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The role of food categories in shaping socioeconomic impacts on the water footprint of household food waste

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ABSTRACT

Household food waste poses a serious threat to planetary boundaries, particularly regarding water use, since it translates directly into unnecessary consumption of virtual water, contributing to freshwater depletion and threatening water security in water-scarce regions. This study examines how household socioeconomic factors differentially drive the water footprint embedded in food wasted, and how these impacts vary across food categories. To do so, we combine detailed data on food waste quantities of representative Spanish households for the period 2018–2022 with data on unitary water footprint of consumption, in order to calculate the volume of virtual water embedded in food discarded by households. We then employ a pooled regression approach to estimate the socioeconomic characteristics influencing it, analysing differences across food categories and testing how the impact of household characteristics varies by categories. Our results reveal that higher socioeconomic status and larger households significantly increase the water footprint of food waste, while the age of the main shopper and the presence of children are associated with a reduction. Moreover, our findings show that the water footprint of vegetables and other foods categories is more sensitive to socioeconomic status, while the water footprint of meat and dairy categories shows a stronger effect driven by age and household size. These insights offer policymakers valuable guidance for the design of tailored policies for specific groups to reduce the water usage, focusing not only on those products with a higher waste level, but also with a higher water footprint.

1. Introduction

Food loss and waste have emerged as a critical global concern (Reynolds et al., 2020), affecting every stage of the food supply chain and posing a significant threat to the sustainability of our food systems (Principato, 2018). Although a globally accepted definition remains elusive, food loss generally refers to unintentional reduction of food before consumption, whereas food waste refers to the deliberate disposal of edible food (Santeramo, 2021). This challenge is particularly pressing within the context of sustainability paradigm, which integrate the triad of economy, environment, and society. This paradigm stands as the cornerstone shaping the formulation of the United Nations' Sustainable Development Goals (SDGs) and the ambitious targets outlined in the Agenda 2030. The inclusion of food waste in this Agenda reflects a strategic recognition of its profound implications on the many dimensions of the sustainability. Specifically, target 12.3 of SDG12 -responsible consumption and production-calls for halving per capita global food waste at retail and consumer levels by 2030 (United Nations, 2015).

The largest proportion of food waste occurs at the consumer level, where households have direct control over what they generate (e.g., Lipinski et al., 2013; Hebrok and Heidenstrøm, 2019; Reynolds et al., 2020). In the European context, updated figures show that 129 kg of food waste are generated by inhabitant in 2022. Within this total, households were responsible for 53 % (68 kg per inhabitant) and even more strikingly, nearly doubling the quantity arising from upward chain levels (primary production and manufacture). In Spain, households generated 26 kg per inhabitant. Despite being the lowest per capita magnitude of the EU, Spain ranks seventh in terms of total household food waste volume (with approximately 1.2 million tonnes), which makes its study particularly relevant (Eurostat, 2021).

Food waste presents a complex issue with far-reaching consequences across economic, environmental, social and ethical dimensions (e.g., Abeliotis et al., 2014; Schanes et al., 2018; Álvarez de Los Mozos et al.,

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2020). The substantial quantity of food wasted annually not only leads to considerable economic inefficiencies but also results in the wasteful utilization of limited resources such as land, water, and energy, and contributes to the generation of greenhouse gas emissions (e.g., Schanes et al., 2018). Note that the implications at household level are greater than those at earlier stages of the supply chain given that more resources have been invested in getting the food from field to plate. Moreover, in the social sphere, the excessive disposal of food exacerbates food insecurity (e.g., Armstrong et al., 2021; Santeramo, 2021), threatening the access to sufficient, safe and nutritious food to meet dietary needs and preferences for a healthy life (European Commission, 2021).

The growing recognition of the food waste challenge has translated into a growing body of research that delves into the multifaceted nature of consumer food waste, reflecting its varied impacts and complexities. This includes, among others, volume quantification (e.g., Van Herpen et al., 2018; Giordano et al., 2019), analysis of consumer behaviour (e.g., Aschemann-Witzel et al., 2015; Mondéjar-Jimenez et al., 2016), measurement of socioeconomic effects (e.g., Lusk and Ellison, 2020; Slorach et al., 2020) and environmental impacts (see, for a review, Xue et al., 2024), experiences with recycling or other food waste uses (e.g., Dou et al., 2018; Xiao and Siu, 2018; Waitt and Rankin, 2022), and empirical research that increasingly focuses on micro aspects of food waste behaviour and its economic drivers (e.g., Lusk and Ellison, 2017; Drabik et al., 2019), as well as interventions for food waste reduction and prevention (e.g., De Laurentiis et al., 2020; Kim et al., 2020).

Considerable research efforts have been devoted to identifying the determinants of household food waste, with numerous empirical studies exploring socioeconomic factors under the premise that such characteristics reflect the capacity of individuals to effectively manage or mitigate such waste. For example, household income is frequently associated with access to efficient storage technologies and improved time resources for food-related activities (e.g., Parizeau et al., 2015). Similarly, the age of the primary shopper may serve as a proxy for accumulated experience and skills in food management (e.g., Smith and Landry, 2021; Jörissen et al., 2015). Household composition variables, such as size and the presence of children, also introduce greater complexity due to heterogeneous preferences and increased handling of perishable goods, thereby influencing the household's overall capacity to reduce food waste (e.g., Parizeau et al., 2015; Tonini et al., 2023).

