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Are there gender differences in household carbon footprints? Evidence from Spain

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ABSTRACT

Identifying the main drivers of the household carbon footprint (HCF) is a priority to reduce greenhouse gas emissions and move towards a more sustainable economy. Among the multiple factors that explain the HCF, some previous research has confirmed the relevance of gender. In this paper, we calculate the HCF of individual Spanish households using an environmentally extended multi-regional input-output model (EEMRIO) that quantifies the emissions embedded in the supply chain of goods and services that households consume. We assess the differences in consumption and emissions patterns, measuring the gender effect by a new variable, the female share of the household. This represents a remarkable improvement over previous literature that used simpler approaches. Moreover, we assess the partial effect of gender on HCF using multivariate regressions for total and sectoral emissions. Our results show that households with a majority of men have a higher HCF and carbon intensity. Even when controlling for economic, sociodemographic, and regional factors there are differences in the sectoral emissions according to gender. Female households spend more (and generate more emissions) on housing and food products, while male households show that pattern for restaurants and transport. These results can help orientate environmental campaigns and demand-side mitigation policies.

1. Introduction

Over the past few years, many studies have warned about how our mode of production and consumption impacts social and natural systems. The current increase in the concentration of greenhouse gases in the atmosphere is far above that in any other known period in history, which calls for immediate action before the damage becomes irreversible ((World Meteorological Organization, 2020); Government of Spain (2020); IPCC (2021)). It is therefore critical to identify and change unsustainable consumption habits, promoting greener lifestyles.

In this study, we analyse the pattern of emissions—specifically carbon dioxide (CO_2)—of Spanish households by calculating their carbon footprints through the input–output methodology. This approach has been previously used for household carbon footprint calculations by López et al. (2017), López et al. (2016) and Tomás et al. (2020) for Spain; by Feng et al. (2020) for the United States; by Druckman and Jackson (2010) for the United Kingdom; by Salo et al. (2021) for Finland; and by Long et al. (2021) for Japan, among many others. Most studies in this area analyse the differences in household consumption patterns, identifying income as the main driver of household carbon footprint and finding other influential factors, such as household size and composition, regional characteristics, and education level. In addition to all these factors, the consideration of gender in the study of carbon emissions is relevant for several reasons.

Gender interacts with multiple socioeconomic and cultural factors, which leads to significant differences in lifestyles. In general, women face several gaps in the labour market, education, and their private life, resulting in lower incomes, a greater burden of care and household chores, and fewer opportunities for personal development. These circumstances obviously vary across regions and over time. In Spain, previous studies on gender roles and the division of unpaid work in the household have shown that women's specialisation in caring activities does not depend on their relative work productivity or their spouses' earnings but is more linked to social and cultural factors (Sevilla-Sanz et al., 2010). Even with increasing female educational achievement, differences in the labour market—such as the pay gap and the glass ceiling—and in the distribution of roles persist (García-Román, 2023). The recent evolution in the workplace is slowly changing the perception

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of gender stereotypes, and data on time use show a reduction in the difference between men and women—despite women still spending more time on household chores and caring activities (Lopez-Zafra and Garcia-Retamero, 2021). Education and marital status are factors that still largely determine women's lifestyles in Spain (Moreno, 2010). In the XXI century, however, some of those factors are slowly changing. For example, increasing immigration has resulted in a decrease in the cost of domestic services, which has allowed an increase in the number of skilled Spanish women in the labour force (Farré et al., 2011). As a result, the activity gap in the country has decreased rapidly compared to that in other EU countries since 1995 (Cipollone et al., 2014).

Consumption decisions are also influenced by differences in attitudes and perceptions between women and men. The link between sustainability and gender has been confirmed in many studies (McCright (2010); Brough et al. (2016); Brough et al. (2016); Vicente-Molina et al. (2018); Fan and Joffre (2020); Zhao et al. (2021); Bloodhart and Swim (2020); The Planet App (2021); IPCC (2022)). According to McCright (2010), women are more knowledgeable about climate change than men. Furthermore, women express slightly more concern about climate change, which is related to their tendency to be more altruistic and empathetic than men (Dietz et al. (2002)). It is clear, therefore, that there are differences in attitudes and perceptions that are determined by gender roles and the different socialisation processes. Indeed, women receive a type of education based on the ethic of care (Toro and Rojas (2005); Zelezny et al. (2000)), which leads them to assume the role of caregivers for both the household and the planet.

Furthermore, there is an interaction between gender and other socioeconomic characteristics, providing some heterogeneity even within male or female environmental awareness and attitudes. Previous studies using surveys have found that environmental behaviour in Spanish women increases with age until 60–65 years old and decreases slightly afterwards, while the factors of marital status and living with others are not found to be significant (Casaló and Escario, 2018).

The factors mentioned above affect the lifestyles of women and men, which in turn have an effect on their consumption and emission patterns. There are significant differences by gender, especially for certain goods and services. In terms of mobility, women are more conditioned by their caring activities and household chores, even when they have a paid job (Kawgan-Kagan (2020), Banda García (2012)). Women are more likely to use public transport more frequently, even in households with more than one vehicle, and their commutes tend to be more complex due to the double burden of balancing work and family responsibilities. In addition, women's commuting typically involves shorter distances, in many cases due to the nature of their jobs—mainly associated with services and located close to urban areas—and their working part-time jobs. In contrast, men's mobility is characterised by commuting longer distances in private vehicles (Ortiz et al. (2021); Ciocoletto (2014); Ng and Acker (2018); Fan and Joffre (2020); Closingap (2019); Johnsson-Latham (2007); Red2Red Consultants (2014)). Nevertheless, it has been found that Spanish women with higher education, no family responsibilities and no partner have similar commuting patterns to men in similar circumstances (Casado-Díaz et al., 2023).

Another consumption category showing considerable differences by gender is that of food. The consumption of animal products is associated with a larger carbon footprint, as 58% of all emissions from the food system are related to animal products, according to Poore and Nemecek (2018). Multiple studies have shown gender differences in food consumption patterns (Díaz (2017); Schösler et al. (2015); Räty and Carlsson-Kanyama (2010); Fan and Joffre (2020); Modlinska et al. (2020); Rosenfeld and Tomiyama (2021); Carlsson Kanyama et al. (2021)), indicating that men spend more on meat and alcoholic beverages, while women consume more fruits and vegetables. Women are also more likely to follow vegan or vegetarian diets, which are considered to be "less masculine" than meat-based diets. In addition, men also stand out for eating out more frequently (Osorio and Tobarra (2022); Red2Red Consultants (2014)). This trend has been confirmed for Spanish society ((Chiara and Alamillo-Martínez, 2012); (Martín Palomo, 2014)) and is linked to gender roles, with women cooking and taking care of household chores (private dimension) to a greater extent and men generally disengaging from these activities in favour of eating out (public dimension). This gender dimension also interacts with other characteristics, such as age, with Spanish female adolescents' and adults' meat intake being found to be higher than that for women over 65, while the reverse is true for vegetables and fruits (Partearroyo et al., 2019).

In this context, we assess the influence of gender on the consumption and carbon footprints of Spanish households, looking at both levels and patterns. Given that income is the main driver of the household carbon footprint (Druckman and Jackson (2016); Wiedmann et al. (2020); Christis et al. (2019)) and that women's wages are still 37% lower than men's wages globally (World Economic Forum (2021)) and 16% lower nationally (Government of Spain, 2022), we expect women to spend less than men. This lower consumption could largely determine our carbon footprint results. However, it is worth noting that a lower level of consumption does not necessarily mean a lower impact on the environment since lower spending on products with a higher emission intensity—measured in CO_2 per euro spent—could be more polluting. It is therefore important to look at patterns, not just levels, to understand the link between gender and emissions.

Previous research has studied differences in consumption and emissions by gender but has faced important limitations stemming from the complexity of measuring gender with the available household data. In fact, only a few studies (Toro et al. (2019); Druckman et al. (2012)) have conducted gender-focused analyses, with the results showing significant differences in the carbon footprints between women and men. Our research departs from those studies in several ways. First, while the research by Toro et al. (2019) uses a national input–output framework to compute household carbon footprints, in our case, we use a multiregional framework. This approach allows for a more precise calculation of emissions and an appropriate allocation of final responsibilities. Furthermore, in the abovementioned study, gender is only considered through single-person households, i.e., male or female, without considering other types of families. On the other hand, Druckman et al. (2012) analyse emissions per unit of time for different types of activities with a gender dimension, thereby using a unit of measurement that is different from that used in our study. Last, other studies (Carlsson Kanyama et al. (2021), Ivanova et al. (2018), Büchs and Schnepf (2013)) have explored the gender effect on consumption-based emissions as a secondary issue without fully focusing on it, as our study does.

