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Environmental footprints of German food consumption by gender and socio-economic status

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ABSTRACT

Germany's dietary patterns are among the most environmentally intensive in the world. In light of the multitude of environmental pressures originating from the current food system, we scrutinise the carbon, land, blue and green water foodprints of German consumers, distinguishing between two subgroups of interest: gender and socio-economic status. Using the multi-regional Food and Agriculture Biomass Input-Output model we are able to capture emissions throughout dispersed global supply chains. For allocating environmental responsibilities to the respective subgroups, we rely on the largest study to record eating habits and beverage consumption in Germany: the National Nutrition Study II. For male consumers, land requirements, carbon emissions and green water foodprints decline with increasing socio-economic status. Among females, differences in carbon, land, and green water foodprints across socio-economic strata are relatively minor and lack a consistent pattern. We identify meat and dairy product consumption to be the largest contributor to environmental foodprints, accounting for up to two-thirds of overall carbon emissions, land requirements and green water use. Notably, blue water use is highest among high socio-economic status females and males, largely driven by greater consumption of blue water-intensive foods such as nuts and seeds and fruits, vegetables, and legumes. Our results carry important policy implications, highlighting that prominent push measures – such as extending the Emissions Trading Scheme to the agricultural sector or introducing a meat tax – may have disproportionate adverse effects on households of low socio-economic status.

1. Introduction

The agriculture sector is a major contributor to GHG emissions: Carbon dioxide (CO_2), methane and nitrous oxide emissions (e.g. from enteric fermentation, fossil fuel use, fertiliser production, transportation, land use change, etc.) are associated with virtually every stage of the global food supply chain (Bellarby et al., 2008; Carlsson-Kanyama and González, 2009; Clark et al., 2020; Garnett, 2011; Ivanovich et al., 2023). In fact, when accounting for all stages of global supply the food system is responsible for 21–37 % of total anthropogenic GHG emissions (Arneth et al., 2019; Crippa et al., 2021; Garnett, 2011; Pachauri et al., 2014).

Agricultural activities also consume vast amounts of water. Overall, 92 % of the global water footprint (Mekonnen and Hoekstra, 2011) and 80 % of total human blue water use (Rost et al., 2008) can be attributed to agricultural production. However, with 60–70 % of foodstuff being produced by precipitation-fed agriculture, green water outweighs blue water use by a factor of 4 and thus continues to be the main water source for agricultural purposes (Falkenmark and Rockström, 2006; Rockström et al., 2009; Rost et al., 2008).

Another critical and scarce input for the agricultural system and thus global food security is fertile land, with cropland covering around

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12–14 % and pastures about 38 % of the earth's total ice-free surface (Foley et al., 2011). In light of population growth, shifts towards more energy dense diets and the greater use of bioenergy, estimates predict global demand to further increase. In fact, global cropland is predicted to expand by 1.1–3.35 million km^2 from 2010 to 2050 (Alexandratos and Bruinsma, 2012; Williams et al., 2021), possibly leading to the transgression of the suggested planetary boundary for cropland of 15 % of terrestrial surface (Henry et al., 2018; Stehfest et al., 2019). Resulting environmental impacts encompass biodiversity loss, soil erosion, deteriorating soil conditions and carbon storage loss, to only name a few (Foley et al., 2005; Karamage et al., 2016; Kehoe et al., 2017; Molotoks et al., 2018).

Transforming the global food system is essential not only to meet the Paris Agreement's target of limiting average temperature rise to ‘well below 2°C' (M. A. Clark et al., 2020), but also critical for securing global water resources, preserving precious ecosystems and ensuring long-term food security. Nonetheless, environmental stress originating from the global food system is likely to further increase (Bellarby et al., 2008; Stehfest et al., 2019; Westhoek et al., 2011), partly due to what Grigg (1995) has termed the nutrition transition (see also Popkin and Ng, 2022; Poulain, 2021). Shifts in diets towards a higher caloric intake have indeed been empirically observed on a global scale (Popkin, 2006; Popkin et al., 2012; Pradhan et al., 2013). This is problematic due to calorie rich dietary patterns – containing relatively higher amounts of animal and hydrogenated fats as well as sugar, and lower amounts of fibre – exhibiting higher resultant GHG emissions (Carlsson-Kanyama and González, 2009; Pradhan et al., 2013; Taylor, 2000; Tilman and Clark, 2014), larger blue and green water footprints (Harris et al., 2020; Meier and Christen, 2012, 2013; Vanham et al., 2013) and substantially higher land requirements (Helander et al., 2021; Meier and Christen, 2012, 2013).