While this increase in scientific production has provided valuable insights into food waste literature, significant gaps remain concerning consumer-driven food waste within private households and its environmental implications. One critical area that has received limited attention in the household food waste literature is the consequences of food waste in terms of water use. Water is an essential input in food production, and when food is wasted, so too is the water used to produce it. This poses a significant challenge in a context in which two-thirds of the worldwide population live under water scarcity (Mekonnen and Hoekstra, 2016), and almost 80 % of water withdrawals is used in the agrifood sector. A well-established indicator in this field is the water footprint (WF). This metric offers a valuable framework for assessing the direct and indirect water use of food waste, as it measures the total cumulative volume of freshwater used along the entire supply chain to produce goods and services until consumption. The global WF of food wastage is about 250 km^3 per year (FAO, 2013), an important substantial figure that exacerbates existing water implications of food waste.

Water scarcity is an acute problem in many regions of the world, and Spain is no exception. The country faces significant challenges, with one of the highest water stress levels of OECD countries (OECD, 2017). Spain's unique geography and Mediterranean climate, characterized by extended dry periods and irregular rainfall patterns, intensifies these issues, especially in its southern and eastern regions, and set the stage for inherent water challenges. However, the situation is further complicated by the significant demands placed on water resources by various sectors, particularly agriculture, a cornerstone of Spain's economy that uses around 81 % of the water consumed in Spain (Sancho and Santamaría, 2023). The complexities of water scarcity in Spain are the result of a multifaceted interplay between climatic conditions and human activities. As the impacts of climate change become increasingly apparent, such as the rising frequency of droughts, the need to understand and manage water resources becomes ever more pressing.

Despite the magnitude of this problem, there remains a notable gap in the literature concerning the drivers of the water footprint associated with consumer-level food waste. Existing studies have predominantly focused on quantifying the resources embedded in food waste using environmental footprints (e.g., Chapagain and James, 2011; Liu et al., 2013; Song et al., 2015; Vanham et al., 2015; Reutter et al., 2017; Blas et al., 2018; Conrad et al., 2018; Mekonnen and Fulton, 2018; Adelodun et al., 2021). Another sort of investigations has also centred on obtaining projections of the water resources requirements linked to future food waste (e.g., Ogunmoroti et al., 2022) or on estimating the potential reduction of water usage due to a given reduction of food waste (e.g., Rasines et al., 2023). Although most of this literature has analysed the water footprint of food waste for diverse food categories, the forces driving a greater or lower water footprint associated to food waste of different products have been overlooked and mainly associated exclusively to a greater or lower water intensity. Specifically, a major shortcoming is the study of how household socioeconomic characteristics contribute to these water inefficiencies due to the waste of different products with diverse water requirements.

To address this gap, the objective of this paper is to analyse how the impact of household characteristics on the water footprint associated to food waste varies across food categories. To do so we quantify the water footprint of household food waste in Spain using a unique product-level dataset on food waste of representative Spanish households for the period 2018–2022, which reports wasted volumes by product and household socioeconomic characteristics, in contrast to the aggregated figures used in past studies such as Blas et al. (2018). Then, we estimate via pooled regression approach how socioeconomic characteristics affect the water footprint of household food waste, explicitly testing for cross-category heterogeneity.

Our research makes several contributions to the food waste-water use nexus literature. While previous studies have focused solely on the calculation of the volume of water associated to food waste, the present study moves beyond quantification to systematically identify the socioeconomic characteristics that drive these losses. This provides valuable information for policymakers to develop targeted strategies for specific sociodemographic groups to prevent food waste while simultaneously reducing its water-related impacts. Moreover, this study departs from prior studies with the analysis of the drivers of the water footprint associated with food waste of different food products, thereby enabling more targeted interventions. By encouraging adjustments in consumption, specific strategies may favour products with a lower water footprint and ultimately empower consumers to play a more active role in reducing the pressures on water resources. From a methodological perspective, our approach provides a clearer view of how socioeconomic determinants interact with product categories to shape household water footprint and allow us to test whether these interactions differ significantly across food groups.

The remainder of the paper is organized as follows. Next section describes the methodology employed to quantify the water usage associated with food waste and the specification of the econometric model used in the analysis. Then, the main results of the study regarding households' water footprint of food waste and its determinants are presented. Finally, a section concludes providing insights into the potential policy implications, and the limitations of the present study, proposing potential avenues for future research.

2. Methodology

2.1. Quantification of water usage associated with food waste

The complex nature of both the food waste and the supply chain, as highlighted by studies such as Parfitt et al. (2010) and Spang et al. (2019), is reflected in ongoing debate about the definition of food waste, with numerous interpretations in the literature. In this paper, food waste is defined as any food, whether (semi-) processed or raw that was purchased for household consumption but is ultimately discarded. This includes items in their original uncooked form that are thrown away for various reasons such as spoilage, extended storage, or simply not being consumed (MAPA, 2021). This understanding aligns with the definition provided by Directive EU, 2018/851, currently in effect (EU, 2018).