The key feature of our research is that we look at disparities in consumption and carbon emissions by gender using a new indicator, namely, "the female share in the household". This indicator is defined as the percentage of women in the household in relation to the total number of members over the age of 13. Avoiding the dichotomous classification of households allows us to consider household gender as a continuous variable and to include all households in the analysis instead of focusing on a reduced part of the sample with very peculiar characteristics, i.e., single-person households. Studies using this approach account for only 26% of all households and thus are clearly not representative of Spanish society in terms of either size or characteristics. Moreover, considering only the reference people is particularly misleading in the Spanish case, as 68% of all households in Spain have a male main breadwinner in a population that is 51% female. This is the result of socioeconomic (rates of employment, wages, industries), cultural, and anthropological characteristics of Spanish society compared to other EU countries. Our "female share" variable avoids the fundamental biases of the previous literature, which omits many observations or renders invisible a large part of the consumption decisions made by women. Furthermore, we isolate the gender effect in the presence of other factors by estimating econometric models that explain the carbon footprints of Spanish households. These econometric models allow us to find out whether the "female share" is significant in determining emissions after controlling for all other relevant factors, such as income, location, or age.

To carry out this analysis, we use microdata from the Household Budget Survey (INE, 2023b), which collects detailed data on the consumption expenditure of Spanish households for the year 2015. To account for the total (direct and indirect) input requirements for that consumption, we rely on the World Input–Output Tables (WIOD) in their last update of 2016 (Timmer et al., 2016; Timmer et al., 2015). We also use the emissions vector $\hat{e}$ (expressed in CO_2 kilotonnes) provided by the Joint Research Centre (Corsatea et al., 2019). Before performing the carbon footprint calculations that combined both types of information (survey and input–output), some transformations are carried out to homogenise and reduce potential biases in the data. Regarding the econometric analysis, several models are estimated to explain the total household carbon footprint, and sectoral models are included to examine the main determinants of the carbon footprint, namely, food, restaurants and hotels, transportation and housing supplies.

Thus, the novelty of our work is twofold. First, we calculate the carbon footprints of Spanish households, adding methodological improvements in the combination of household survey data with input–output models. Second, we propose a new approach that includes gender as an explanatory variable of household carbon footprints, which allows us to consider all households within the survey in the analysis and present them according to their "female share". In this way, a more realistic, comprehensive, and informative analysis of the role of gender in household carbon footprints is possible.

The article is structured as follows. Section 2 explains the methodology used to calculate the carbon footprints of households and the econometric methods applied, including the basic equations and data treatment. Section 3 presents and discusses the results obtained from the analysis. Section 4 outlines the main conclusions and policy implications drawn from our findings.

2. Methodology and data

2.1. Calculation of household carbon footprints

In this study, we calculate two types of household carbon footprints: 1) the total household carbon footprint ($THCF_h$), which represents the global emissions for that household h both as a direct result of that household burning fuels (home heating, vehicles, etc.) and those which are embedded in all the goods and services consumed by that household (both directly while providing a good or service and indirectly as generated in all previous stages of production); and 2) the sectoral household carbon footprint ($SHCF_h$), which includes direct and indirect emissions again for household h but only those that are related to a specific sector (such as food or transport).

The total carbon footprint for household h ($THCF_h$) can be calculated as shown in Eq. (1):

$$THCF_h = iHCF_h + dHCF_h \tag{1}$$

where $iHCF_h$ gathers all the emissions directly and indirectly generated through the global value chains to satisfy the household final demand, and $dHCF_h$ includes emissions produced directly by the household due to its demand for energy goods.

The sectoral household carbon footprints are subsets of the total footprint, restricted to emissions from a particular industry or energy use (including both direct and embedded emissions). Four categories will be considered in our results: food, restaurants, transport, and housing.

2.1.1. Emissions embedded in goods and services

The indirect carbon footprints *(iHCF)* are computed based on an environmentally extended multiregional input–output (EEMRIO) model, which captures all emissions generated along the production chain of the goods and services consumed by the household. In this way, we can provide a measure of the full responsibility of households in CO_2 emissions due to their consumption decisions, following the growing literature on carbon footprint and consumer responsibility (López et al. (2016) Ivanova et al. (2017); Christis et al. (2019); Long et al. (2021); Tomás et al. (2020)).

The input–output methodology developed by Leontief and Ford (1972), which allows the analysis of the interlinks between all industries and regions in production, has subsequently been applied for the calculation of different types of impacts from production and consumption activities. Recently, various studies have calculated water footprints (Cazcarro et al. (2014), Mekonnen and Gerbens-Leenes (2020)), material footprints (Lenzen et al. (2022)), López et al. (2017)), emissions into the atmosphere (Cadarso et al. (2022)) and social impacts (García-Alaminos et al. (2021)). Within this general topic, the specific calculation of household footprints is also becoming increasingly relevant in recent literature (Salo et al. (2021), Feng et al. (2020), Hernández and Vita (2022), Lévay et al. (2021)).

This EEMRIO methodology calculates a set of multipliers that include the relevant impact, including all stages of production that are then applied to a particular vector of demand that comprises the set of all demanded goods and services regardless of their origin. This can be summarised (Miller and Blair (2009)) in Eq. (2), where we specifically consider our case of interest (CO_2 impact from household demand):

$$iHCF_h = \hat{e} \cdot L \cdot \widehat{HD} = \hat{e} \cdot (I - A)^{-1} \cdot \widehat{HD} \tag{2}$$

where $iHCF_h$ represents the total emissions embedded in producing the goods and services that are demanded by household h; $\hat{e}$ is the diagonalised vector of direct CO_2 emissions per unit of output in each sector of each region; L is the Leontief inverse matrix calculated from the identity matrix I and the matrix of technical coefficients A; the multiplication of the two first components provides the carbon multipliers; and $\widehat{HD}$ is the diagonalised matrix of Spanish household h's final demand for each sector and region.

Eq. (2) can be expressed in matrix form for a simplified economy, assuming two regions (r,s) and two sectors (i,j) as follows:

$$iHCF_h = \begin{pmatrix} E_{ii}^{rr} & E_{ij}^{rr} & E_{ii}^{rs} & E_{ij}^{rs} \\ E_{ji}^{rr} & E_{jj}^{rr} & E_{ji}^{rs} & E_{jj}^{rs} \\ E_{ii}^{sr} & E_{ij}^{sr} & E_{ii}^{ss} & E_{ij}^{ss} \\ E_{ji}^{sr} & E_{jj}^{sr} & E_{ji}^{ss} & E_{jj}^{ss} \end{pmatrix}$$

$$= \begin{pmatrix} e_i^r & 0 & 0 & 0 \\ 0 & e_j^r & 0 & 0 \\ 0 & 0 & e_i^s & 0 \\ 0 & 0 & 0 & e_j^s \end{pmatrix} \cdot \begin{pmatrix} L_{ii}^{rr} & L_{ij}^{rr} & L_{ii}^{rs} & L_{ij}^{rs} \\ L_{ji}^{rr} & L_{jj}^{rr} & L_{ji}^{rs} & L_{jj}^{rs} \\ L_{ii}^{sr} & L_{ij}^{sr} & L_{ii}^{ss} & L_{ij}^{ss} \\ L_{ji}^{sr} & L_{jj}^{sr} & L_{ji}^{ss} & L_{jj}^{ss} \end{pmatrix} \cdot \begin{pmatrix} HD_i^{rr} & 0 & HD_i^{rs} & 0 \\ 0 & HD_j^{rr} & 0 & HD_j^{rs} \\ HD_i^{sr} & 0 & HD_i^{ss} & 0 \\ 0 & HD_j^{sr} & 0 & HD_j^{ss} \end{pmatrix}.$$

where E_{ij}^{rs} represents emissions generated in industry i and region r to provide the demand of a final product of sector j demanded in region s. We obtain the total embedded carbon footprint by adding the resulting expression by columns. This expression indicates all the emissions incorporated in all inputs (for all industries and regions of origin of those inputs) required to produce the household's final demand for that product and region.

This equation requires 1) data on the specific CO_2 emissions for each industry and region, 2) data on input–output matrices, and 3) data on household demand. The input–output data are provided by the 2016 WIOD database (Timmer et al. (2015); Timmer et al. (2016)), and the emissions data (in CO_2 kilotonnes) are provided by the European Commission's Joint Research Centre (Corsatea et al. (2019)). These data allow us to calculate the emissions multipliers. The households' final demand is obtained from the Household Budget Survey (HBS), provided by the Spanish Statistical Office (INE (2023b)). The HBS data not only

Table 1
Emission factors of energy goods (COICOP categories).

	Energy goods			Emission factors	
Housing	4511	Electricity (main dwelling)	*kWh*	0	$kgCO_2/\ kWh$
	4512	Electricity (other dwellings)	*kWh*	0	$kgCO_2/\ kWh$
	4521	Gas (main dwelling)	m^3	0.182	$kgCO_2/\ kWh$
	4522	Gas (other dwellings)	m^3	0.182	$kgCO_2/\ kWh$
	4523	Liquefied gas (main dwelling)	*kg*	2.951	$kgCO_2/\ kg$
	4524	Liquefied gas (other dwellings)	*kg*	2.951	$kgCO_2/\ kg$
	4531	Liquid fuel (main dwelling)	*l*	2.868	$kgCO_2/\ l$
	4532	Liquid fuel (other dwellings)	*l*	2.868	$kgCO_2/\ l$
	4541	Solid fuel (main dwelling)	*kg*	2.439	$kgCO_2/\ kg$
	4542	Solid fuel (other dwellings)	*kg*	2.439	$kgCO_2/\ kg$
Transport	7221	Fuels and lubricants	*l*	2.388	$kgCO_2/\ l$

Source: The demand for energy goods in physical units was obtained from INE (2023b).

detail Spanish households' consumption expenditures but also supply information about their members' characteristics for over 22,000 households representative of Spanish society. Due to its sample size and design, the HBS survey allows precise and robust estimations.