Europe, a conglomerate of high-income countries, is emblematic of Grigg's nutritional transition (Grigg, 1995; Popkin, 2006), with a consumption of animal protein twice the global average (Westhoek et al., 2011). Germany is no exception to the European food consumption approach. It exhibits a dietary pattern characterised by the second highest caloric intake of all dietary patterns observed in the world: close to 3500 cal $person^{-1}$ day^{-1} (Pradhan et al., 2013). This dietary profile features a particularly high intake of animal products, vegetable oils, sugar, and sweeteners (Heuer et al., 2015; Pradhan et al., 2013). Data availability as well as other high-income countries exhibiting a likewise tendency towards calorie intense diets (Pradhan et al., 2013) qualify Germany as a suited case study.

In this context, it is important to highlight that nutrient intake, dietary patterns and attitudes towards specific foods may vary greatly among different societal groups, with socio-demographic and economic factors playing a critical role in the formation of food consumption patterns (Einhorn, 2020a; Heuer et al., 2015; Johansson et al., 1999; Koch et al., 2019; Milligan et al., 1998; Prättälä et al., 2007). Manhood and masculinity, for instance, is often associated with meat eating, while vegetables and non-meat foods are perceived as women's food, leading Adams (2015) to conclude that men who become vegetarian challenge an essential part of their masculine role. In fact, several studies found empirical evidence for Adam's hypothesis linking meat consumption with masculinity (De Backer et al., 2020; Rosenfeld and Tomiyama, 2021; Rothgerber, 2013; Ruby and Heine, 2011). This also applies to Germany. Even after adjusting for body weight, men consistently consume more meat products, while women incorporate relatively more fruits and vegetables into their diet (Heuer et al., 2015; Koch et al., 2019). Subsequently, German males' diets were estimated to have a 25 % higher global warming potential, cause 30 % more ammonia emissions and create 11 % higher blue water demand than that of women (Meier and Christen, 2012).

Besides gender, socio-economic indicators such as education, income and occupational status also play a significant role in shaping food consumption patterns (Boylan et al., 2011; De Irala-Estevez et al., 2000; Franco et al., 2022; Harrington et al., 2011; Lallukka et al., 2007; Peleg-Mizrachi and Tal, 2019; Reynolds et al., 2015, 2019). In terms of their resulting environmental impacts, however, the results are somewhat ambiguous and highly context dependent. For Australia, the UK, the Netherlands and Chile, scattered evidence points at relatively better-off households causing greater environmental impacts when compared to individuals of lower socio-economic status (Franco et al., 2022; Reynolds et al., 2015, 2019; van Dooren et al., 2018). In contrast, Peleg-Mizrachi and Tal (2019) identify no significant differences in the ecological footprints of food consumption across individuals of different socio-economic backgrounds in the case of Israel. Likewise, Kanemoto et al. (2019) find income and savings to be only weakly correlated with household carbon footprints associated with food consumption in Japan.

The present study can be located within the intersection of two structural indicators shaping dietary patterns, namely gender and socio-economic status, and investigates the following research question: *What are the environmental foodprints (*i.e. *footprints of food consumption) of German consumers by gender and socio-economic status?* This work adds to existing literature threefold: First, it enriches the debate revolving around environmental footprints associated with food consumption across different socio-economic groups. Second, to the best of our knowledge there currently exists no comprehensive data on the environmental impacts of (German) food consumption by gender across different socio-economic status (SES).[1] While the literature generally agrees upon men having higher foodprints than women (Adams, 2015; Rothgerber, 2013; Ruby and Heine, 2011), gender differences of environmental impacts may be more pronounced across different socio-economic strata. This may occur if (a) gender norms influence individuals of different socio-economic backgrounds to a varying degree or (b) class effects being more noticeable for one gender.[2] Third, while foodprint assessments for Germany relying upon intake data from the National Nutrition Study II (NNSII) have so far primarily followed a life cycle assessment (LCA) approach (Eberle and Fels, 2016; Meier et al., 2014; Meier and Christen, 2011, 2012, 2013; Treu et al., 2017), we perform a multi-regional input-output analysis. This allows for a holistic perspective that covers emissions from the entire food system and dispersed global supply chains while precluding double-counting (Bruckner et al., 2015). We conclude with a discussion of the implications for policy and practice.

