22.30	-4.29	25.03
	TOTAL	**-9.52**	**-53.00**	**7.03**	**0.47**	**35.98**	**-20.03**	**-32.41**	**-10.94**	**0.41**	**22.91**	**-18.60**	**-20.29**	**-27.52**	**0.46**	**28.75**
Mediterranean Countries	H1	-27.99	-20.51	0.93	-11.57	3.07	-28.12	-20.73	-1.33	-11.98	5.93	-37.53	-26.06	-5.66	-11.25	5.44
	H2	-17.64	-22.65	0.75	0.34	3.97	-17.14	-22.75	-0.83	-0.61	7.06	-29.76	-30.62	-4.99	-0.48	6.32
	H3	-16.30	-22.50	0.89	1.28	3.94	-14.87	-24.58	1.06	1.66	6.98	-28.52	-32.81	-3.41	1.41	6.28
	H4	-17.32	-22.51	0.25	0.98	3.99	-14.85	-26.56	2.91	1.79	7.00	-29.38	-34.96	-2.06	1.40	6.23
	H5	-11.71	-23.47	4.14	3.46	4.22	-13.62	-30.61	6.61	3.06	7.32	-29.18	-40.05	1.27	3.03	6.57
	TOTAL	**-17.08**	**-22.53**	**1.65**	**-0.12**	**3.92**	**-17.03**	**-25.60**	**2.15**	**-0.50**	**6.92**	**-30.46**	**-33.74**	**-2.52**	**-0.43**	**6.23**

Source: Own Elaboration

as Nordic Countries or Atlantic Countries should focus their attention on the evolution of their consumption pattern with the aim of reducing their water intensity. Finally, the last policies seem to have more effect in consumption pattern when we refer to land use. In this way, only Nordic Countries and Atlantic countries, still remain as regions with land intensive consumption pattern, especially for the high-income groups. The distributive effect, again, for the total of the regions show a neutral effect. However, in GHG emissions, it plays a relevant role for high-income group and low-income group of Nordic Countries and Eastern Europe, respectively, increasing the emission. It would be completely the opposite for the low-income group of Atlantic and Mediterranean countries. These patterns are also found for water consumption and land use.

Finally, in Figure 1, we can see in which position is each European Region by demand and technology effect. The results are displayed by each environmental impact. We see, that for all regions and environmental impacts, the demand effect contributes to increase the climate change, while the technology effect provokes a reduction. The highest reduction by technology effect is found in Eastern Europe for the GHG Emissions, while this same region presents the lowest technology effect when we speak of Land Use. The Nordic Countries, for the water consumption and land use, present the highest demand effect. The Mediterranean Countries display the lowest demand effect. Joining this with the reduction of technology region, it makes of the Mediterranean Countries the region with the greatest environmental reduction for most environmental impacts.