As input–output tables conform with national accounts (NA) principles, we need to align the HBS microdata with those principles to build the relevant demand vectors HD. Four transformations to these data were implemented, following (Cazcarro et al., 2020) to avoid several potential biases.

First, it is necessary to adjust the population value using a correction factor, as the HBS does not match the population census used by NA (INE (2023d)). Second, each of the HBS COICOP categories must be readjusted (uprated/downrated) to fully match the reported data according to COICOP-NA categories in NA. This is due to some expenses that families do not report or that they under- or overreport with regard to their actual spending.

After the alignment, the data classified according to the Classification of Individual Consumption by Purpose (COICOP) must be converted to the Classification of Products by Activity (CPA), which is the European version of the Central Product Classification (CPC) recommended by the United Nations Organization for NA (INE, 2023c). We use a bridge matrix that presents the CPA products in rows and the COICOP products in columns, provided by Cazcarro et al. (2020) for 2010. As the HBS data used in this study correspond to 2015, the GRAS method is applied using the code for MATLAB by (Temurshoev, 2022), which is described in (Temurshoev et al., 2013).

The next step is based on revaluating the data obtained from the previous step, which are valued at purchasers' prices, into basic prices. To carry this transformation out, taxes less subsidies on products (excluding deductible taxes such as VAT) must be subtracted, and the transport and trade margins must be reallocated to their specific sector. As these data on tax percentages and margins for the Spanish economy are not publicly available, we use the estimated data from (Cazcarro et al., 2020).

Furthermore, the data must be adapted to the specific input–output format. As the I–O table to be used is presented in the industry-by-industry format, the data must be adjusted from a product classification (CPA) to an industry classification (ISIC) using the so-called "Model D", as explained in the Handbook on Supply Use and Input–Output Tables of the United Nations (Mahajan et al., 2018).

In the last step, the demand for each industry must be allocated by country of origin. As the HBS does not provide this information, we use the distribution by country provided by the WIOD database for the global Spanish household demand for each industry. The resulting vector of demand for household h is a column vector of 2464 elements (56 sectors, 44 geographical regions) that, when included in Eq. [2] above, provides, for each household h in the sample, a 2464 × 2464 matrix of emissions, that can be added up for particular industries or all emissions to provide the whole carbon footprint for that household.

For the sake of clarity, the results are shown aggregated into the following thirteen sectors: agriculture and manufacturing of food products; mining and quarrying; manufacturing; electricity, gas, and water supply; construction; wholesale and retail trade, repair of motor vehicles, motorcycles, and personal and household goods; hotels and restaurants; transport and storage[1]; communications; financial intermediation, real estate, renting and business activities; public services; and other services.

2.1.2. Emissions directly produced by the household

The direct carbon footprint (*dHCF*) measures the CO_2 directly produced in households due to their energy consumption. Ten categories for the energy goods related to housing supplies (electricity, gas, and different types of fuels) and one category for the energy goods related to private transport are extracted from the HBS (INE (2023c)). Therefore, we calculate $dHCF_h$ for each household h, including all energy goods, using emissions factors provided by MITECO (2023) and combining them with the HBS energy consumption data, as expressed in physical units. Specifically, the equation is as follows:

$$dHCF_h = \sum_e f^e \cdot c_h^e \tag{3}$$

where f^e is a vector of direct emissions factors that indicates the CO_2 emissions per unit consumed for e energy goods, and c_h^e is a vector that contains the basket of e energy goods consumed by an h Spanish household. For the calculation of sectoral footprints, we divide those direct emissions into two categories (housing and transport), as shown in Table 1.

Direct emissions factors were obtained from MITECO (2023).

The conversion factor from m^3 to kWh was obtained from BOE (2017).

2.2. Regression analysis and methodological considerations

Each household h included in our sample consumes goods and services, which allows us to calculate its carbon footprint. On the other hand, gender is collected in the survey as information for each individual within each household. This makes sense since gender is something tied to individuals and not to households, except in the case of single-person families. Since carbon footprints are calculated for households and the gender dimension is captured for individuals, the assessment of their relationship (partial effect) is not straightforward.

Different strategies have been devised to overcome this issue thus far. One of the approaches that has been previously followed is

[1] The sector "transport and storage" only includes transport services (land, air and water transport) and warehousing, while vehicle production and fuel are included in "manufacturing", and vehicle repair is included in "wholesale and retail trade; repair of motor vehicles, motorcycles; and personal and household goods", following WIOD sector classification.

comparing the carbon footprint of single-person households formed by a woman or a man (Carlsson Kanyama et al. (2021); Räty and Carlsson-Kanyama (2010); Toro et al. (2019)). Some of these studies rely on a simple comparison of the carbon footprints of single-person households (Carlsson Kanyama et al. (2021); Räty and Carlsson-Kanyama (2010)). Although their findings are certainly revealing, they only allow one to determine whether women's single-person households emit, on average, more than men's single-person households or vice versa. However, they cannot determine the causal relationship between gender and household carbon footprint. Toro et al. (2019) employ regression analyses to achieve the abovementioned goal. However, they only take into account a part of the total population under study (i.e., single-person households) to infer the causal relationship between gender and household carbon footprint. Thus, their results are not based on the whole population and therefore do not allow general conclusions to be drawn from them. Another approach is to use the gender of the household head to infer its effect on the carbon footprint of households (Ottelin et al. (2020)). This variable is defined for each household, so it can be used as an explanatory variable for household carbon footprint in a regression analysis, inferring results for the entire population. Nevertheless, the gender of the household head explains only a part of the intrahousehold consumption behaviour. In this sense, this variable can be considered an inaccurate indicator for gender at the household level.

In this work, we propose a new indicator to help overcome the limitations mentioned above, namely, the female share in the household. This gender-related indicator is calculated considering only household members over 13 years of age. It represents the percentage of females over the total number of individuals in the household. Thus, the female share ranges from 0 to 1, where 0 indicates no females over 13 years of age in the household, and 1 implies that all individuals over that age are female. Out of a total of 22,120 households, almost 50% present a female share score between 0.4 and 0.6, only 9% present a female share score between 0 and 0.2, and 15% of the total households present a share score between 0.8 and 1 (see Annex 2 for detailed statistics).

Once we define the variables of interest, we formalise multivariate regression models estimated by ordinary least squares to understand how gender affects household carbon footprints in Spain. Many studies have used these models to determine the drivers of households' environmental impacts (see, among others, Baiocchi et al. (2010); Ivanova et al. (2016); Ottelin et al. (2020); Salo et al. (2021)). In this case, we aim to estimate the expected value of the household carbon footprint conditional on the female share and a set of control variables.

We consider three different models for which the dependent variable is the household's total emissions (i.e., *THCF*). In Model 1, we use the female-headed household to capture the effect of gender on emissions. In Models 2 and 3, on the other hand, we measure this effect using the female share in the household. The difference between the latter two models is the way in which income is introduced. In Model 2, income is considered as a numerical variable, while in Model 3, it is categorized into ten deciles. This change allows us to examine how consistent our results are when the income variable, which is the main determinant of household carbon footprints, is introduced in different ways.