2. Material and methods

We consider four environmental indicators: greenhouse gas emissions measured in CO_2 equivalents (CO_2e), land requirements, and blue and green water use. For the calculation of environmental pressures caused by German food consumption, an environmentally extended input-output analysis (EE-IOA) was performed. This method serves as a powerful tool to capture hidden environmental impacts embodied in the final consumption of products and follows a top-down approach attributing all responsibility to the final consumer (Kitzes, 2013). A more comprehensive overview of the methodological foundations of EE-IOA can be found in Schaffartzik et al. (2014). Food intake values from the NNSII were translated into raw material (i.e. crop) equivalents for plant-based products, carcass equivalents for meat, and raw milk equivalents for dairy products to match the classification of the applied input-output (IO) model. Subsequently, we complemented German food intake values with official FAO data on the total amounts of the respective commodities available as human food during the reference period (FAOSTAT, 2023). This approach helps address potential

[1] Note that SES, socio-economic strata, socio-economic background and socio-economic group are used interchangeably.

[2] Similar assumptions on the intersectionality between gender and social class have been drawn in the field of social psychology, however, with regard to women's employment (McGinn and Oh, 2017).

underreporting in food intake documentation (Straßburg et al., 2019) and accounts for food waste and losses not captured in the NNSII. Finally, the adjusted intake values for individuals within the subgroups of interest (i.e. gender and SES) were multiplied with the respective emission and resource intensities. The subsequent sections provide a more detailed description of the methodological process employed.

2.1. The foodprint concept

The concept of the environmental footprint serves as a heuristic to illustrate the effects of the continuous human appropriation of ecosystems in a tangible manner and has been widely acknowledged in the literature (Hoekstra and Mekonnen, 2012; Liu et al., 2018; Wiedmann and Lenzen, 2018). We apply the concept of *foodprints* as a means to scrutinise the environmental impacts of the food system. The *carbon foodprint* captures to the total amount of CO_2e associated with food production (Wiedmann and Minx, 2008). The *land foodprint* measures the area of cropland as well as permanent meadows and pastures in the production of agricultural products (Fischer et al., 2017). The *blue water foodprint* refers to water withdrawals for irrigation (Rost et al., 2008). Finally, with precipitation being a major water source for agricultural purposes (Mekonnen and Hoekstra, 2011; Rockström et al., 2009), the *green water foodprint* estimates the amount of rainwater used in food production.

2.2. Calculating environmental foodprints

In line with Helander et al. (2021), we base our foodprint calculations on the Food and Agriculture Biomass Input-Output model (FABIO). The database provides physical multi-regional IO tables for agricultural and food products at a high level of detail covering 130 different product categories for 191 countries between 1986 and 2013 (Bruckner et al., 2019). In terms of the environmental extension, FABIO relies on carbon emission data from Piñero et al. (2022), land-use data from FAOSTAT (2023) and green and blue water data from Mekonnen and Hoekstra (2011). Following this approach allows for a highly detailed analysis of material flows and embodied environmental pressures across complex and globally dispersed supply chains. To match the reference period of the applied food intake data, we averaged the values FABIO for 2005 to 2007.

Our calculations of environmental foodprints follow the standard EE-IOA procedure by calculating $\mathbf{F}_i = \widehat{\mathbf{e}}_i(\mathbf{I}-\mathbf{A})^{-1}\mathbf{Y}$. Thereby, the matrix $\mathbf{F}$ represents the total foodprint of German consumers and is defined as the product of the Leontief inverse matrix $(\mathbf{I}-\mathbf{A})^{-1}$, the final demand matrix for the respective product categories and countries $\mathbf{Y}$, and the diagonalised environmental extension vector $\widehat{\mathbf{e}}_i$, which specifies the environmental inputs of resource i (i.e. carbon, land, blue and green water) required for the production of a single unit of output of each agricultural product.

2.3. System boundaries

The analysis captures the environmental impact of agricultural production including land use, green and blue water consumption, and greenhouse gas emissions from enteric fermentation, rice cultivation, manure management, energy use, land use (net emissions/removals from grassland and cropland), fertiliser application (manure and synthetic fertilisers), land use change and others (e.g. burning crop residues and savannah). Emissions from post-harvest handling and storage until the final purchase and consumption of a product – such as transportation from supermarkets to households, final storage, preparation and use – were excluded. Thus, while food waste and losses may occur across various life cycle stages, the assessment of foodprints is limited to environmental impacts during agricultural production.