Figure 1. Technology Effect and Demand Effect of Environmental Impacts



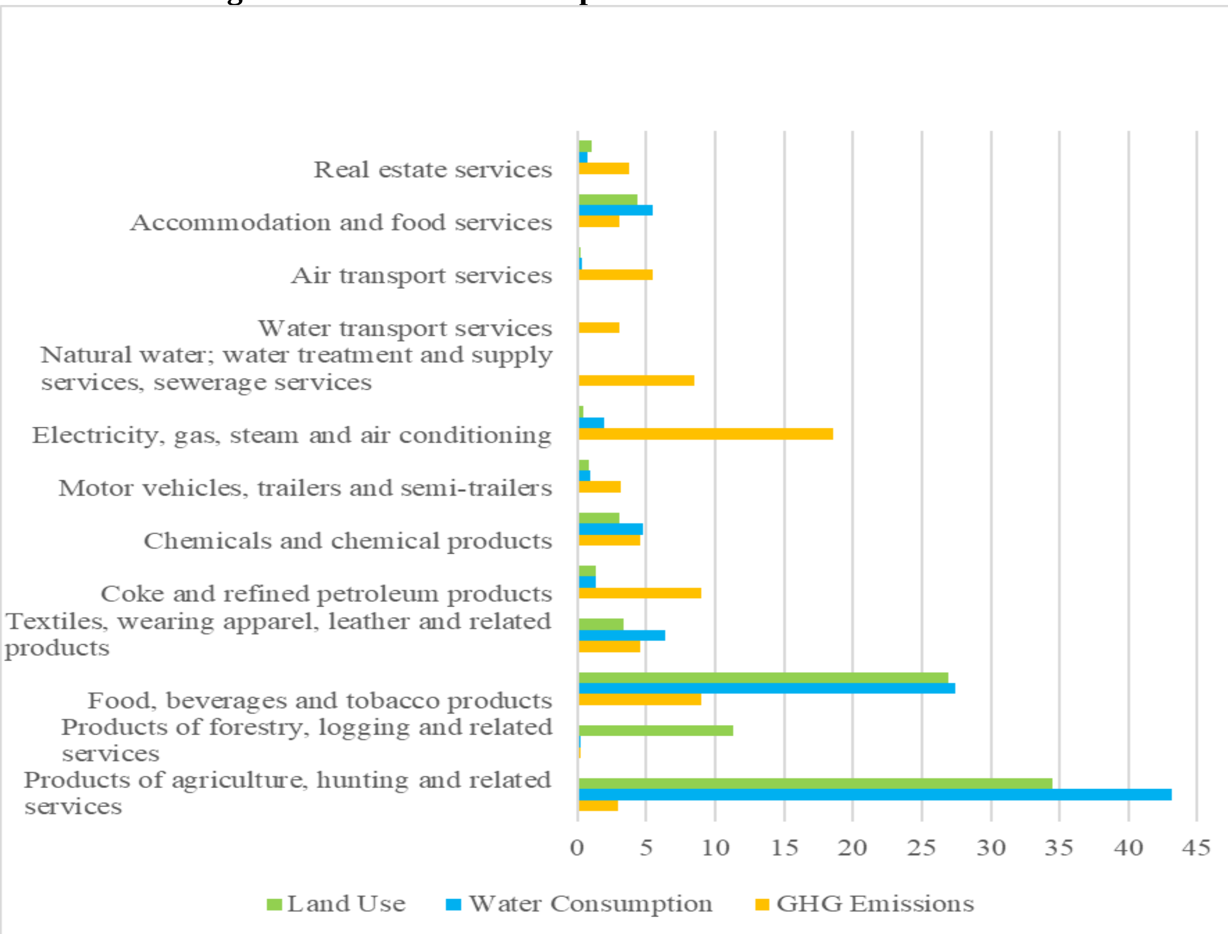
Source: Own Elaboration

3.2 Environmental impacts associated with economy structure.

In Figure 2, we can see the analysis of the relevance of each sector for each environmental indicator, what could allow us to design better policies, focusing on the sectors that each environmental indicator pollute more. In Figure 2, we see the most relevant sector when we refer to environmental terms.

In the case of the GHG emissions, this environmental impact highlights in the *Electricity, gas, steam and air conditioning* with 18.51% of the total emissions. In addition, another energy sectors such as *Natural water; water treatment and supply services, sewerage services* or *Coke and refined petroleum products*, also present a high representation in the GHG emissions impact, being in line with the literature results (Barisa et al., 2015, Guerra and Sancho, 2018, Jåstad et al., 2020)). We also see, that sectors related which transport and food are also relevant.

Figure 2. Environmental impacts associated to sectors



Source: Own Elaboration

The land use is focused on food sectors, being the *Products of agriculture, hunting and related services* a 34.52% of the total land use, being in line with the literature. *Food, beverages and tobacco products,* and *Products of forestry, logging and related services* represent also high percentage of land use. Also, the water consumption is relevant for food related sectors (Ivanova et al., 2016), but also it is for the *Accommodation and food services* and *Textiles, wearing apparel, leather and related products.*

3.3 The role of income inequality in the embodied and direct impacts of the European Union

The results displayed in Figure 3 shows the distribution of environmental impacts between the different countries in terms of income groups (the correspondence of each country to each income group is explained as a note in the Figure) and also, on function of embodied of direct environmental impacts. This figure presents the existence of inequality distribution of environmental impacts between different income groups.

Our results show that high income groups concentrate, in general, a higher percentage of environmental impacts, in line with the literature (see Zhang and Zhao, 2014, Shan et al., 2015, among others), for both kinds of environmental impacts. In this way, concerning with embodied environmental impacts in 2015, the high-income group, which represent the 41.72% of the total income and the 30.84% of the European population, present its highest contribution in CO_2 emissions (40.66 %), N_2O (36.89%) and CH_4 (36.71%). It is highlighted the increase that the CH_4 present between 1999 to 2015, moving from 20.28% to 36.71%, and also, the decrease in SF_6 emissions (these countries represent the 34.20% of these emissions in 1999, and in 2015, they display the 26.00% of the total). In terms of direct emissions, the high-income group displays its greater percentage in CO_2 emissions (36.75%), N_2O emissions (31.14%) and CH_4 emissions (30.94%). As we see, in both kind of environmental impacts, the high-income group highlight due to its participation in the GHG emissions. The lowest percentage is found on water consumption, where they represent the 11.47% on 2015. The high-income countries show that their embodied environmental impacts caused by their consumption are higher than those that they provoke with their production, doubling, for example the impact associated to water consumption (in embodied water consumption, they concentrate the 33.04% when in direct, they would represent the 11.47%).