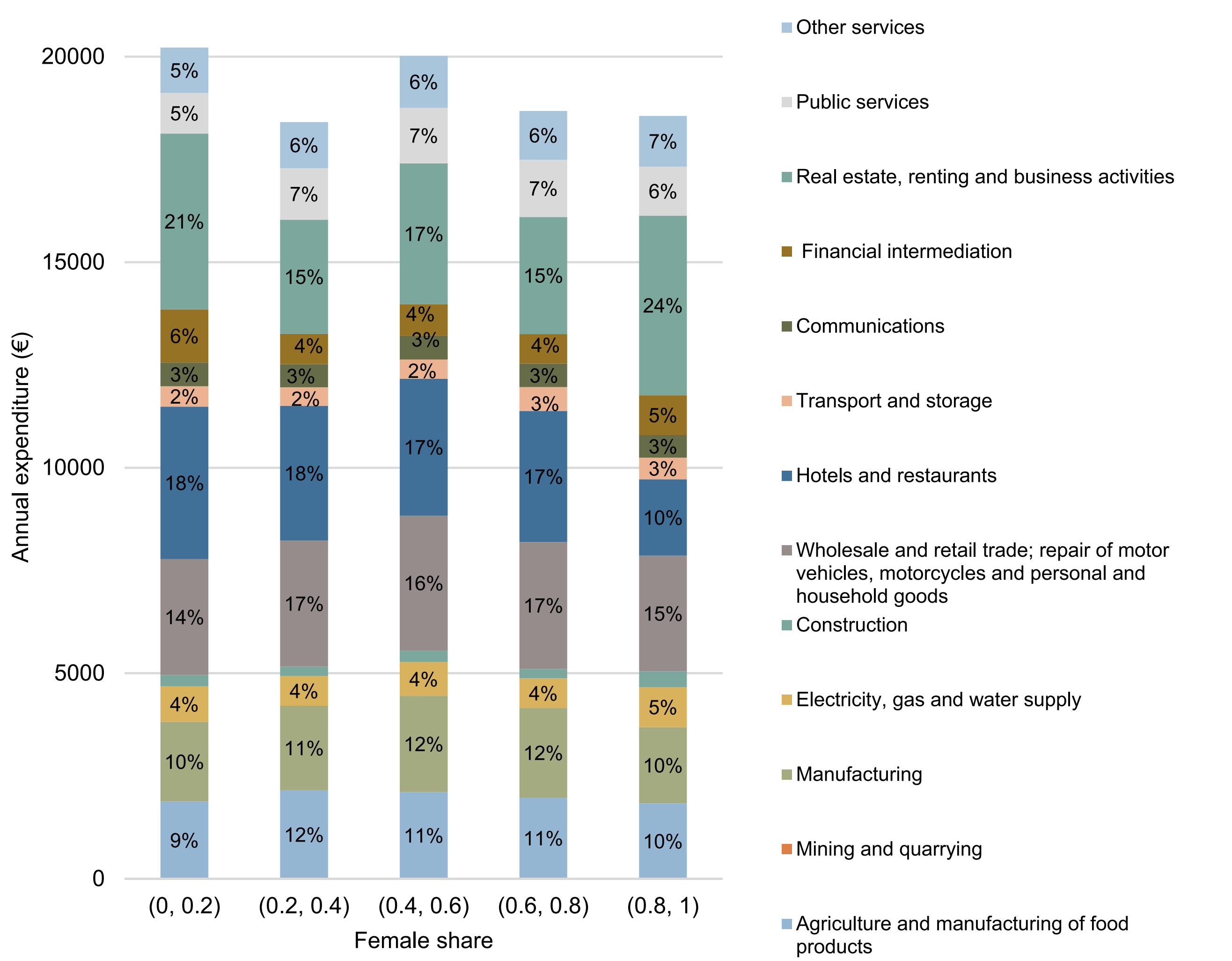

Fig. 1. Average expenditure by ECU in households, by female share in 2015 (€).
(Source: Own elaboration)

Furthermore, we estimate models for which the variable explained is the household's total emissions in a specific sector k (i.e., $SHCF^k$). Note that $k = 1, \ldots, K$, with K being equal to the number of sectors for which a model is specified; in this case, there are four sectors, namely, transport, food, restaurants and hotels, and housing.[2] The form of the models is given by the following:

$$ln(THCF)_h = \alpha + \beta ln(Gender)_h + \sum_{s=1}^{S} \gamma_s {Z^s}_h + u_h \quad (4)$$

$$ln\left(SHCF^k\right)_h = \alpha + \beta ln(Gender)_h + \sum_{s=1}^{S} \gamma_s {Z^s}_h + u_h \quad (5)$$

where α is a constant; β is the parameter of interest that determines the relationship between gender and emissions; γ_s represents parameters to be estimated for $s = 1, \ldots, S$, with S being the total number of controls; *Gender* stands for the variable that represents the gender, that can be the female-headed household or the female share depending on the model; Z^s contains S socioeconomic and demographic variables used as controls; and u is a random error. Note that *THCF*, $SHCF^k$, the female share and any other numerical variable used in the models is expressed in Napierian logarithms.[3] β may be interpreted as an elasticity between either the total or per sector household emissions and gender.

Our econometric models include relevant factors affecting household emissions as regressors. It is essential to correctly estimate the partial effect of the female share of households on their carbon footprints. Previous literature has thoroughly assessed the drivers of household carbon footprints. We refer here to Druckman and Jackson (2016) for a detailed overview. These authors, based on evidence from multiple works, identify income as the main driver. This variable is included in the HBS and could therefore be used as a control in our models; unfortunately, it is of poor quality. The reason is that the information on income in the HBS is collected in a rough fashion (i.e., through few and general questions) compared to the detail and large number of questions considered in the Spanish Statistics on Income and Living Conditions (SILC) (INE (2023a)). Therefore, we impute the total household disposable income variable from the SILC into the HBS data using a statistical matching procedure performed for the reference year of the HBS data used. We refer to Tomás et al. (2021) for further details on the statistical matching procedure implemented. Another important aspect is that economies of scale arise in households with a larger number of members. This is taken into account in our analysis by using equivalent consumption units (ECUs) according to the modified OECD equivalence scale. In addition, we control for other variables, such as household size, housing type, age, education, region, or household location. More detailed information on all the variables used is provided in Annex 1. Finally, it is important to mention that the raw survey data have been treated appropriately. First, we exclude from the analysis some records following economic criteria. This implies that households with an annual expenditure/income close to 0 are eliminated. Second, we address outliers using a statistical criterion whereby the extremes of the distribution of the endogenous variable are eliminated. At the end of the cleaning process, approximately 5% of the sample is discarded, which means that approximately 21,059 households are included in the sample.

3. Results

3.1. Exploratory analysis

This section shows the exploratory analysis of the consumption and carbon footprint data of Spanish households prior to outlier treatment. These results emphasise the differences found in households according to female share per ECU with the aim of comparing families/multiperson households with people living alone.

First, analysing the expenditure of these equivalised households allows us to obtain a panoramic view of the type of data used in the calculation of the carbon footprints (both scale and distributional effects). An average household spends approximately 19,423€ per year (in basic prices, in ECU). Most of the final demand of an average household is explained by spending on agriculture and manufacturing of food products, other manufactures, wholesale and retail trade (that includes repair of motor vehicles, motorcycles, and personal and household goods), hotels and restaurants, and real estate, renting and business activities. Differentiating by female share, households with the lowest share (mostly formed by a man living alone) have an annual expenditure per ECU that is 8.9% higher than that of households with the higher share (mostly formed by one woman). Regarding mixed households, which take advantage of economies of scale in the household, the level of expenditure is 18,408€ when the female share is approximately 20–40%, 20,018€ when the share is between 40 and 60%, and 18,678€ when it is between 60 and 80%.

As Fig. 1 shows, households with the lowest female share spend 3% more on food within the home, although the share of total spending is quite similar, and they spend 99% more on restaurants and hotels (114% more on restaurants and 40% more on accommodation), which represents 8% more over total spending in comparison with households with the highest female share. In addition, households with the lowest female share spend 11% less on housing supplies and 5% less on transport, although the sector called “transport and storage” only includes services (land, air, and water transport). These differences in housing supplies and transport are only relevant in terms of expenditure level since the share of total spending is practically the same. Regarding real estate, renting, and business activities, this sector represents the largest percentage of total expenditure, accounting for 21% of total spending in households with the lowest female share and 24% in households with the highest female share.

Moving on to mixed households, the presence of several women and men in the household does not allow us to isolate gender. However, it does allow us to analyse the particularities of households with several members. Due to the advantages of economies of scale, mixed households reduce spending per ECU, and this is reflected in both their level and pattern of consumption. For example, the share of spending on real estate, renting, and business activities is reduced compared with that of single-person households. Therefore, a greater part of spending goes to other purposes (food, manufactures, wholesale and retail trade, restaurants, etc.).

In terms of the carbon footprint, an average household emits 7.24 tCO_2 per ECU, although this amount differs considerably according to income, female share, and other uncontrolled factors. Specifically, households with the lowest female share have a carbon footprint of 6.9 tCO_2, which is 11% larger than that of households with the highest female share (6.2 tCO_2). Regarding mixed households, the carbon footprint is 7.27 tCO_2 when the presence of women in the household is 20–40%, 7.62 tCO_2 when the presence of women is between 40 and 60%, and 7.25 tCO_2 when the presence of women is between 60 and

[2] Transport carbon footprint includes emissions embedded in goods and services from the air and land transport industries, as well as direct emissions from the combustion of fuels for private transportation; Food carbon footprint accounts for emissions embedded in goods and services from agriculture, fishing and food manufacturing activities; Restaurants and hotels carbon footprint comprises emissions embedded in goods and services from hotels and restaurants related activities; Housing carbon footprint takes into account the emissions embedded in goods and services from emissions from the supply of electricity, gas, steam and air conditioning and those related to coke and refined petroleum activities, and direct emissions generated in homes burning energy products.

[3] Notice that zeros are avoided when transforming the variables into Napierian logarithms by approximating them to zero from the positive side. This applies to all variables of models expressed in Napierian logarithms.