2.4. Nutritional data

The NNSII is currently the largest study to record eating habits and beverage consumption in Germany and provides a comprehensive overview of and concrete data on food intake values across the German population aged 14 to 80. The study is based on a representative sample of 20,000 participants, with intake data collected at the individual rather than household level (Max-Rubner-Institut, 2008a). Household-specific factors (e.g. household size) that influence individual food consumption behaviour are therefore indirectly captured, as the observed intake data reflects these contextual influences. By disaggregating consumption into a range of subgroups, the NNSII allows for a more nuanced understanding of differences in food consumption patterns among different genders, socio-economic backgrounds and the gender-status nexus. SES is defined as an index incorporating educational qualification, occupational status of the main earner and household net income (Max-Rubner-Institut, 2008a).[3] The NNSII distinguishes between a total of 52 food categories, including 12 beverages (8 non-alcoholic and 4 alcoholic beverages) and 40 foods or compound dishes (e.g. 'Fruits', 'Meals on the Basis of Bread', 'Soups and Stews', etc.) (Max-Rubner-Institut, 2008b). A detailed overview of the food items and intake quantities can be found in the supplementary material (SM_A) (A).

As self-reported food intake data generally tends to be subject to reporting biases (Briefel et al., 1997; Heuer et al., 2015; Straßburg et al., 2019), we complemented NNSII intake values with official FAO Food Balance Sheets data on the total amounts available as human food (FAOSTAT, 2023). Specifically, we calculate $\mathbf{C}_{\mathbf{FC,G,SES}} = \mathbf{Int}^{\mathbf{NNSII}}_{\mathbf{FC,G,SES}}/(\mathbf{1}/\mathbf{CF}_{\mathbf{FC}})$, where $\mathbf{C}_{\mathbf{FC,G,SES}}$ represents the estimated consumption of individual food categories $\mathbf{FC}$ by gender $\mathbf{G}$ and socio-economic status $\mathbf{SES}$; $\mathbf{Int}^{\mathbf{NNSII}}_{\mathbf{FC}}$ denotes NNSII-reported intake values for each food category and subgroup of interest; and $\mathbf{CF}_{\mathbf{FC}}$ is a food category-specific conversion factor defined as $\mathbf{CF}_{\mathbf{FC}} = \mathbf{Int}^{\mathbf{NNSII}}_{\mathbf{FC}}/\mathbf{Cons}^{\mathbf{FAO}}_{\mathbf{FC}}$. Due to FAO data not distinguishing between gender or socio-economic groups, an average value for each food category was applied for calculating the $\mathbf{CF}$. With regards to FAO data, we use a three-year average that matches the base period of the NNSII in order to smoothen annual variations. FAO Food Balance Sheets are assembled using a blend of official government data (e.g. industrial output, trade statistics) and unofficial (imputed data) sources, alongside the FAO's own estimates and data adjustments. Further details on the methodology used for compiling the Food Balance Sheets are provided in FAOSTAT (2023). A comparison between total FAO food supply data and NNSII intake data is presented in SM_A (F). The observed patterns of under- and overreporting across food categories align well with the findings of Meier et al. (2014), with the exception of the categories 'Fruits', 'Coffee and products', and 'Tea (including mate)'. Variations may be attributed to differences in category composition and/or data sources. The procedure of matching food intake data with total available amounts furthermore enabled us to capture food waste and losses (FWL). However, with the NNSII lacking data on individual food waste levels, differences in FWL occurrence across genders and SES could not be determined.

2.5. Harmonisation of NNSII and FABIO

NNSII intake values represent the final consumption stage. FABIO, in contrast, reports on most processed food products in the form of converted primary crop or product equivalents. This mismatch necessitated the translation of NNSII categories into FABIO items (e.g. conversion from intake of 'Cheese and curd' as reported by the NNSII into FABIO item 'Milk – Excluding Butter').

Whenever possible, NNSII food items were disaggregated into

[3] For further information on NNSII index composition, please see SM_B.

individual ingredients. In some cases, however, NNSII food items were allocated to broader FABIO item groups to minimise uncertainty associated with the re-categorisation process. For the 8 composite food items reported in the NNSII, i.e. multi-ingredient meals (e.g. 'Meals on the basis of bread', 'Meals on the basis of egg', etc.), we followed Meier and Christen (2012) by allocating 67 % of the intake weight to the primary ingredient, while excluding minor components and water content. This approach was necessary to circumvent the uncertainties associated with disentangling compound food items into their constituent ingredients. The category 'Other food items' comprises all FABIO items for which no corresponding NNSII intake data was available (i.e. spices and fermented beverages). In addition, 'Other food items' contains 75 % of overall vegetable oil consumption. This can be attributed to the NNSII providing intake values for 'Margarine' while lacking data on other forms of vegetable oil consumption (e.g. within multi-ingredient meals). For simplification, we assumed the consumption of foodstuffs incorporated into the 'Other food items' category to be equally distributed across gender and SES. Finally, a total of 6 NNSII food categories were excluded from the analysis because their aggregated nature impeded a logically coherent allocation to FABIO items (e.g. 'Soups and stews', 'Snacks', 'Sauces', etc.). Considering that the neglected item categories demonstrate no substantial differences in consumption values among the various socio-economic groups of both genders, we theorise them to have little to no distorting effects on the foodprint results. A more detailed documentation of the harmonisation process can be found in the SM_A (B & C).