In this study, a unique database on household food waste is supplied by Kantar covering the period 2018 to 2022. Data contains comprehensive information on food waste quantities of 2500 representative Spanish households across five food categories (meat, fish, dairy products, vegetables, and other food products). Households were enrolled in the food waste panel through a stratified random sampling approach, ensuring representativeness across diverse socioeconomic variables: socioeconomic status[1] (low, middle-low, middle, high and upper-middle), age of the main shopper (under 35, 35–49, over 50), household size (1–2 people, 3 people, 4 people, 5 or more people), presence of children (yes, no), and region (Andalucía, Aragón and rest of Cataluña, Barcelona Metropolitan Area, Madrid Metropolitan Area, Levante, North-Centre, North-West, and rest of Centre). Participants are required to log, for a reference week, all discarded food whether bought, opened or unopened (but uncooked), irrespective of where it was stored (e.g. pantry, refrigerator, or freezer). This weekly recording, covering all reasons for disposal (e.g., spoilage, extended storage, or not intended for consumption), allowed for the calculation of annual food waste quantities, which were extrapolated to the population level to estimate the total food waste generated by all Spanish households.

The water embodied in household food waste is calculated using the water footprint metric, which accounts for the direct and indirect usage of water within the production process, encompassing the cumulative consumption of this resource throughout the entire supply chain (Mekonnen and Hoekstra, 2011). Although this indicator usually distinguishes between the green, blue and grey WF, this paper focus on the consumptive WF (green and blue), as commonly done in the literature (e.g., Liu et al., 2013; Vanham et al., 2015; Mekonnen and Fulton, 2018). The blue WF refers to the consumption of surface and groundwater resources such as irrigation, while the green WF refers to the consumptive use of rainwater stored in the soil by crops (Hoekstra et al., 2011). This paper considers the water footprint as the sum of both the green and blue water footprints.

Computing the water footprint associated to consumer-level food waste involves multiplying the quantity of food waste (in tonnes) by the unitary water footprint of consumption (measured in m^3/tonne) obtained from the CWASI database (Tamea et al., 2020). The CWASI database furnishes details on the unitary water footprint of consumption that refers to the domestic supply of products, which relies both on local production and on international trade. Information is available for diverse crops and animal products at country level and offers annual data for the crop category (we use 2016 for being the most recent available year) and an average value centred on year 2000 for the animal category. Note that a water footprint equivalent to zero is assigned for fisheries, as this study only evaluates the water footprint associated with the production of consumed products, without accounting for the water demands for cooking (e.g., Blas, 2019).

The use of the CWASI database offers a distinct advantage compared to the water footprint databases by Mekonnen and Hoekstra (2011, 2012). Starting from the latter databases, which only provide data for the unitary water footprint of production, the CWASI database differentiate between the production side and the supply side, directly providing information on the unitary water footprint of consumption. This eliminates the need for additional calculations, like the construction of a complex trade matrix for various products to estimate virtual water embedded in imports of products consumed domestically (as in Blas et al., 2018). Moreover, the CWASI database provides time-varying annual data for the period 1961–2016, while the datasets of Mekonnen and Hoekstra offer average values over the period 1996–2005 (Tamea et al., 2021).

Nevertheless, the quantification of water usage associated with food waste poses a significant challenge, particularly in reconciling the Kantar's panel and the CWASI database. The CWASI database offers highly detailed information at product level, whereas the Kantar's panel provides aggregated data for five food categories (meat, fish, dairy, vegetables, and other products). To calculate the water footprint associated with consumer-level food waste, we need to aggregate the unitary water footprints of various products from the CWASI database into the five food categories outlined by Kantar. This process involves obtaining the weighted average unitary water footprint (UWF) for each food category j, based on the individual unitary water footprints of products i within the CWASI database, weighted by their relative consumption within the Kantar food categories j, as follows:

$$UWF_j = C_j^{-1} \sum_{i \in j} UWF_{i,j} \cdot C_{i,j} \tag{1}$$

where $UWF_{i,j}$ is the unitary water footprint of product i from the CWASI database corresponding to category j in the food group in Kantar, $C_{i,j}$ is the consumption quantity of product i in the Kantar food group j, and C_j is the total consumption quantity of food category j in Kantar. The consumption data for each product is sourced from the Food Balances of the FAOSTAT database (FAO, 2023), specifically using the domestic supply quantity variable encompassing production, imports, exports, and changes in stocks (both decreases and increases). It must be acknowledged that, although this aggregation may introduce certain measurement errors, it constitutes an essential step in estimating the water footprint associated with food waste. This procedure is commonly employed in the literature (e.g. Chapagain and James, 2011), as it is unlikely that the level of detail available for food waste data matches exactly the product disaggregation of the water footprint data.

Then, we obtain the water footprint associated with food waste ($WFFW_{h,j,r,t}$) as:

$$WFFW_{h,j,r,t} = \sum_j UWF_j \cdot FW_{h,j,r,t} \tag{2}$$

where $WFFW_{h,j,r,t}$ is the aggregated water footprint associated with food waste across j food categories for each household type h, in region r, and year t. Also, $FW_{h,j,r,t}$ is the quantity of food waste of household h for food category j, in region r and year t.

2.2. Model specification

The quantification of the water footprint linked to food waste enables the exploration of how various socioeconomic characteristics of households affect the water usage associated with food waste, and how this effect varies across product categories.