The high-middle income group represents the 39.29% and 35.32% of the income and population in 2015, respectively. This group is responsible of the 36.60% and 35.73% of the embodied water consumption and land use, respectively. They have moved from being the 26.25% of the CH_4 embodied emissions in 1999, to represent the 34.29% in 2015. As the high-income group of the European Union, this group has increased its direct emissions of CH_4 and N_2O (34.79% and 34.64% in 2015, respectively), while they have reduced its direct SF_6 direct emissions (being a 11.75% in 2015). The high-middle income countries display a similar concentration in both, embodied and direct, environmental impacts, being slightly higher the effect that they provoke in other countries. It is just in the SF6 emissions, where they receive more emissions than they create.

The middle-income group, which is only represented by Spain, represents the 7.94% and 9.11% of the income and population, respectively. This income group highlights due to its embodied consumption of water, displaying the 15.19% of this environmental impact. This high consumption is not only found in the embodied impacts, but also it is showed in the direct, being in that case, that this group represent the 27.15%. In direct terms, also we can highlight its role in the land use, being the 10.82% of itself. The middle-income group, as the high-middle income, shows similar percentage between embodied and direct environmental impacts, displaying, as we have mentioned, its most relevant role in the water consumption.

On the other hand, the low-middle income group, displays the 4.57% and the 7.77% of the European income and population. This group is relevant due to its great concentration of embodied N_2O and CO_2 emissions (8.94% and 8.73%, respectively). Focusing on direct impacts, the low-middle income highlights due to these same emissions, but also because of its direct water consumption (12.22%). We can notice that this group present a smoothly higher representation in the embodied impacts than the direct, and we have seen that present a high relevance in some of the GHG emissions.

Finally, the low-income group, being the 16.96% of the European population, this group only concentrates the 6.48% of the European income, but they represent the 53.57% of the SF_6 embodied emissions. Despite the increase that they have presented in these emissions, they have move from a 43.77% and 27.63% to a 15.91% and 15.26% of the CH_4 and N_2O embodied emissions, respectively. The same pattern we can note in the direct environmental impacts, highlighting the decrease of its participation in CH_4 direct emissions, due to their higher share between high-middle and high-income groups. Low-income groups display lower embodied impacts than direct, in general.

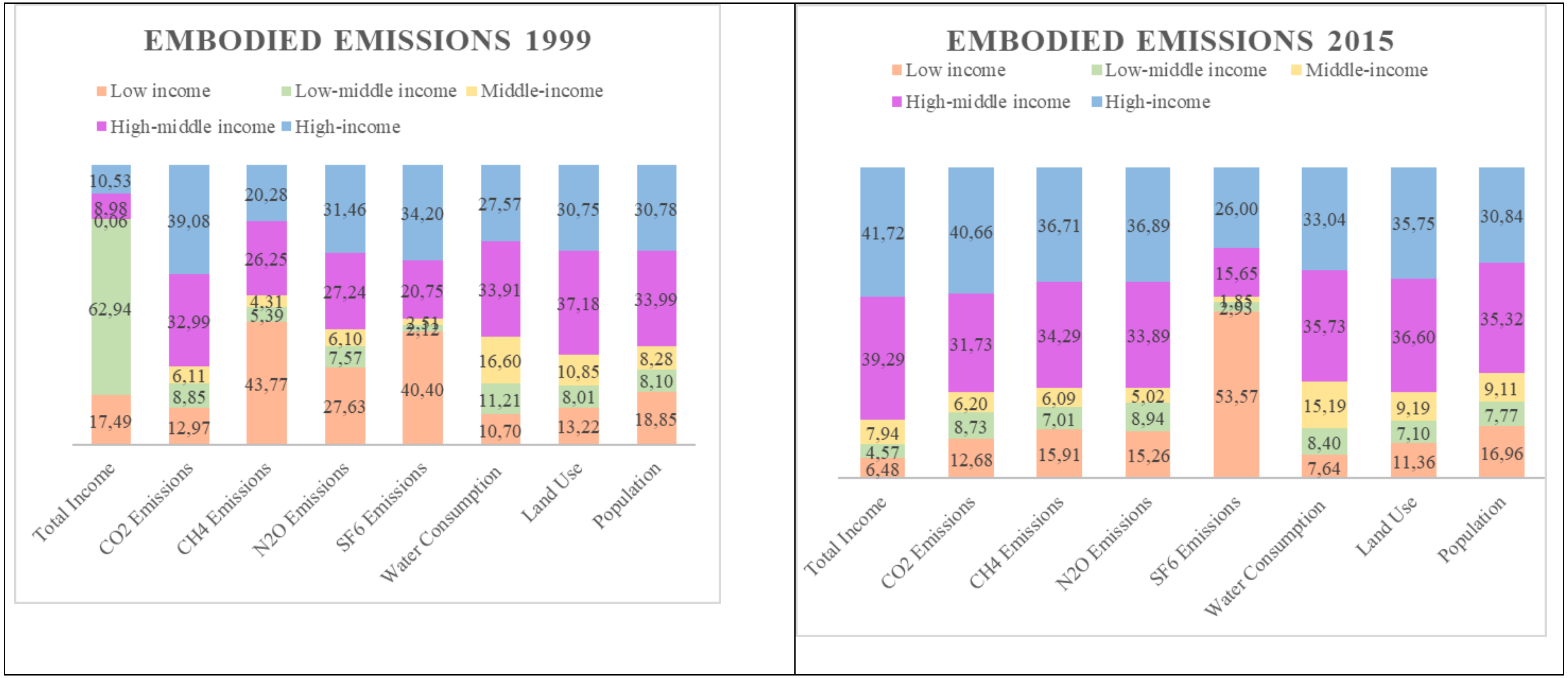
Some conclusions that we can obtain for this analysis would be the following. First, there are disparities between income groups when we evaluate embodied and direct environmental impact. Second, high-income group show greater representation in their embodied impacts than in their direct. Third, this higher representation of the embodied impacts tends to balance when we move towards high-middle and middle-income groups. Finally, the poorest countries show than the direct environmental impacts become more important in their environmental footprint.