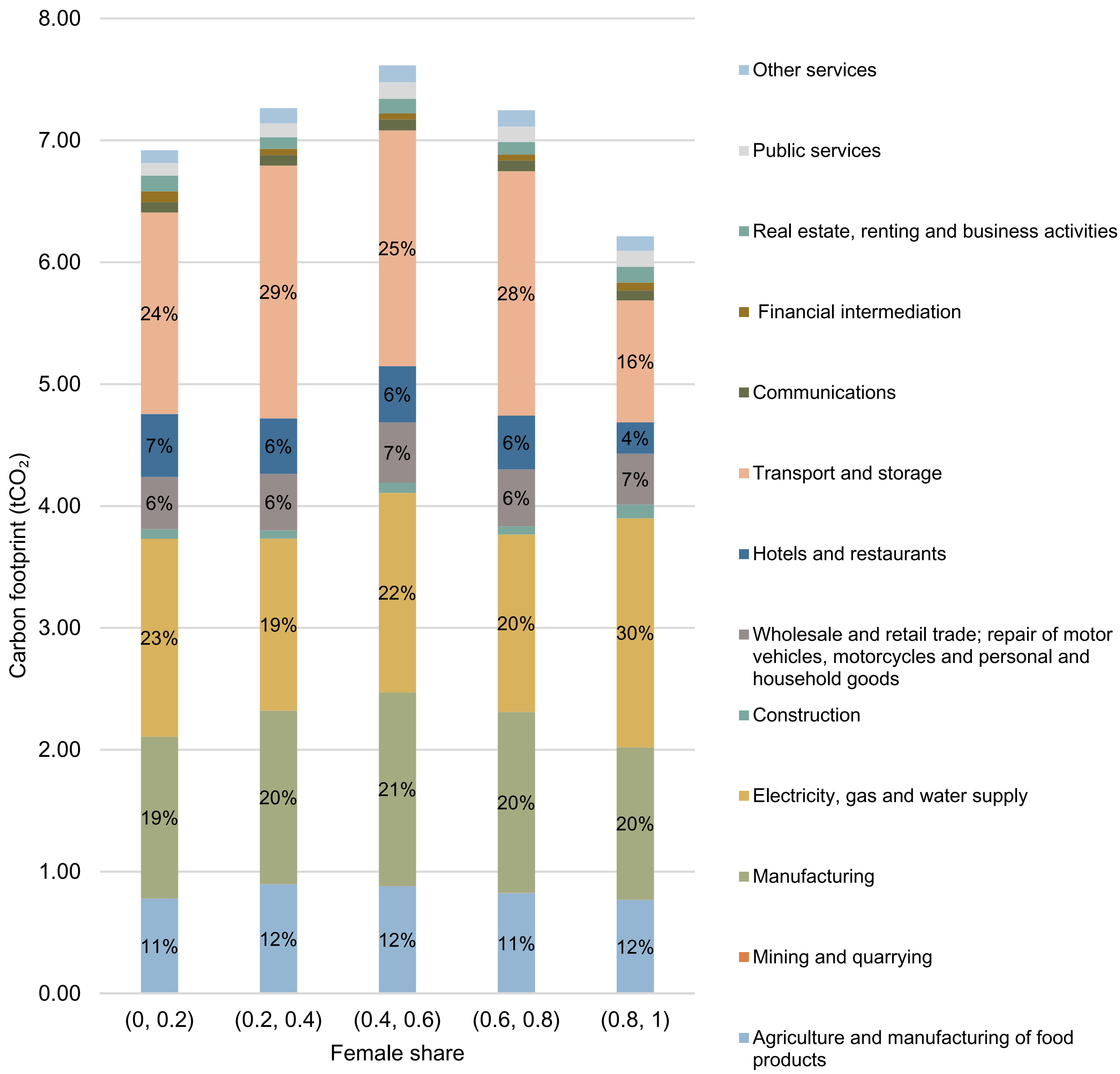

Fig. 2. Average carbon footprint by ECU in households, by female share in 2015 (tCO_2).
(Source: Own elaboration)

80%.

It is crucial to analyse the differences in households both in the generation of emissions by sector (the total amount) and in the share of emissions (Fig. 2). Households with the lowest female share emit twice as much emissions in regard to restaurants and hotels (256 kg CO_2), 65% more in regard to transportation (653 kg CO_2), and 6% more in regard to manufacturing (76 kg CO_2), while they emit 14% less in regard to electricity, gas, and water (255 kg CO_2 less) compared to the highest female-share households. Regarding the pattern of emissions, the electricity, gas, and water sector accounts for 23% of the total carbon footprint in the lowest female-share households, while in the highest female-share households, it reaches 30%. There are also notable differences in transport since there is a greater share of the total carbon footprint in households with a lower female share (24% vs. 16%), as is the case for hotels and restaurants (7% vs. 4%). With respect to mixed households, their emissions from household supplies are reduced due to the advantages of economies of scale; therefore, their share of the total emissions is reduced, while the share of emissions associated with transport is increased.

Thus far, we have only considered spending and emission patterns according to the female share. However, it is still necessary to consider all remaining factors, as is done in the next section. For example, households with a higher female share are mostly single-woman households, are older than single-man households (61 vs. 54 years on average) and have lower incomes. Households with lower incomes tend to emit less due to their level of consumption. At the same time, they have a higher share of spending on “basic” needs (e.g., heating or cooking). Given the considerable differences in emissions associated with income level and age, it is necessary to analyse emission patterns with these characteristics at stake (Fig. 3 and Fig. 4).

Three conclusions can be drawn from Fig. 3. First, the higher the income is, the larger the carbon footprint is, although the relationship is not completely linear. Second, gender differences depend on income quintiles. Specifically, in regard to income quintiles Q1, Q2, and Q5, households with a low female share have a larger carbon footprint, although in Q3 and Q4, these households have a smaller carbon footprint than households with the highest female share. Third, the carbon intensity of households with a lower female share is higher than the carbon intensity of households with a higher female share; specifically, the most significant differences are found in Q2 and Q3. Furthermore,

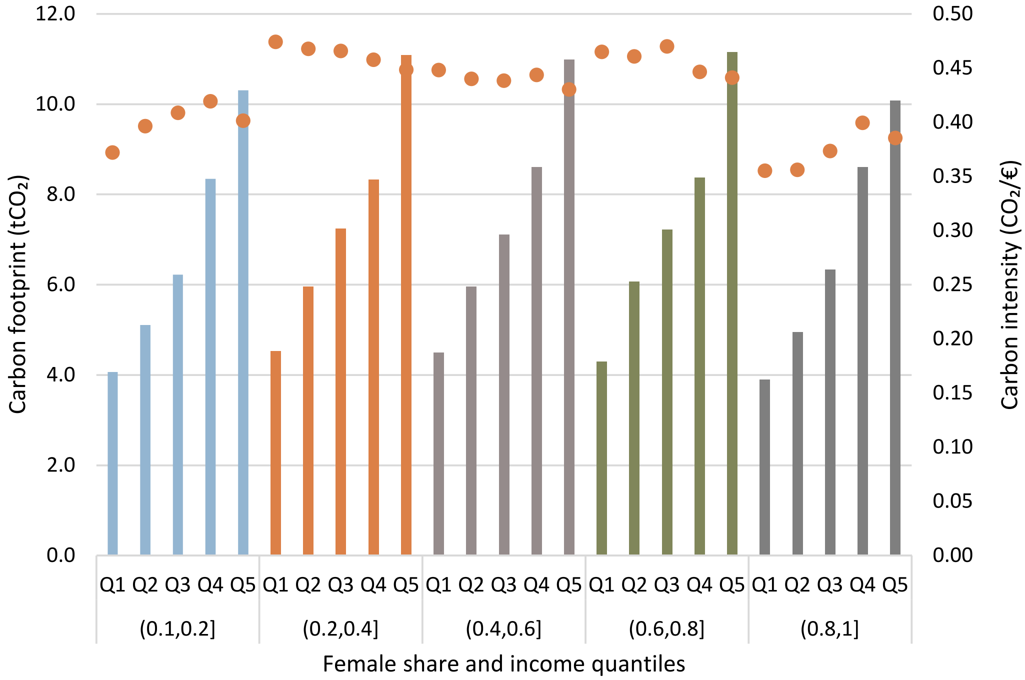

Fig. 3. Carbon footprint (tCO_2, bars) by ECU and carbon intensity (CO_2/€, dots), according to income quintiles and female share in households in 2015. (Source: Own elaboration)

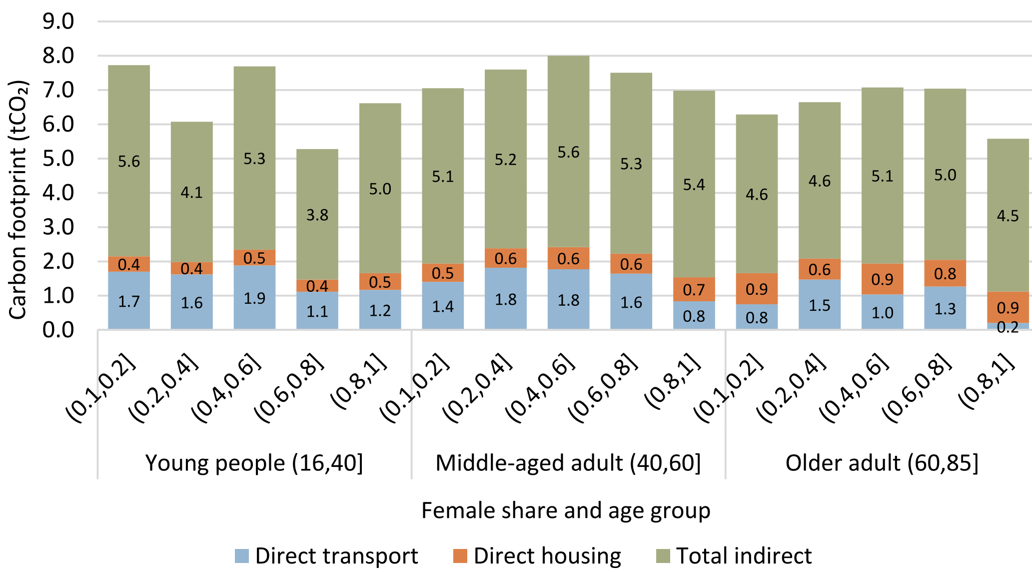

Fig. 4. Carbon footprint (tCO_2) by ECU according to age group and female share in households in 2015. (Source: Own elaboration)

households with 0–20% and 80–100% female shares (mostly one-person households) have a much lower carbon intensity than mixed households. These differences in carbon intensities by gender and income are due to the different emissions patterns discussed above.