Drawing upon factors identified in recent literature, our model delves into this relationship. Food waste is attributable to a myriad of intricate factors, many of which are beyond individual's control (Quested et al., 2013; NASEM, 2020). Given the scope of the paper, we focus on the influence of various socioeconomic and demographic

[1] The socioeconomic status variable, as provided by Kantar, is derived from a composite assessment of household attributes. This incorporates the occupation status of all household members, the characteristics of the living place (like size, location, ownership, or equipment), and details on their vehicle ownership (number and type).

factors on the water footprint of household food waste. As noted by Quested et al. (2013), a combination of socio-demographic factors may impact the quantity of food wasted in households. Thus, the socioeconomic variables for this study were obtained from the Kantar's database, which categorises households according to several socioeconomic and demographic characteristics (socioeconomic status, age, size of household, and presence of children). These variables are likely to shape key behavioural dimensions that affect the efficiency of food utilization within households. Specifically, they may influence factors such as the relative costs and constraints associated with food storage (e.g., Smith and Landry, 2021; Bellemare et al., 2017), the complexity of managing food perishability (e.g., Hebrok, 2018), and the role of experiential learning over time in developing effective food management practices (e.g., Nikolaus et al., 2018).

Regarding the specification of the model, although a household-level fixed effects model is a standard approach for panel data, this specification was not appropriate in this study due to the nature of our dataset. Despite having data from 2018 to 2022, the socioeconomic variables analysed show limited temporal variation for most households. Hence, a fixed-effects model discards the rich cross-sectional information in our data and fails to estimate the effects of our variables, since it requires within-household variation over time to estimate coefficient.

In our case, we adopt a pooled regression framework, combining all observations across the available years. To estimate the impact of socioeconomic household characteristics on the water footprint of food waste we specify the following regression model:

$$\ln\left(WFFW_{h,j,r,t}\right) = \alpha + x'_{h,r,t}\beta + \lambda_r + \tau_t + \varepsilon_{h,j,r,t} \quad (3)$$

where the endogenous variable WFFW is the water footprint per household associated with food waste for each household h, food group j, region r and year t. $x_{h,r,t}$ are regressors, including the socioeconomic status based on 4 items (low, middle-low, middle, high and upper-middle); the age of the person responsible for doing the shopping for the household, distinguishing 3 items (under 35, 35–49, over 50); the household size measured as the number of persons living in a household, and including 4 items (1–2 people, 3 people, 4 people, 5 or more people); and a dummy variable that takes value 1 if children are present in the household and 0 otherwise. α denotes the intercept and ε is the idiosyncratic error. The model also includes time dummies (τ_t) to capture commons shocks or trends affecting all households in a given year, and regional dummies (λ_r) to control for unobserved heterogeneity that is time-invariant across Spanish regions (e.g., cultural norms, food preferences, waste management practices or retail environments). Moreover, to ensure that our statistical inference is robust to potential correlation within households and spatial correlation within regions, we computed robust clustered-standard errors as suggested by Cameron and Trivedi (2022).

Table 1 shows the socioeconomic characteristics of the household sample compared to the Spanish household universe. The distribution of the different categories in our sample closely resembles that of the overall population, supporting the sample's representativeness.

Based on this model, our aim is to investigate whether the influence of socioeconomic factors on the water footprint of food waste differs across product categories. To that end, equation (3) is estimated considering three different specifications. First, the restricted model, which includes the socioeconomic characteristics (socioeconomic status, age of main shopper, household size, children) along with regional and time dummies. So, in this model, we pool the observations for all food categories in a single model. Then, the extended model, which includes the socioeconomic characteristics, along with regional and time dummies, as well as a set of dummy variables to represent each product category (note that one category is omitted as a reference to avoid multicollinearity). Finally, the full model, which includes the socioeconomic characteristics, regional and time dummies, and food category dummies, along with the interaction of these category dummies with the socioeconomic variables, allowing us to capture potential differences in the effect of each socioeconomic factor on the endogenous variable across product categories.

Table 1
Socioeconomic characteristics of household sample.

Characteristics	Household sample (%)	Household universe (%)
Socioeconomic status		
Low	24.27	26.20
Middle-low	26.50	26.79
Middle	29.47	30.70
High and Upper-middle	19.76	16.31
Age of main shopper		
under 35	18.89	11.87
35–49	40.35	31.15
over 50	40.77	56.97
Household size		
1–2	32.70	56.65
3	28.86	20.48
4	25.01	17.24
5 or more	13.43	5.62
Children		
Yes	54.09	74.01
No	45.91	25.99
Regions		
Andalucía	16.47	19.78
Aragón and rest of Cataluña	12.57	12.82
Barcelona Metropolitan Area	10.73	9.54
Levante	13.82	15.27
Madrid Metropolitan Area	12.79	13.40
North-Centre	10.73	9.86
North-West	11.44	9.80
Rest of Centre	11.46	9.52

Source: Kantar provided the data for the household population of Spain, defined as all households in the Peninsula and the Balearic Islands, not including the Canary Islands, Ceuta and Melilla. The figures reported are the 2018–2022 mean.

To test these differences, we conduct a likelihood ratio (LR) test defined as:

$$LR = -2(LL(0) - LL(1)) \quad (4)$$

where $LL(0)$ represents the Log Likelihood for the model under the null (the restricted model), and $LL(1)$ is the Log Likelihood for the model under the alternative hypothesis. Note that we first compare the fit of the extended model (which includes the food category dummies) with that of the restricted model (where the coefficients for the category dummies are constrained to zero). Next, we compare the fit of the full model (which includes the food category dummies, and their interactions with the socioeconomic variables) with that of the restricted model (where the coefficients for the category dummies and their interactions are constrained to zero). If the null hypothesis is not rejected, that is the effect of the socioeconomic factors is uniform across all categories, then we conclude that the impact of these variables on the water footprint of food waste does not vary among product categories. However, if the null hypothesis is rejected, we can claim that the impact of socioeconomic household characteristics exhibits significant differences across food categories.