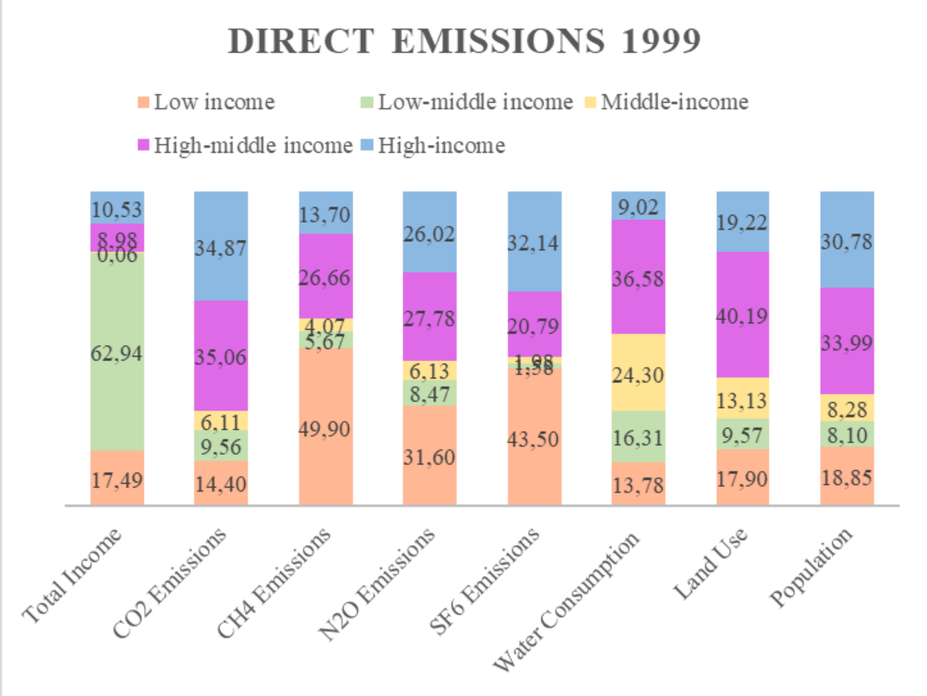
3.4 Environmental impact distribution by different countries and regions of the European Union.