In what followed, the adjusted raw material consumption values (incl. FWL) by subgroup of interest were multiplied with the respective emissions and resource use per kg of product.

2.6. Consumption profiles

Fig. 1 displays an overview of the absolute consumption profiles based on NNSII intake data. Socio-economic backgrounds for both males (M) and females (F) respectively are divided into low SES (LSES), low-middle SES (LMSES), middle SES (MSES), upper-middle SES (UMSES) and upper SES (USES). As this work focuses on the overall environmental impacts embedded in individual food consumption rather than comparing dietary profiles across subgroups, differences in caloric intake requirements between genders were not accounted for. As a result, under ceteris paribus conditions (i.e. equal dietary composition across the subgroups of interest), higher annual food consumption (Fig. 1) directly translates into greater environmental impacts. Note that the category 'Alcohol, sugar & cocoa' includes the water contained in beer consumption. As visualised, both men and women exhibit a slight increase in overall consumption values with improved SES. This tendency can be mainly explained by increments in 'Fruits, vegetables and legumes' consumption among higher socio-economic backgrounds. In addition, we observe an increase in the intake of 'Dairy products' and 'Cereals', while the consumption of 'Meat' decreases with SES. For a visualisation of the relative consumption profiles by SES and gender see SM_A (D).

Fig. 2 visualises the nutrition profiles based on FAO data (FAO, 2001). Interestingly, increased overall consumption among males of higher SES does not translate into higher caloric intake. In fact, even though more food is consumed, caloric intake decreases slightly with SES. This can be attributed to differences in commodities' average nutrition values, with 'Fruits, vegetables and legumes' being less energy intensive than, for instance, 'Meat' and 'Cereals'. In the case of more affluent males, a substantially higher caloric intake from 'Fruits, vegetables and legumes' is outweighed by fewer calories originating from 'Meat' and 'Alcohol, sugar & cocoa' consumption. Female consumers, in contrast, exhibit an increase in overall caloric intake with rising SES. This is a consequence of women of different SES showing only small variations in 'Meat' consumption, insufficient to offset the substantial increase in caloric intake from 'Cereals' and 'Fruits, vegetables and legumes' consumption.