3. Results and discussion

3.1. Water usage associated with food waste

The quantification of water usage associated with food waste in Spain during the period 2018–2022 indicates that per capita food waste in Spain amounts to 23.52 kL per person per year, which according to Blas et al. (2018) accounts for approximately 4 % of the total food consumed. This wastage is equivalent to a water footprint of 48.79 m^3 per person per year or 133.67 L per person per day, which implies that total water footprint of Spanish food waste is equivalent to 2314.42 hm^3. These figures are consistent with results from previous studies for the case of Spain, such as the study of Blas et al. (2018) that reported a value of 47.7 m^3/person and a total water footprint of Spanish food waste of 2095 hm^3, using aggregated data for the year 2014/2015. These magnitudes are substantially lower than those obtained in the previous literature for other countries, which calculates 284 L per person per day for the UK (Chapagain and James, 2011), 321 for the EU (Vanham et al., 2015), 231 for China (Ogunmoroti et al., 2022), or 568 for the USA (Mekonnen and Fulton, 2018).

According to Chapagain and Hoekstra (2004), the national water footprint of Spain raises 2325 m^3 per person and year, so the water footprint associated to household food waste (48.79 m^3) represents 2 % of the Spanish water footprint. This percentage is also lower compared to previous findings in the literature for other countries. For example, Chapagain and James (2011) obtained that 6 % of the water footprint is embodied in household food waste in the UK, while Liu et al. (2013) obtained a percentage of 14 % for China, Vanham et al. (2015) an 8 % for the and Reutter et al. (2017) provided a figure of 9 % for Australia.

Over the annual span, Fig. 1 reveals a significant reduction of water footprint associated to food waste of 34.57 %, from 59.51 m^3/person in 2018 to 38.93 m^3/person in 2022. Examining food categories, beyond the 'other' food products, dairy and meat categories emerge prominently (constituting 19.59 % and 10.90 % of total water footprint associated with food waste in 2022, respectively), in comparison with vegetable products (that represents 4.73 %). However, the two former categories exhibit the most substantial reductions in the water footprint during the analysed period (−39.23 % for dairy products and −38.19 % for meat products).

On this regard, it should be noted that the water footprint of each food category is determined by the quantity of food wasted and the unitary water footprint of each food category. For example, vegetable products are those with a lower water footprint due to its reduced unitary water footprint (567.71 m^3/ton on average), despite being the food category with the highest food waste (4,06 kL/person on average). On the contrary, meat products are those with the highest unitary water footprint (5158.43 m^3/ton), but with the lowest quantity of food waste (1.03 kL/person). In a middle point we found dairy products, with an average unitary water footprint of 3357.42 m^3/ton and a quantity of food waste of 2.85 kL/person. These results are consistent with previous studies. For example, Adelodun et al. (2021) observed, for a case study of South Korea, that although animal-based food only contributes to 13 % of total household food waste, it represents 66 % of the total water footprint associated to household food waste. Mekonnen and Fulton (2018) also show that, in the USA, red meat accounts for the largest share (53 %) of the WF associated with food waste despite representing only 6 % of the total volume of household food waste, due to its high water intensity.

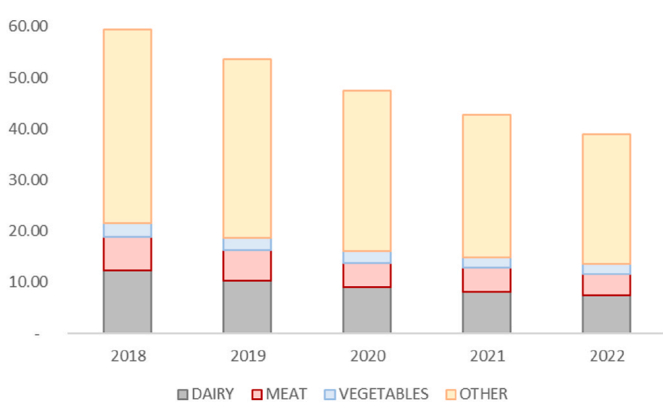

Fig. 1. Water footprint of food waste (m^3/person) by year and food category.

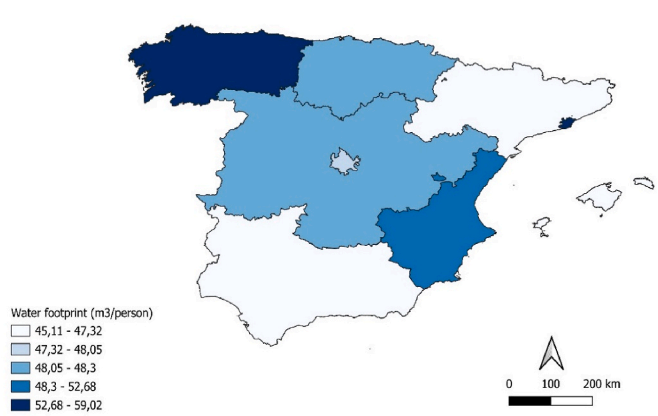

Fig. 2. Average water footprint of food waste (m^3/person) for the period 2018–2022 by region.