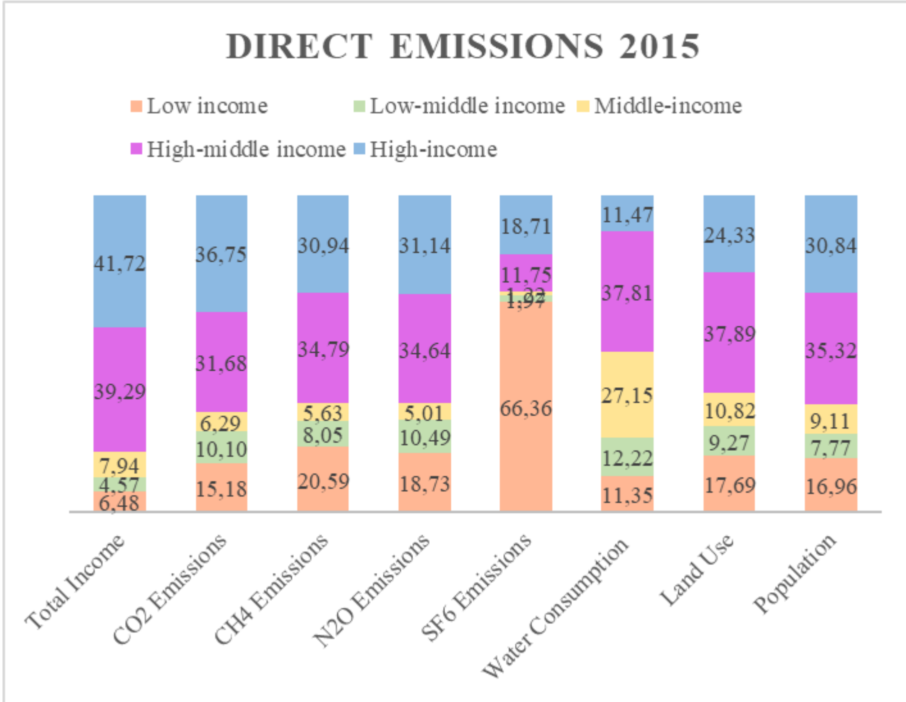
In Figure 4, we have displayed the distribution of environmental impacts by the different European regions, and in Table 3, we can see in more details, the environmental impact associated to each country. The Central Europe concentrates the 4.28% and 6.76% of the European income and population, respectively. This region shows its higher representation, for both, direct (8.93%) and embodied (7.26%) impacts, in the N_2O emissions, being the Czech Republic the main responsible of this percentage.

The Nordic Countries present a similar pattern than the Central Europe. However, contrarily to per capita results where the Nordic Countries highlight in most of environmental impacts, in total terms, this region participates in a lower way to the contribution of environmental footprint. In this manner, the Nordic Countries concentrates the 5.48% and 4.11% of the European income and population, and it shows

Figure 3. Embodied and Direct Environmental distribution by income regions







Source: Own Elaboration. Note: Income Groups. Low -income group: Bulgaria, Croatia, Hungary, Latvia, Poland, Romania, Slovakia. Low-middle income group: Cyprus, Czech Republic, Estonia, Greece, Lithuania, Malta, Portugal, Slovenia. Middle-income group: Spain. High-middle income group: Austria, Belgium, Denmark, Finland, France, Ireland, Italy, Netherlands. High-income group: Germany, Luxembourg, Sweden, United Kingdom.

its highest contribution for the N_2O emissions, being a 9.28% and a 10.80% for embodied and direct emissions, respectively.

Contrary for these two regions, the Atlantic Countries covers a higher relevance in total environmental terms, and also, represent the 61.28% and 48.44% of the European income and population, respectively, being the region that concentrate the highest amount of income in Europe. Nevertheless, this region is not only the richest, but also is the most pollutant. In this way, this region presents its highest participation in the CO_2 emissions and in the land use, for both, embodied and direct terms. In addition, for direct terms, it is relevance the role that they play in CH_4 and N_2O emissions. In the embodied land use, we can highlight the impact associated to United Kingdom (279688 km^2) and Germany (214651 km^2). However, France and Germany would be the countries with caused the highest impact associated to land use in the rest of Europe, following, again, by the United Kingdom.

The Eastern Europe, concentrates only the 5.59% of the European income (there has been a decrease in comparation with the levels of 1999, where they concentrate the 29.95% of the income), but the 13.96% of the European population. In 1999, these countries highlight due to its GHG embodied emissions (especially, for the case of CH_4, where they concentrated the 42.40% of the total emissions), and, although in 2015 they present a similar trend but in lower levels (more of them are near of the 15% of these emissions), these countries now are more relevance due to its SF_6 embodied footprint, concentrating the 52.71% of itself. The same pattern we can see in the case of the direct environmental impacts. Nevertheless, the concentration in the SF_6 direct emissions is higher (65.33% in direct emissions versus the 52.71% in embodied emissions).

Being the 26.73% of the European population, the Mediterranean Countries accumulate the 23.38% of the European income in 2015 (being that in 1999, they got the 48.03% of the income). Despite this reduction of its income, the Mediterranean countries show large percentages in the participation for environmental impacts, for both, direct and embodied. The most highlighting fact of this region is its high percentage in the embodied (34.29%) and direct (53.17%) water consumption. The main driver of these percentage are Spain, Italy, Greece and Portugal, being the special relevance, the direct water consumption associated to Spain (11053 mm^3) and Italy (6157 mm^3). This region is important in what concerns to land use too. In this way, despite its reduction from 33.04% to 26.75% of direct land use between 1999 to 2015, Spain and Italy provoke one of the highest impacts associated to this environmental indicator in the European Union.