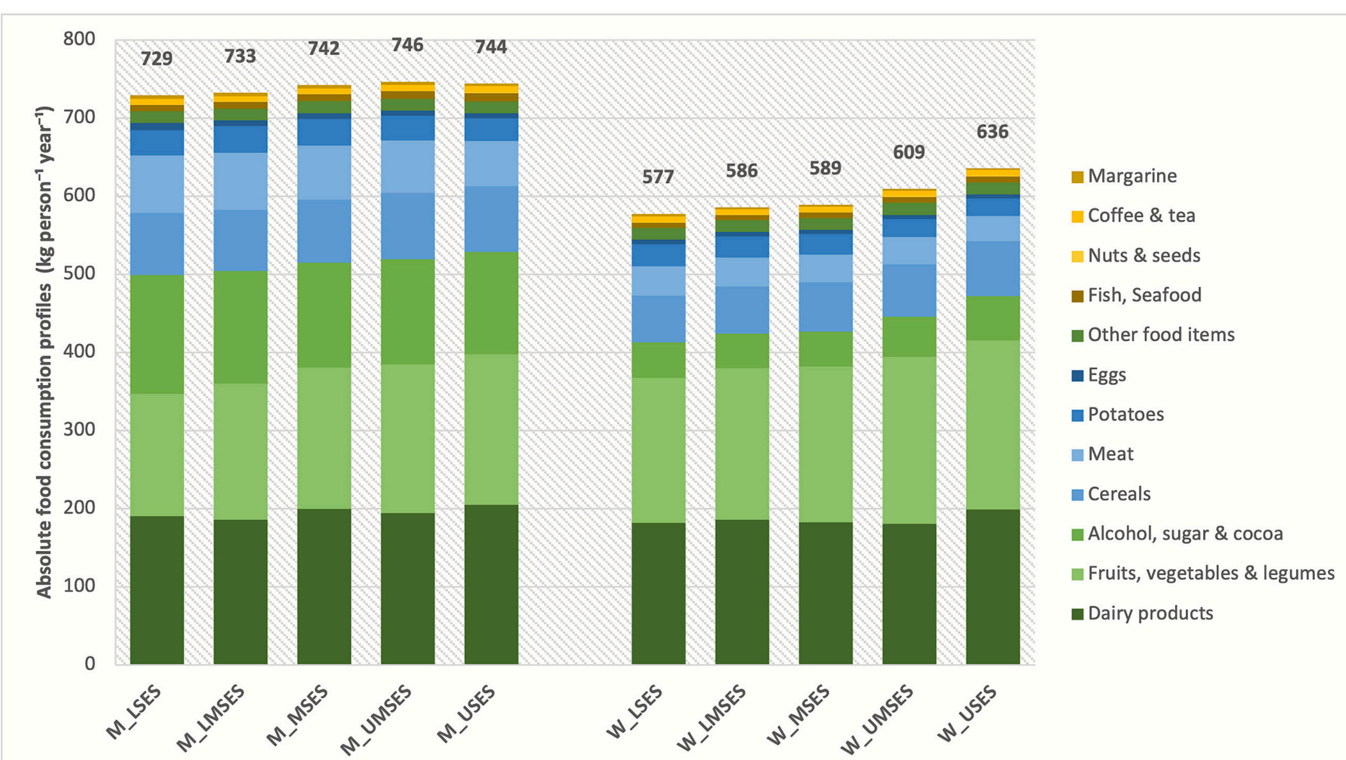

Fig. 1. Absolute consumption profiles based on NNSII intake data in kg person^{-1} year^{-1} by gender and SES. For visualisation purposes, diverse food items were aggregated into broader categories, namely 'Alcohol, sugar & cocoa' and 'Fruits, vegetables & legumes'.