Fig. 2 illustrates the spatial distribution of the water footprint associated with food waste. As evidenced in this map, only modest unconditional differences emerge across the country. The Metropolitan Area of Barcelona (59.02 m3/person) and the north-west region of Spain (55.32 m3/person) record higher water footprints on average for the period 2018–2022. While Andalucía shows the lowest value (45.11 m3/person) and experiences the highest reduction in water footprint (−44.87 %). Regions with elevated water footprint, such as the Metropolitan Area of Barcelona (−17.76 %) and Andalucía (−20.45 %), display comparatively lower reduction rates. This limited variation suggests that broad regional patterns, before controlling for household characteristics, may not be particularly relevant in explaining the water footprint from food waste.

3.2. Exploring the drivers of the water footprint of household food waste

As previously described in the methodology section, the first step prior to estimating the impact of driving socioeconomic characteristics on the water footprint associated with food waste is to test whether the impact of these socioeconomic variables varies significantly across food categories. According to Table 2, the result of the Likelihood Ratio (LR) test specified in equation (4) rejects the null hypothesis between the restricted and the extended models. The value of the LR test (5060.84) is higher than the critical chi-square value with 4 degrees of freedom (9.488) at 5 % significance level. This suggests that there exist significant differences across food categories. Moreover, the LR test also rejects the null between the restricted and the full model, since the value of the LR test (5412.99) is higher than a chi-square with 40 degrees of freedom (55.758) at 5 % significance level. As the value of this last LR test is higher than the previous, this means that the full model is the best model specification for our purposes. This confirms that the desirable strategy is to estimate equation (3) as a separate pooled regression for each food category. Results of these estimations are presented in Table 3.

Our results indicate that, in general, all of the socioeconomic household characteristics play a significant role in shaping the water footprint, exhibiting notable heterogeneity among food categories. Moreover, the lack of statistical significance of the individual regional dummies suggests that regional differences in the water footprint of food waste are negligible, suggesting the absence of spatial heterogeneity among the regions analysed.[2]

[2] To further confirm whether the impact of these variables is stable across regions, we expanded equation (3) with the full set of region-interaction terms for the socioeconomic variables. We then estimated this fully interacted model for each food group and tested the null hypothesis of no heterogeneous effect across regions. The results did not reject the null and are available from authors upon request. This confirms our approach of estimating a single model for each food group rather than estimating separate models per region, as the socioeconomic effects did not show statistically significant variation across regions.

Table 2
Likelihood Ratio test for testing whether the impact of socioeconomic household characteristics across food categories is heterogeneous.

Model	Log-likelihood	LR test (df)	p-value
Restricted	−11,539.77		
Extended	−8,495.26		
H_0: All food categories = 0		5,060.84 (4)	0.000
Full	−8,319.18		
H_0: All food category coefficients + socioeconomic interacting with food categories = 0		5,412.99 (40)	0.000

Note: df denotes degrees of freedom.

The socioeconomic status variable exhibits a positive impact in all of its three subcategories (middle-low, middle, and high and upper-middle) with respect to the reference subcategory (low social status), implying that higher status leads to higher water footprint associated with food waste. When comparing with other studies focusing on the determinants of household food waste, it becomes apparent that higher-income households tend to waste more than lower-income ones (e.g., Koivupuro et al., 2012; Stefan et al., 2013; Stancu et al., 2016), although some studies also found non-significant elasticities (e.g., Williams et al., 2012; Qi and Roe, 2016; Visschers et al., 2016). This positive correlation could be attributed to the fact that households with higher income levels may perceive food waste as a way to save time, maintain meal freshness, or prevent food-related illnesses (Qi and Roe, 2016). The lower coefficient obtained for the 'high and upper-middle' status, in comparison with the other two subcategories, may reflect the effect of two opposite events: their higher economic capacity -that leads to a higher waste- and their potentially greater awareness of sustainable consumption patterns. This finding, where the effect appears to taper off at the highest socioeconomic level, provides evidence of the complex and potentially non-linear relationship that can exist between socioeconomic status and the water footprint of food waste.

Comparing product categories, the obtained estimates for the socioeconomic status variable are especially high for the vegetables and the other food category. For instance, the impact of middle-status households on vegetables is 0.88, higher than for meat and dairy (0.56 and 0.58, respectively). This result is consistent with the previous literature showing that higher income and education levels usually involves a greater share of vegetables consumption (e.g., Robertson et al., 2004) and a lower share of meat consumption (e.g., Ritzel and Mann, 2021). The higher consumption of vegetables in households with a higher socioeconomic status, in comparison with the other food categories, may imply a higher waste of these vegetable products and, therefore, a higher increase of its associated water footprint, despite being the category with the lowest unitary water footprint.