Finally, comparing direct and embodied environmental impacts, we see that most regions show similar percentages between their contribution to direct and embodied environmental footprint. However, we see that for regions such as Mediterranean Countries, Eastern Europe and Central Europe, the direct environmental impacts are slightly higher. For Nordic Countries, despite the percentage are so similar, it tends to contribute in a smoothly higher way to the embodied impacts. The Atlantic Countries are the only region which their households seem to embed more impacts in their consumption than these ones they provoke.

Table 3. Total environmental impacts from the European Countries by 2015

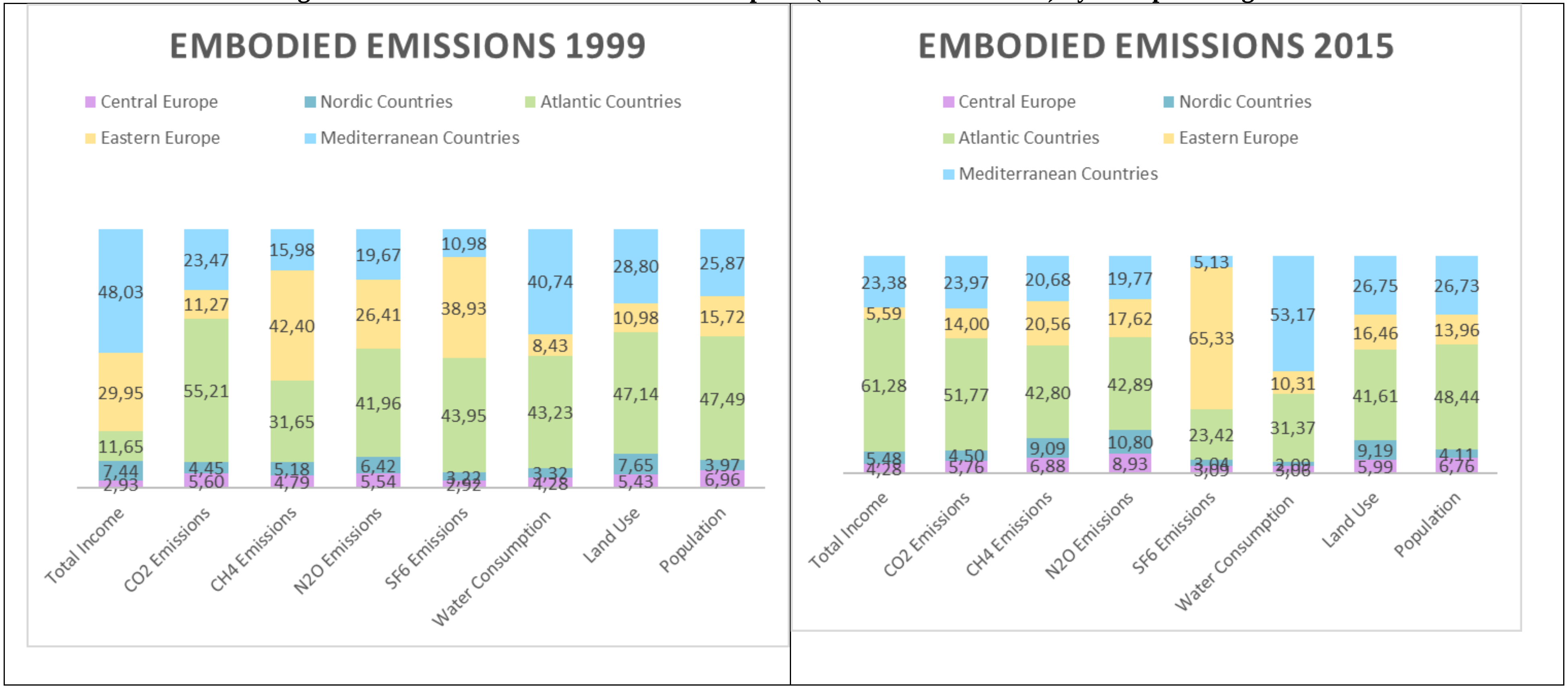
	GHG Emissions		Water Consumption		Land Use	
Countries	**Direct**	**Embodied**	**Direct**	**Embodied**	**Direct**	**Embodied**
Austria	26268	36789	281	1050	53388	92421
Belgium	41359	45692	1411	2747	86382	158058
Bulgaria	29039	29297	333	363	59335	52157
Croatia	5147	6791	55	243	17312	25858
Cyprus	3813	5715	173	243	6866	9873
Czech Republic	36168	31367	366	631	56893	62027
Denmark	29079	31702	407	809	37673	64712
Estonia	10002	9739	58	136	17173	17858
Finland	22429	28036	166	655	121629	150305
France	129786	183748	3794	8397	380347	648972
Germany	362552	437373	3160	10985	350021	742089
Greece	76284	80188	2418	2832	78223	110782
Hungary	17799	17409	268	405	48248	47182
Ireland	17006	18859	327	626	51522	47684
Italy	172191	203328	6157	9171	311576	474541
Latvia	3768	5071	84	119	26444	20871
Lithuania	8041	11046	172	353	41912	47608
Luxembourg	2948	3844	140	425	9982	22917
Malta	1511	1738	30	69	1339	2923
Netherlands	79393	86435	2851	4244	168441	257664
Poland	164137	161972	2509	3121	231059	247564
Portugal	22771	27235	1656	1964	81346	97819
Romania	27676	30374	1039	1208	150155	156828
Slovakia	14454	14321	331	460	32749	37265
Slovenia	5674	6951	103	286	12387	18582
Spain	102107	123406	11053	11772	345882	475515
Sweden	23307	37049	279	1425	134424	183385
United Kingdom	210858	334847	1089	12782	283205	901924
UE+UK	**1645568**	**2010323**	**40709**	**77521**	**3195911**	**5175383**