To obtain a more complete picture, Fig. 4 delves into gender differences by emphasising the average age of the household, considering its members over the age of 13. Household emissions fluctuate over the life course. Starting with young people, their carbon footprint reaches 6.7 tCO_2; this footprint then increases to 7.4 tCO_2 for middle-aged people, and finally decreases to 6.5 tCO_2 for older adults. The highest direct transport emissions are emitted by young people, but they emit the lowest direct housing emissions; however, for older people, more CO_2 is emitted in regard to heating and cooling dwellings. Many studies have confirmed that older people tend to have higher emissions related to housing, as they are more sensitive to extreme temperatures, stay at home for longer periods of time, and experience accompanying changes in dwelling size, among many other factors (The Planet App (2021); (Chancel and Piketty, 2015; Estiri and Zagheni, 2019; Long et al., 2019).

If we disaggregate by gender, then the most pronounced differences are found for young people; households with a low female share emit 17% more emissions than those with the highest female share. On the other hand, there is no substantial gap for middle-aged adults, and the gap is approximately 13% for older adults. This is consistent with the results of expenditure patterns and emissions found, since the average age of women is higher and, therefore, they emit more in goods related to life within their homes. This is another example of the lifestyle of older Spanish women, which has a clear link to gender roles, the division of spaces, and the distribution of work (paid and unpaid).

According to the IPCC (2022), the carbon footprint of households (or individuals) is determined by economic and technological factors, psychological, social, and cultural contexts, and environmental and geographical factors. Some of these factors can be easily controlled in a model, and many others need to be approximated with the quantitative information available. Thus, to understand the effect of gender, we go one step beyond the exploratory analysis based on average households by using econometric techniques to quantify and contrast relationships between variables (Section 3.2).

3.2. Econometric results

This section presents the econometric results obtained in the different models considered (Table 2), assessing the role of each exogenous variable in determining household carbon footprints according to Eqs. 4 and 5 in Section 2.2.

The three THCF models (Models 1, 2, and 3) provide an overview of how household economic, demographic, personal, and regional characteristics determine the household carbon footprint. As shown in Table 2, the parameters are significant in most cases, and the models' goodness-of-fit measures are acceptable (adjusted R^2 >40% in THCF models) and in line with the results of previous studies (Pottier, 2022).

Model 1 accounts for the effect of gender through the variable "gender of the head of the household", which is highly significant and negatively related to the carbon footprint (−0.03). This means that the carbon footprint is 3% smaller for female-headed households. However, as we previously argued, this variable may not fully represent the gender effect since it only looks at the head of the family and does not consider the rest of members in the household. A more accurate approach to measure the gender effect is shown in Models 2 and 3. In these two models, the gender effect is measured through the variable we propose, namely, the female share in the household, which accounts for the gender of all household members over 13 years of age. This variable is statistically significant in Models 2 and 3, with a positive elasticity, but is practically 0. This is explained by the fact that most of the differences observed in the previous section (3.1) are explained by the role of income, age, and other effects already controlled for in the model, in addition to the fact that sectoral differences (food, restaurants, transport, etc.) are compensated in a full model.

Given that the main driver of households' carbon footprint is income, the robustness of the models to small variations in this variable is tested in Models 2 and 3. These models explain THCF through the same sociodemographic and regional variables and differ just in the form of measuring income (see Section 2.2 for a detailed explanation). In Model 2, we find an income elasticity of 0.4, which means that a 1% increase in income is associated with a 0.4% variation in the THCF. This finding is in line with previous research on income elasticities (Pottier, 2022). In Model 3, we also capture the effect of income on household carbon footprint by considering the characteristics of the income distribution instead of the mean, via the variable "income deciles". This variable enables us to consider part of the non-linear relationship between emissions and income. Indeed, Model 3 shows that as we move to upper-income deciles, emissions increase with respect to decile 1, but not proportionally.

Regarding sectoral household carbon footprint (SHCF) models, we find that the effect of the female share is significant and positively related to emissions in food and housing, while the female share is negatively related to emissions in restaurants and hotels. Therefore, the more women are in the household, the lower the emission level is in transport, restaurants, and hotels.

These results reinforce the idea that men and women occupy different spaces (inside and outside), perform different types of work (paid and voluntary), and spend their time in different ways. All of these factors have an apparent influence on their carbon footprint. Basically, women spend more time inside the home, as they are responsible for household chores such as cooking and childcare; therefore, they generate more emissions related to food and housing. On the other hand, men spend more time out of the home for work and leisure activities and thus emit more emissions due to related goods and services, such as eating out and commuting. Therefore, a correct interpretation of the results should not lead to the literal conclusion that we have to increase the number of women in the household but rather to explore what would happen to household emissions if there were a change in climate awareness, gender roles, and power dynamics within households.

Apart from the effect of income and gender in household carbon footprints, other factors are found to be relevant. Starting with ECU, this variable is positively related to household carbon footprints (THCF and SHCF), as the more people in the household (weighted persons), the more consumption and the more emissions there will be. For households with larger dwellings, their total carbon footprint is positively related to the size of the house. This is because larger houses take longer to heat and cool, which results in higher household emissions. For household size, it is found that, in general, multiperson households (couples with/without children or other households with/without children) generate more emissions than single-person households; we also find no significant difference between the carbon footprint of a single-person household and that of a single-parent household.

Regarding the elasticities of sociodemographic factors, our model shows that the carbon footprint of a household increases when the head of the household has a higher educational level (except for food and housing carbon footprints) as education modifies behaviour, and lifestyle or social status (Chancel and Piketty, 2015). For example, those with a higher level of education are more likely to travel actively and by air and less likely to use public transport, according to Ivanova et al. (2018). Concerning the relationship between age and household carbon footprint, the elasticity is negative when controlling for other influential factors (such as income and household size), except for food and housing carbon footprints, as we mentioned in Section 3.1.

Both the NUTS region in which the household lives and the area (rural/urban) in which it is located are significant in explaining the total carbon footprint. The NUTS region variable acts as a proxy for the climate zone where the household is located, which conditions the level of emissions since the energy requirements of a household differ according to weather temperatures. Our models show that the household carbon footprint is lower when families live in warm areas (the Canary Islands and the southern area of Spain) compared with households residing in the Community of Madrid (the reference area), which has a continental climate known for its severe cold winters and hot summers. In addition, rural households have a total carbon footprint that is almost 8% larger than that of urban households on average (considering that all other variables remain constant); these differences are magnified when analysed by SHCF.

Overall, our results are consistent with the standard hypotheses of consumption theory, with income being the primary driver of household carbon footprint, although sociodemographic (such as gender, education, household size, age, etc.) and regional variables also play a crucial role. This has already been treated in the literature from different angles (Pottier et al. (2021), Salo et al. (2021), Shigetomi et al. (2021), among many others), sometimes ignoring the effect of gender. In addition, we go beyond regressions for the total carbon footprint and evaluate regressions by sectors, which is an approach that has been barely explored since, to the best of our knowledge, only a few previous studies taken this approach to analysing HBS data (Büchs and Schnepf (2013); Ivanova et al. (2017), Shigetomi et al. (2021)).

3.3. Discussion

Our study offers some advantages over previous research. On the one hand, we propose a new gender-related indicator, namely, the "female share of the household", which allows us to adequately investigate how

Table 2
Results of the estimated multivariate regression models.