In contrast, the age of the person responsible for shopping shows a negative impact and its coefficient remains statistically significant. The results show that the estimated impact is more pronounced in older age groups, a result that aligns with prior research on food waste drivers (e.g., Secondi et al., 2015; Visschers et al., 2016). The negative correlation between age and food waste is often attributed to more time (Qi and Roe, 2016), attitudes towards waste reduction, and a greater awareness of the environmental impacts of food waste (Schanes et al., 2018). In our case, another plausible explanation is the role of family in shaping food practices (Monterrosa et al., 2020), due to the severe food shortages and rationing suffered by elder individuals in Spain. Results also exhibit notable differences on the impact of age across food groups, with an effect more pronounced for meat and dairy products (−1.47 and −1.01 for the 'over 50' group, respectively), and more limited among vegetables and other groups (−0.65 and −0.52). This may be due to both a lower consumption (and, therefore, waste) of meat by elderly people (e.g., Gossard and York, 2003) and a higher unitary water footprint of meat products.

Results also show that the family size increases the water footprint of food waste, illustrating economies of scale. This relationship, however,

Table 3
Estimated impact of socioeconomic household characteristics on water footprint of household food waste across food categories.

Variables	WFFW for MEAT	WFFW for DAIRY	WFFW for VEGETABLES	WFFW for OTHER
Socioeconomic status				
Middle-low	0.517*** (4.21)	0.602*** (5.72)	0.838*** (8.87)	0.674*** (7.16)
Middle	0.563*** (4.99)	0.576*** (5.85)	0.880*** (9.55)	0.849*** (8.37)
High and upper-middle	0.440*** (4.21)	0.184 (1.47)	0.522*** (5.09)	0.414*** (3.60)
Age				
35–49	−1.098*** (−8.99)	−0.756*** (−7.66)	−0.452*** (−4.95)	−0.325*** (−3.51)
over 50	−1.474*** (-11.39)	−1.013*** (−8.95)	−0.646*** (−6.40)	−0.518*** (−4.81)
Household size				
3	1.822*** (10.32)	1.284*** (9.41)	0.899*** (7.80)	0.773*** (6.89)
4	1.912*** (9.15)	1.267*** (7.66)	0.969*** (7.25)	0.879*** (7.04)
5 or more	2.548*** (12.38)	1.774*** (10.85)	1.156*** (8.63)	0.957*** (7.53)
Children				
Yes	−1.754*** (10.09)	−1.534*** (10.81)	−1.611*** (14.23)	−1.558*** (14.46)
Region				
BMA	0.496** (3.30)	0.375* (2.26)	0.275 (1.82)	0.190 (1.18)
LEV	0.155 (1.00)	0.301 (0.24)	0.036 (0.29)	0.201 (1.39)
MMA	0.273 (1.57)	0.0854 (0.56)	0.001 (0.01)	0.049 (0.32)
NW	0.615** (3.28)	0.224 (1.72)	−0.075 (0.58)	0.221 (1.64)
NC	0.422** (2.64)	−0.063 (−0.45)	−0.072 (−0.54)	−0.015 (−0.10)
ARAGON	0.434* (2.45)	0.193 (1.30)	0.058 (0.41)	0.085 (0.60)
CENTRE	0.336 (1.85)	−0.009 (−0.06)	0.017 (0.14)	0.035 (0.25)
Constant	1.023*** (4.24)	2.006*** (10.08)	0.285* (1.68)	2.920*** (16.94)
R^2	0.466	0.312	0.313	0.383
Observations	771	1195	1567	1854

Note: t-statistics in parentheses. *** p-value<0.01, ** p-value<0.05, * p-value<0.1. Clustered-robust standard errors were obtained as in Cameron and Trivedi (2022). Time dummies are omitted for simplicity. Regions are abbreviated as follows: BMA (Barcelona Metropolitan Area), LEV (Levante), MMA (Madrid Metropolitan Area), NW (North-West), NC (North-Centre), ARAGON (Aragón and rest of Cataluña), and CENTRE (rest of Centre). R^2 is reported as a measure of quality of fit for each model. The reference household profile is a low socioeconomic status, with 1–2 members, no children, and age under 35. Reference region is Andalucía.

exhibits clear non-linearities: the growth of this effect diminishes with larger households. Previous studies have similarly found that larger households tend to produce more waste than smaller ones (e.g., Quested et al., 2013; Stancu et al., 2016), with the growth rate of waste diminishing as family size increases (Parizeau et al., 2015). The obtained coefficients also indicate, as for the age variable, a more pronounced effect for the meat and dairy categories (2.55 and 1.77 for the '5 or more' group, respectively), compared with vegetables and other food products (1.16 and 0.96). Again, two factors may be influencing these differences: a higher share of meat consumption in larger households (e.g., Ritzel and Mann, 2021) and a higher unitary water footprint of meat products.

The presence of children in the household is associated with a reduction in the water footprint of food waste. The obtained negative effect contrasts with earlier studies suggesting higher food waste levels in households with children (e.g., Parizeau et al., 2015; Visschers et al., 2016). However, as noted by Evans (2011), eating patterns of children are rather unpredictable. In our case study, we believe that several factors may account for the effect obtained. First, households with children often purchase food in larger quantities to meet family needs, which can be more cost-effective. In addition, due to budget constraints, these households may be more conscientious about food waste, leading to better meal planning and increased efforts to use leftovers efficiently. Moreover, the variability in children's appetite often means that parents save leftovers for future meals rather than discarding them. In this case, the differences across products are limited, although we observe a higher coefficient for meat (1.75) than for vegetables (1.61), other food products (1.56) and dairy (1.53). Again, the higher unitary water footprint of meat products may be influencing this result. Moreover, the previous studies (e.g., Merlino et al., 2017) have observed that households without children tend to have higher meat consumption habits than those with children.