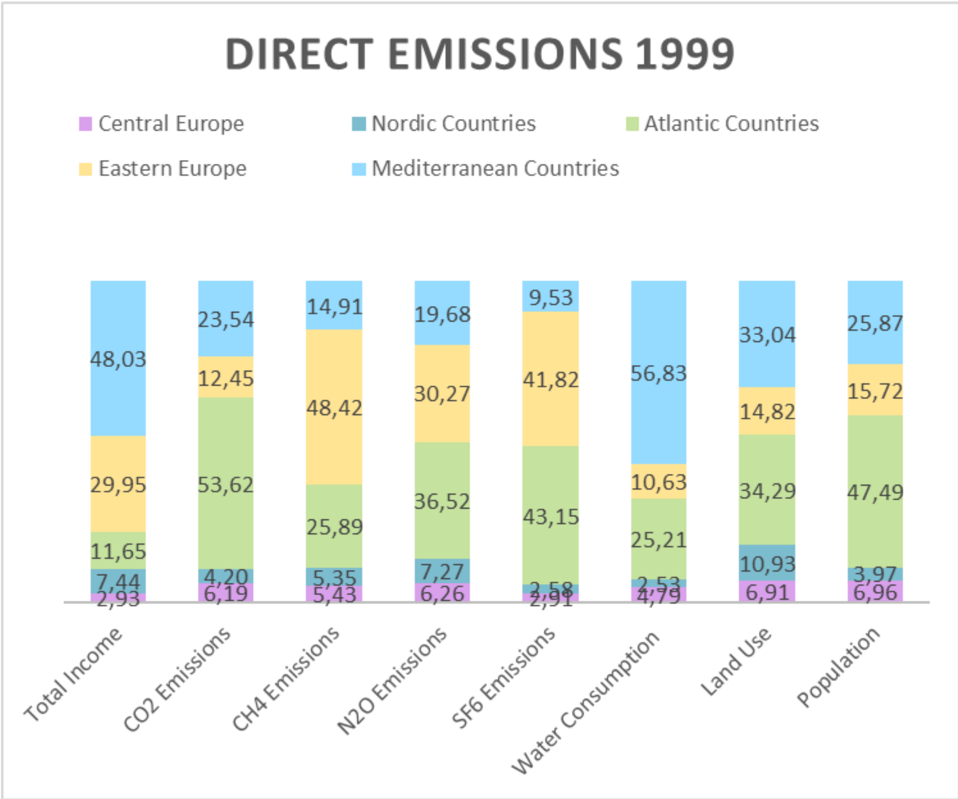
Source: Own Elaboration

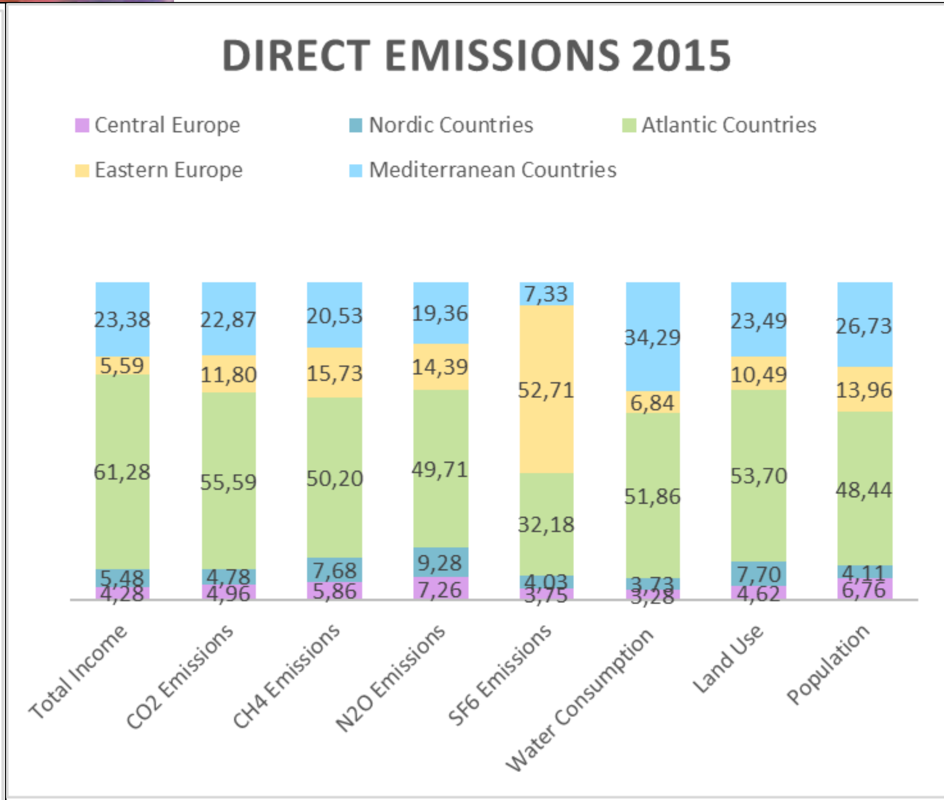
4. CONCLUSIONS

The arisen environmental impacts produced by global warming affect to the total of our economy in such a different way, elevating other relevant problems such as poverty and inequality. In this fight against climate change, it is important to deal it with both perspectives, a productive and demand framework.

Figure 4. Distribution of Environmental impacts (embodied and direct) by European Regions







Source: Own Elaboration

In this work, 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 an SDA. The EU27+UK achieved a reduction in GHG emissions and land used associated with household consumption, from 1999 to 2015, which is clearly associated with declines in emissions per unit. In other words, due to structural and technological factors. This shows the importance of the incorporation of cleaner technologies in the different stages of the EU supply chains.

In the literature, until last years, researchers have focused their attention on the role of the technology in the aim to reduce environmental impacts. Instead of technology effect, in general, produces a reduction of environmental footprints, that is not also true. In this way, in this work, we find that for most environmental impacts, this relation is a reality. However, when we focus on the N_2O and SF_6, the results display a completely different pattern, meaning that in these cases, the technology is increasing the amounts of emissions. Considering that, and the effect of these gases in the economic structure, it would be necessary that the design of policies focus on sectors related with energy and also food, because their relevance in these two gases.

However, concerning with demand side, there is no clear impact associated with changes in consumption patterns and income distribution, which could lead to more sustainable modes of consumption. Indeed, in general we are going towards a more environmentally harmful pattern consumption, especially, when we refer to water consumption, being that the European Union is moving towards more water intensive lifestyles. Consequently, there is still considerable improvements in consumption patterns, mainly related to changes in diet, shorter food-supply chains, sustainable transport, renewable energy, etc.