	Total household carbon footprint			Sectoral household carbon footprint			
	Model 1	Model 2	Model 3	Transport	Agriculture & manufacturing of food products	Restaurants and hotels	Housing supplies
Intercept	*−1.65 ****	*−1.65 ****	*2.04 ****	*5.51 ****	*−1.69 ****	*1.85 ****	*−2.92 ****
	−0.09	*−0.09*	*−0.07*	*−0.25*	*−0.09*	*−0.2*	*−0.18*
Female-headed household	*−0.03 ***						
	−0.01						
Female share		*0.000485***	*0.000647****	*-0.002413****	*0.001134****	*0.005693****	*0.002379 ****
		0	*0*	*0*	*0*	*0*	*0*
Income	*0.43 ****	*0.44 ****					
	−0.01	*−0.01*					
Income decile 2			*0.25 ****	*0.59 ****	*0.16 ****	*0.72 ****	*0.25 ****
			−0.02	*−0.07*	*−0.02*	*−0.05*	*−0.04*
Income decile 3			*0.41 ****	*0.92 ****	*0.25 ****	*1.13 ****	*0.40 ****
			−0.02	*−0.07*	*−0.02*	*−0.05*	*−0.04*
Income decile 4			*0.56 ****	*1.32 ****	*0.33 ****	*1.43 ****	*0.43 ****
			−0.02	*−0.07*	*−0.02*	*−0.05*	*−0.04*
Income decile 5			*0.61 ****	*1.35 ****	*0.37 ****	*1.74 ****	*0.53 ****
			−0.02	*−0.07*	*−0.02*	*−0.05*	*−0.04*
Income decile 6			*0.72 ****	*1.55 ****	*0.44 ****	*1.95 ****	*0.60 ****
			−0.02	*−0.07*	*−0.02*	*−0.05*	*−0.04*
Income decile 7			*0.81 ****	*1.79 ****	*0.47 ****	*2.15 ****	*0.66 ****
			−0.02	*−0.07*	*−0.02*	*−0.05*	*−0.04*
Income decile 8			*0.84 ****	*1.85 ****	*0.49 ****	*2.27 ****	*0.65 ****
			−0.02	*−0.07*	*−0.02*	*−0.05*	*−0.04*
Income decile 9			*0.96 ****	*2.01 ****	*0.58 ****	*2.57 ****	*0.72 ****
			−0.02	*−0.07*	*−0.02*	*−0.05*	*−0.04*
Income decile 10			*1.07 ****	*2.17 ****	*0.60 ****	*2.82 ****	*0.83 ****
			−0.02	*−0.07*	*−0.02*	*−0.05*	*−0.04*
Equivalent consumption unit	*0.43 ****	*0.43 ****	*0.44 ****	*0.87 ****	*0.83 ****	*0.41 ****	*0.65 ****
	−0.03	*−0.03*	*−0.03*	*−0.11*	*−0.03*	*−0.08*	*−0.06*
Single-parent household with children	*0,05*	*0,02*	*0,00*	*−0,10*	*0.07 **	*0,12*	*0,12*
	−0.03	*−0.03*	*−0.03*	*−0.1*	*−0.03*	*−0.08*	*−0.07*
Couple without children	*0.17 ****	*0.15 ****	*0.13 ****	*0.59 ****	*0.14 ****	*0.44 ****	*−0,06*
	−0.02	*−0.02*	*−0.02*	*−0.06*	*−0.02*	*−0.05*	*−0.03*
Couple with children	*0.12 ****	*0.11 ****	*0.08 ****	*0.29 ***	*0.10 ****	*0.26 ****	*−0,02*
	−0.02	*−0.02*	*−0.02*	*−0.09*	*−0.03*	*−0.07*	*−0.05*
Other households with children	*0.10 ****	*0.09 ****	*0.06 ***	*0.54 ****	*0.10 ****	*0.29 ****	*−0.12 ***
	−0.02	*−0.02*	*−0.02*	*−0.08*	*−0.03*	*−0.07*	*−0.05*
Other households without children	*0.09 ***	*0.06 **	*0,04*	*0.33 ***	*0,06*	*0.20 **	*−0,11*
	−0.03	*−0.03*	*−0.03*	*−0.11*	*−0.04*	*−0.09*	*−0.06*
Big-size house	*0.34 ****	*0.33 ****	*0.34 ****				*0.69 ****
	−0.02	*−0.02*	*−0.02*				*−0.05*
Medium-size house	*0.17 ****	*0.17 ****	*0.16 ****				*0.35 ****
	−0.02	*−0.02*	*−0.02*				*−0.04*
Average age	*−0.23 ****	*−0.24 ****	*−0.21 ****	*−1.95 ****	*0.25 ****	*−1.42 ****	*0.64 ****
	−0.02	*−0.02*	*−0.02*	*−0.06*	*−0.02*	*−0.05*	*−0.04*
High education	*0.09 ****	*0.08 ****	*0.09 ****	*0.34 ****	*−0.03 ***	*0.26 ****	*0,03*
	−0.01	*−0.01*	*−0.01*	*−0.03*	*−0.01*	*−0.02*	*−0.02*
NUTS Canarias	*−0.12 ****	*−0.12 ****	*−0.12 ****	*0.29 ****	*−0,03*	*−0.20 ***	*−0.97 ****
	−0.02	*−0.02*	*−0.02*	*−0.07*	*−0.03*	*−0.06*	*−0.04*
NUTS Central	*−0,03*	*−0,03*	*−0,02*	*−0.48 ****	*0,00*	*−0,02*	*0,04*
	−0.01	*−0.01*	*−0.01*	*−0.05*	*−0.02*	*−0.04*	*−0.03*
NUTS East	*−0.07 ****	*−0.07 ****	*−0.07 ****	*−0.23 ****	*0.06 ****	*−0,06*	*−0.30 ****
	−0.01	*−0.01*	*−0.01*	*−0.05*	*−0.02*	*−0.04*	*−0.03*
NUTS Northeast	*−0.03 **	*−0.03 **	*−0.03 **	*−0.58 ****	*0.07 ****	*0.19 ****	*0,04*
	−0.01	*−0.01*	*−0.01*	*−0.05*	*−0.02*	*−0.04*	*−0.03*
NUTS Northwest	*−0.09 ****	*−0.09 ****	*−0.09 ****	*−0.49 ****	*0,03*	*−0.14 ***	*−0.18 ****
	−0.02	*−0.02*	*−0.02*	*−0.06*	*−0.02*	*−0.05*	*−0.03*
NUTS South	*−0.12 ****	*−0.12 ****	*−0.12 ****	*−0.17 ****	*0.07 ****	*0,04*	*−0.56 ****
	−0.01	*−0.01*	*−0.01*	*−0.05*	*−0.02*	*−0.04*	*−0.03*
Rurality	*0.08 ****	*0.08 ****	*0.08 ****	*0.18 ****	*0.03 ***	*−0.10 ****	*0.12 ****
	−0.01	*−0.01*	*−0.01*	*−0.04*	*−0.01*	*−0.03*	*−0.02*
N	**21,059**						
R^2	**0.46**	**0.46**	**0.47**	**0.3**	**0.29**	**0.38**	**0.21**

Note: Numeric variables are in Napierian logarithms. First values represent the estimated coefficients; the more the stars, the more significant the variable (*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$). Standard errors are shown in brackets and are heteroskedasticity robust.

gender explains carbon inequalities. By using this indicator, it is possible to consider in the analysis all households within a population rather than just single-female or single-male families, thereby making our results valid in a generalised way. Additionally, our indicator considers all household members (over 13 years of age) instead of focusing on the head of the household. On the other hand, we account for the full scope of emissions associated with local consumption decisions by using an environmentally extended multiregional input–output model fed with household survey information reconciled with national accounts. In this way, we track the carbon footprints of households' lifestyles along global value chains.

According to our results, the total carbon footprint is smaller for more female households; however, as this outcome crucially depends on the number of members, we focus our descriptive analysis on emissions per ECU. This approach allows us to identify an interesting pattern, with households closer to the 50–50 gender distribution showing the highest emissions, while the extremes of the sample have lower emissions. Nevertheless, emissions seem negatively related to our female share measure; we also find gender differences in the sectoral distribution of emissions. Specifically, the carbon footprint of households with a female share between 0% and 20% (which means a male household) is 11% larger than that of households with a female share of between 80% and 100% (female household). These results are in line with previous research focused on emissions and gender. For instance, the study by Toro et al. (2019) found a larger carbon footprint for male single-person households compared to female households; their study also identified differences by income and age. This is consistent with our findings, although we use a larger sample and change the measurement of gender; therefore, the implications of the results are slightly different. Furthermore, the research by Carlsson Kanyama et al. (2021) showed gender differences close to those found in the current study, although they calculated consumption-based greenhouse gas emissions considering only single-person households. They found that a man living alone emits 16% more than a woman, with a large portion of that increase being attributable to differences in transport. Therefore, the percentages and sectors implicated are in line with our results.

Part of the gender carbon gap is due to other (also relevant) household differences that vary as the female share changes across families. Hence, we include several potential factors affecting the household carbon footprint as regressors in our models. In this fashion, the female share variable captures all differences in carbon emissions that cannot be explained by other factors (e.g., income, household size, rurality). The distinction between female and male behaviour is obviously more significant, as some of the controls used (most notoriously, income) differ by gender.

The results from our regressions point to two main findings: (i) differences in total household carbon footprint by gender are not very significant (elasticity close to 0) once other variables are controlled for and all households are considered; (ii) in contrast, we find significant gender differences in sectoral carbon footprints. This implies that the nonrelevant distinction in total HCF is the result of positive and negative differences in sectoral HCF by gender. More relatively female households tend to spend more (and generate more emissions) on housing and food products, while male households show that pattern for restaurants and transport. The size of the gender parameters is slightly small compared to the very strong influence of income, but they are robust, significant, and consistent with previous research. In this sense, Toro et al. (2019), using econometric models (based on female and male single-person households), found an inverse relationship between female-headed households and household carbon footprint, with elasticities that were significant but not very large, similar to ours. Similarly, Büchs and Schnepf (2013) also found that while female-headed households have lower emission levels, mostly due to transport emissions, they have higher home energy emissions than male-headed households.

4. Conclusions and policy implications

Gender is increasingly considered in the design of environmental policies, particularly those targeting consumers. However, a broader understanding of how this factor affects lifestyles and thus consumption and emissions is needed. In this paper, we contribute to filling this gap by assessing the causal relationship between gender and households' carbon footprint in Spain.

Although we have isolated the gender effect to analyse its weight, it is clear that individuals cannot be separated and classified only considering one factor (such as gender) to apply demand-side mitigation policies. Therefore, a wide range of factors must be taken into account simultaneously to achieve a just transition towards net zero emissions. Income inequality, gender gaps in the labour market, the balance between work and household chores, and the differences between rural and urban lifestyles should be considered, with the aim of providing just and egalitarian solutions.