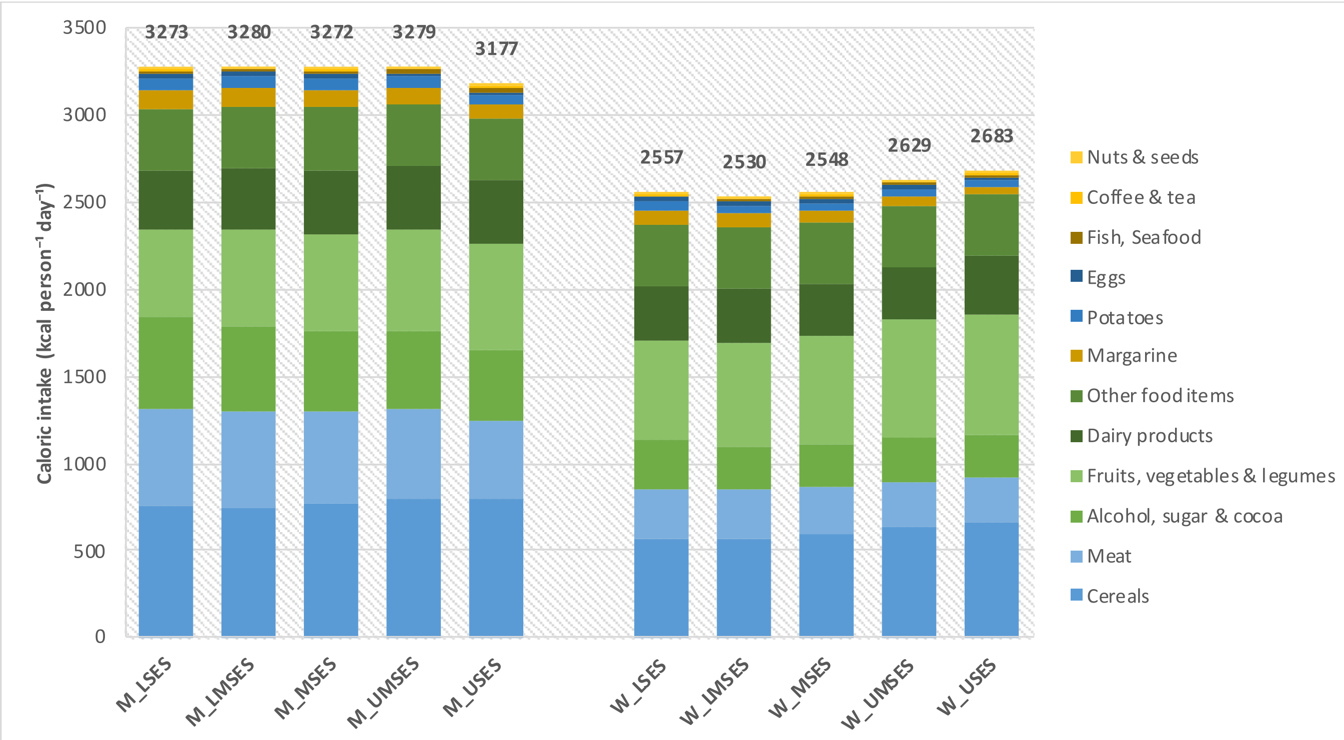

Fig. 2. Caloric intake based on NNSII intake data in kcal person^{-1} day^{-1}. For visualisation purposes, diverse food items were aggregated into broader categories, namely 'Alcohol, sugar & cocoa' and 'Fruits, vegetables & legumes'.

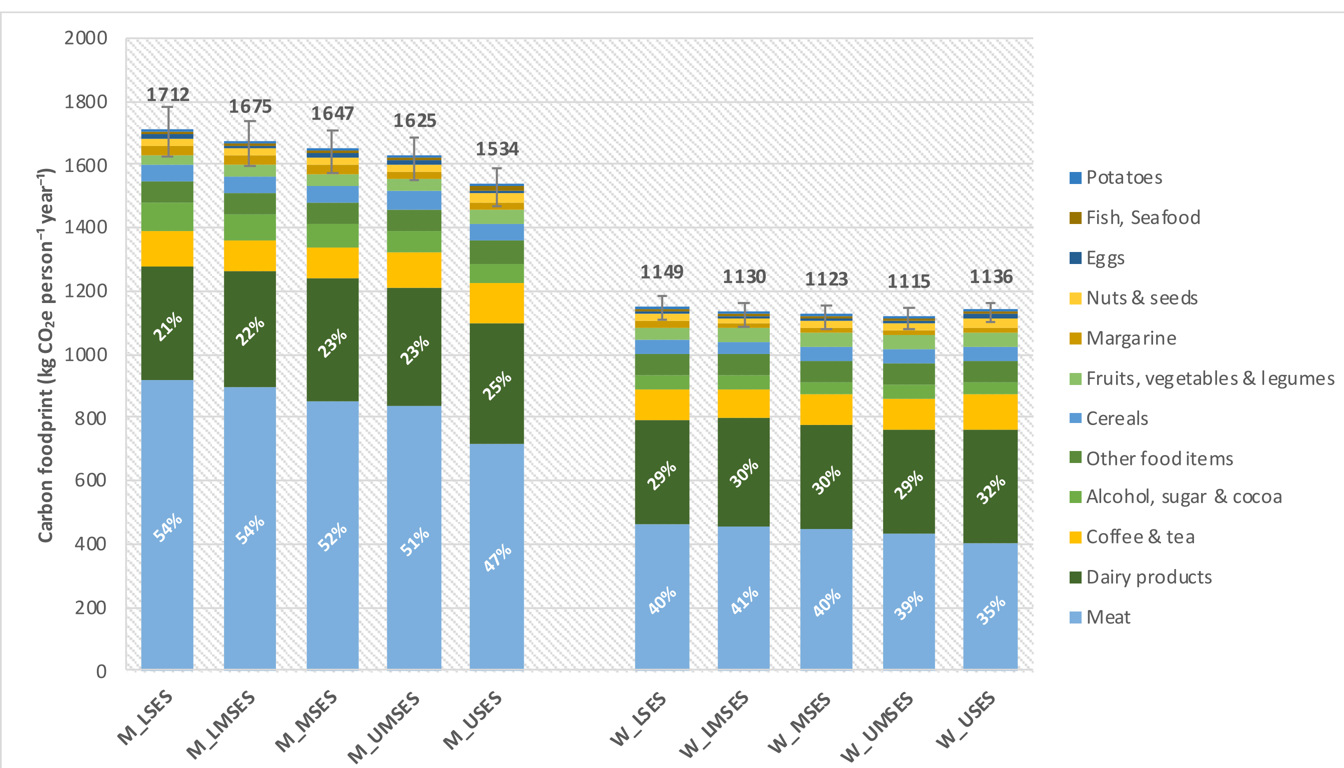

Fig. 3. Carbon foodprint in kg CO_2e person^{-1} year^{-1} by gender and SES. The error bars indicate the results from the uncertainty analyses. The numbers above each bar indicate the total carbon foodprint. For visualisation purposes, diverse food items were aggregated into broader categories, namely 'Alcohol, sugar & cocoa' and 'Fruits, vegetables & legumes'.