Different income level of households and their lifestyles produce different levels of GHG emissions, land use and water consumption. Besides, consumption patterns of EU countries are different between them, and their impacts have different trends, being necessary that policies take into account the differences and features of countries and households in order to design policies more adequate to the goal that they want to accomplish.

The results of environmental impacts by quintiles show that there is an inequality between the distribution of environmental footprints through different income quintiles, being higher the environmental impacts associated to high-income households. In addition, there is a decreasing trend of these environmental impacts in their weight in low-income group, while, in the case of the high-income groups, it would be exactly the opposite, with the only exception for Eastern Europe.

As the literature shows, each kind of environmental impact is related with different sectors, being, in this way, such a relevant to make a deep study of these sectors and how policies could allow to reduce the environmental impacts associated to them, making changes in the production process or developing new technologies that mitigate climate change.

Finally, this work displays the adequacy 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, which is shown here with a disaggregated final demand of households into five income groups, for all the EU27+UK countries. However, as we have mentioned in the introduction and also in the discussion of our results, it is relevant not only to include demand policies, but also technologies policies. So, the next step of this work, would be to join demand and technologies policies in a framework of designing scenarios which would help in the search to a more sustainable economy, evaluating the rebound effects associated. In this same way, it would be interesting make a study of price expenditure elasticities, to a better understanding and design of policies.

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