4. Conclusions

Aligned with global sustainability agendas, the growing awareness of the environmental consequences of consumer food waste has become a pressing concern, particularly in regions facing water scarcity. Understanding these impacts not only reinforces commitments to sustainable practices but highlights key challenges and opportunities in water resource management.

In this study, we analysed the water footprint associated with household food waste in Spain and investigate how socioeconomic characteristics shape it. We focus on product-level heterogeneity to delineate differences across food categories and to examine how changes in the socioeconomic characteristics of households drive changes in the consumption of food products with a different unitary water footprint, thereby resulting in diverse impacts on the total water footprint of food waste. To do so, we first quantify the embedded virtual water in household food waste by combining a product-level food waste data of representative Spanish households with the unitary water footprint of consumption. Then, we apply a pooled regression framework to estimate, for each food category, how these socioeconomic characteristics shape its water footprint. We also assess whether these effects differ significantly across categories using likelihood-ratio tests. This dual approach highlights both the magnitude of water loss due to food waste and the socioeconomic drivers underlying category-specific footprints.

Overall findings evidence that the socioeconomic status and household size have a consistent positive impact on the water footprint of food waste, while the age of the person responsible for shopping and the presence of children reduce the associated water footprint. These outcomes align with much of the previous literature on assessing the drivers of consumer food waste, providing valuable insights for formulating strategies to mitigate food waste and its water-related impacts, reducing water withdrawals, fostering efficient and sustainable water use, and consequently addressing water scarcity while contributing to climate change adaptation. Specifically, they point out the importance of campaigns that continue to support those demographic groups already contributing positively to the reduction of the water footprint of household food waste while encouraging those with less effective practices to make necessary adjustments to lessen their impact.

The estimates across food categories allows us to confirm the existence of statistically significant differences across products. Results indicate that vegetables and other foods are more sensitive to socioeconomic status, while meat and dairy show a stronger effect from age and household size. These findings can help policymakers to design tailored policies for specific groups in order to reduce the water footprint associated to food waste by focusing on those products that require a higher water intensity. In general, the impact of the considered drivers is higher in those categories with a higher unitary water footprint (such as meat and dairy products), despite being food categories with a lower waste level. On the contrary, coefficients are lower in those food categories with a lower unitary water footprint (such as vegetables), despite its greater food waste magnitude. These results add a new dimension to the existing literature that has addressed either the water footprint of food or the food waste separately, but without considering the combination of both dimensions simultaneously. This underscores the necessity of strengthening policies designed to reduce food waste in those food products with a higher impact in terms of water resources, and not only in those with higher waste levels. In particular, policies and actions aimed at promoting more sustainable diets, especially those that are more plant-base, could lead to a reduction of the water impacts of food waste by encouraging the consumption of products with lower resource requirements.

Our study offers novel insights into how household socioeconomic characteristics shape the water footprint of food waste. However, there are still some limitations to overcome. Specifically, despite using a large-scale dataset representative of the overall Spanish household population, we lacked greater disaggregation of food products and region data. This would offer a more granular and precise understanding, allowing for more detailed insights into the water footprint of individual food items and spatial heterogeneity. On the one hand, greater product detail would eliminate the necessity of aggregating water footprints and reduce the risk of measurement errors, allowing us to capture nuanced variations in waste behaviour. On the other hand, higher spatial granularity would allow us to explore the existence of potential spatial patterns, not supported by our current analysis, possibly due to data aggregation over large regional units. While effectively allowing us to identify different effects across household characteristics, the categorical nature of our dataset restricted numerical granularity and thereby limited a more explicit consideration of certain non-linear relationships.

Therefore, further research is needed to address these limitations and enhance the understanding of the household food waste-water footprint nexus. A crucial next step involves obtaining more disaggregated data, both for food products and regions, while ensuring the representativeness of the overall population through the use of large-scale databases, similar to the one employed in this study. Leveraging such disaggregated data, future studies could focus on potential spatial relationships at the local or provincial level, offering deeper insights into the geographical dynamics of food waste and its water footprint. In addition, investigating the different impacts of food waste on water resources across different types of meat products (e.g. red vs. white meat) or crops (e.g. rainfed vs. irrigated) would be valuable. Methodologically, exploring non-linear modelling techniques or more complex regression approaches could provide a more nuanced characterization of the relationships between socioeconomic factors and the water footprint of food waste. Beyond data related and methodological considerations, future research could also explore behavioural factors influencing the water footprint of food waste, as this research primarily focuses on socioeconomic variables. These aspects merit further investigation to provide a more comprehensive understanding of how households play an active role in reducing pressure on water resources through food waste reduction.

In conclusion, this research highlights the importance of evidence-based policy decisions to tackle both food waste and water scarcity. While acknowledging potential limitations, the findings of this study provide valuable insights that can inform the development of a more sustainable food system through targeted household-level interventions. By enhancing our understanding of the relationship between household food waste and water usage, and exploring food product heterogeneity, these findings contribute to the design of effective policies aimed at promoting responsible consumption and hence, optimizing water resource management.

CRediT authorship contribution statement

Pilar Gracia-de-Rentería: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Hugo Ferrer-Pérez:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

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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

Food waste data used for this study are available from Kantar upon request. The data are not publicly available due to licensing and privacy restrictions.

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