Nevertheless, our results can provide valuable insight into the target group for orienting environmental awareness campaigns aimed at mitigating emissions in highly polluting sectors. For example, campaigns that aim to promote energy efficiency could be targeted at more senior women, and campaigns that aim to move towards more sustainable transportation could be targeted at men who use a car for their daily home-work commute. In other words, it is important to consider which individuals are the most polluting in each sector before designing a policy. In addition, our results contribute to bringing many potential gender impacts associated with climate mitigation policies to the table. As Büchs and Schnepf (2013) pointed out, it is crucial to analyse which household characteristics (other than income) could be related to carbon emissions since these relationships will have consequences for distributional effects derived from mitigation policies. In this sense, there is a wide range of climate mitigation measures in which gender impacts must be considered, such as actions taken to redesign workspaces (towards hybrid work or telework), city spaces (towards small and compact urban areas), and mobility (promote public transportation, discouraging private combustion vehicles). Certain measures, such as environmental taxes, could result in regressive effects on women depending on how they are applied (basket of products considered, related income effects, etc.).

While gender explains differences in carbon footprints, either due to socioeconomic and cultural gaps or individual preferences, the emission levels are still far from being sustainable—households emit between 6 and 8 tCO_2 on average at all shares of feminisation—and require rapid and radical reductions. Thus, changes in spending patterns and reductions in consumption levels are urgently needed for both men and women. Indeed, evidence shows that demand-side policies are key to curbing climate change (IPCC, 2022). The gender differences observed in our study could support the design and implementation of such policies. Taking into account the existing gender gaps and the differences in sustainability of consumption by gender, the need for equality and sustainability policies to go in the same direction (coordinated and taking into account potential interlinkages) so that economic equality does not negatively impact the environment is clear. In other words, it is necessary to redistribute not only income but also time to reduce consumption and improve people's quality of life without damaging the environment.

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CRediT authorship contribution statement

Pilar Osorio: Data curation, Methodology, Software, Visualization, Writing – original draft, Formal analysis. **María-Ángeles Tobarra:** Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Manuel Tomás:** Formal analysis, Methodology, Software, Supervision, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A. Annex

Annex 1
Information on the variables used in the analysis

		Type of variable	Definition and units	Summary statistic
Total carbon footprint	THCF	Numeric	Direct and indirect emissions (tCO_2) by household.	Mean: 12.83 Sd: 9.67
Expenditure	EXP	Numeric	Annual expenditure (€) by household. Expenditure is used in emissions calculation.	Mean: 29196 Sd: 17632.76
Equivalent consumption unit	ECU	Numeric	ECU is calculated using the modified OECD scale. This is calculated by the sum of the household members weighted according to the following coefficients: 1 for the first adult in the household, 0.5 for the following adults (>13 years) and 0.3 for children (younger than 14 years).	Mean: 1.77 Sd: 0.55
Average age	AGE	Numeric	Average age of the members above 13 years old.	Mean: 50 Sd: 15.01
Female share	FEMSHARE	Numeric	Percentage of women in the household with respect to the total number of members above 13 years of age.	Mean: 0.53 Sd: 0.26
Main breadwinner gender	GENDER	Categorical	0 Man 1 Woman	0: 15112 1: 7008
Income	INCOME	Numeric	Total household disposable income (€).	Mean: 28,299 Sd: 21,711
Income deciles	INCOME_D	Categorical	Ten equal groups in which the data is divided, according to the distribution of annual income (euros).	1: (0;8894] 2: (8894;12,157] 3: (12,157;15,708] 4: (15,708;19,366] 5: (19,366;23,236] 6: (23,236;27,910] 7: (27,910;32,996] 8: (32,996;41,009] 9: (41,009;53,286] 10: (53,286;384,050]
Household size	HSIZE	Categorical	1 Single-person household 2 Single-parent household with dependent children 3 Couple without dependent children 4 Couple with dependent children 5 Other households without dependent children 6 Other households with dependent children	1: 3951 2: 732 3: 5289 4: 6193 5: 4148 6: 1807
Dwelling type	DTYPE	Categorical	1 Big/ larger house 2 Median size house 3 Small house	1: 1382 2: 2647 3: 18091
High education	EDU	Categorical	0 Non-high education 1 High education	0: 15437 1: 6683
Rurality	RURAL	Categorical	0 Urban area 1 Rural area	0: 18053 1: 4067
NUTS	NUTS 1	Categorical	1 Northwest 2 Northeast 3 The Community of Madrid 4 Central 5 East 6 South 7 Canarias	1: 2999 2: 4678 3: 1641 4: 3705 5: 4517 6: 3562 7: 1018

Note: We provide descriptive statistics (mean and standard deviation) for numeric variables. We provide households distribution for categorical variables. Whole sample is used for this descriptive analysis.

Annex 2
Descriptive analysis on households characteristics according to female share.

FEMALE SHARE	THCF (tCO_2)	INCOME (€)	AVERAGE AGE	HIGH EDUCATION	HOUSEHOLD TYPE	NUTS	RURALITY
(0,0.2]	Min.: 0.2175	Min.: 0	Min.:18.00	Non-high education:1409	Single-person household:60	Northwest:149	Urban:1579
	1st Qu.: 3.6294	1st Qu.: 9790	1st Qu.:40.00	High education: 609	Single-parent household with dependent children: 43	Northeast:120	Rural: 439
	Median: 6.2945	Median: 15976	Median:52.00		Couple without dependent children: 228	The Community of Madrid:341	
	Mean: 8.0022	Mean: 19081	Mean:53.04		Couple with dependent children: 22	Central:367	
	3rd Qu.: 10.3426	3rd Qu.: 24414	3rd Qu.:65.00		Other households without dependent children: 37	East:471	
	Max.:153.2527	Max.:147016	Max.:85.00		Other households with dependent children: 1628	South:264	
						Canarias:306	
(0.2,0.4]	Min.: 0.6104	Min.: 0	Min.:22.25	Non-high education:2267	Single-person household: 44	Northwest:223	Urban:2513
	1st Qu.: 9.2523	1st Qu.: 18464	1st Qu.:35.50	High education: 811	Single-parent household with dependent children: 424	Northeast:142	Rural: 565
	Median: 14.2242	Median: 29534	Median:42.00		Couple without dependent children: 1409	The Community of Madrid:537	
	Mean: 16.1776	Mean: 34744	Mean:43.88		Couple with dependent children: 1201	Central:627	
	3rd Qu.: 20.6482	3rd Qu.: 44343	3rd Qu.:50.33		Other households without dependent children: 0	East:586	
	Max.:224.2057	Max.:384050	Max.:83.00		Other households with dependent children: 0	South:389	
						Canarias:574	
(0.4,0.6]	Min.: 0.3013	Min.: 0	Min.:18.50	Non-high education:7254	Single-person household: 185	Northwest: 799	Urban:8831
	1st Qu.: 7.4983	1st Qu.: 16474	1st Qu.:37.00	High education:3630	Single-parent household with dependent children: 667	Northeast: 472	Rural:2053
	Median: 11.7962	Median: 25639	Median: 45.50		Couple without dependent children: 992	The Community of Madrid:1815	
	Mean: 13.6679	Mean: 30468	Mean: 50.27		Couple with dependent children: 3801	Central:2239	
	3rd Qu.: 17.6969	3rd Qu.: 39062	3rd Qu.: 64.00		Other households without dependent children: 5239	East:2359	
	Max.:328.9044	Max.:384050	Max.:85.00		Other households with dependent children: 0	South:1486	
						Canarias:1714	
(0.6,0.8]	Min.: 1.105	Min.: 0	Min.:22.00	Non-high education: 2012	Single-person household: 43	Northwest: 211	Urban: 2232
	1st Qu.: 9.147	1st Qu.: 18839	1st Qu.: 35.25	High education: 766	Single-parent household with dependent children: 543	Northeast: 125	Rural: 546
	Median: 13.993	Median: 29033	Median: 41.29		Couple without dependent children: 1028	The Community of Madrid: 500	
	Mean: 15.980	Mean: 33822	Mean: 43.74		Couple with dependent children: 1164	Central: 589	
	3rd Qu.: 20.436	3rd Qu.: 43677	3rd Qu.:50.00		Other households without dependent children: 0	East: 497	
	Max.:127.523	Max.:357334	Max.:84.00		Other households with dependent children: 0	South: 368	
						Canarias: 488	
(0.8,1]	Min.: 0.207	Min.: 0	Min.:20.00	Non-high education: 2495	Single-person household: 400	Northwest: 259	Urban: 2898
	1st Qu.: 3.592	1st Qu.: 8852	1st Qu.:44.00	High education: 867	Single-parent household with dependent children: 130	Northeast: 159	Rural: 464
	Median: 5.867	Median: 12768	Median: 61.25		Couple without dependent children: 491	The Community of Madrid: 512	
	Mean: 7.326	Mean: 16349	Mean: 59.30		Couple with dependent children: 5	Central: 695	
	3rd Qu.: 9.589	3rd Qu.: 21159	3rd Qu.:74.38		Other households without dependent children: 13	East: 765	
	Max.:148.543	Max.:338028	Max.:85.00		Other households with dependent children: 2323	South: 492	
						Canarias: 480	

Note: We provide descriptive statistics for numeric variables. We provide households distribution for categorical variables. Whole sample is used for this descriptive analysis.

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