3. Results

The results concerning the carbon, land, blue and green water foodprint by gender and SES are visualised in Fig. 3-Fig. 6. To improve readability, the analysed food categories were further aggregated from a total of 18 to 12 categories. For instance, the items 'Milk – excluding butter' and 'Butter, Ghee' are now conjointly presented within the category 'Dairy products'.

Carbon foodprints range from 1534 to 1712 CO_2e person^{-1} year^{-1} for males and 1115–1149 CO_2e person^{-1} year^{-1} for females; land requirements from 3506 to 3923 m^2 person^{-1} year^{-1} for men and 2533–2599 m^2 person^{-1} year^{-1} for women; green water consumption from 1440 to 1581 m^3 person^{-1} year^{-1} for the male and 1070–1106 m^3 person^{-1} year^{-1} for the female population; and blue water use from 53 to 57 m^3 person^{-1} year^{-1} for males and 38–50 m^3 person^{-1} year^{-1} for females. The error bars indicate uncertainty in terms of the environmental impacts associated with differences in the composition of meat consumption across SES (see 4.2 Uncertainties & limitations).

3.1. Carbon, land and green water foodprints

For the male population, we observe a linear relationship between land requirements, carbon emissions and green water use on the one hand and socio-economic background on the other. While M_LSES contribute the greatest environmental impact, their better-off counterparts (M_USES) account for the least. This is mainly a consequence of higher levels of 'Meat' consumption among males of low SES. The difference in terms of the land, carbon and green water foodprints between the lowest and the highest SES moves between 9.3 and 11.2 % for the male population. Furthermore, we observe the largest rise in environmental pressures (4–5.8 %) between males of the upper and upper-middle SES compared to only 1.3–2.2 % between the other socio-economic groups.

Differences in carbon, land and green water footprints across the female population are only marginal, with highest to lowest values oscillating between a range of 2.5–3.4 %. When considering the uncertainty intervals, the results on the differences in the environmental impacts by socio-economic background are further weakened. We therefore conclude no distinct trend to be observable for women of different SES.

In terms of the foods contributing to carbon, land and green water foodprints, both genders reveal similar tendencies. Unsurprisingly, animal-based products are accountable for substantial shares of environmental burdens. In fact, the share of animal-based foods to the total foodprints remains remarkably stable across all socio-economic groups, namely 67–75 % of carbon, 67–74 % of land and 51–61 % of green water foodprints. The magnitude of individual food items, however, differs among consumers of different SES. As demonstrated by Fig. 3-Fig. 5, 'Meat' consumption accounts for the largest share of foodprints, while the consumption of 'Dairy products' is the second largest contributor to environmental pressures for both men and women independent from their SES. The results point towards a complex relationship between climbing up the social ladder and the ecological burden resulting from the consumption of meat and dairy products: with improved SES a relative decrease in foodprints originating from meat consumption is accompanied by an increase in the contribution of dairy products. This trend, however, is far less pronounced among the female than male population, with women of low-middle SES (F_LMSES) representing an outlier. A possible explanation may be that, instead of substituting meat with vegetables or other plant-based foods, individuals seem to replace it with other animal-based foods. This observation is in line with Koch et al. (2019) as well as findings on meat reducers (meat for dinner at maximum 1–2 times per week) ranking cheese and cheese products on top of their subjective food hierarchy by Dagevos and Voordouw (2013).

3.2. Blue water foodprints

The results for blue water differ substantially. Mainly, food consumption profiles of both males and females of upper SES cause the greatest blue water use. Contrary to our findings on the carbon, land and green water foodprints outlined above, we observe blue water consumption to remain more or less stable across the various socio-economic strata in the case of male consumers, while women exhibit a higher volatility in foodprints. Differences in blue water use become particularly evident when comparing W_LMSES to W_USES. A substantial part of the differences in blue water foodprints among individuals of different SES can be explained by diverging NNSII intake values for nuts and seeds – a food category that is heavily blue water intense (1.26 m^3 kg^{-1}), especially in comparison to 'Meat' and other foodstuff.

'Meat', 'Fruits, vegetables & legumes' and 'Nuts & seeds' are responsible for the largest shares of the overall foodprint. With improved SES, male consumers exhibit a continuous decline in blue water use resulting from 'Meat' consumption and, at least in the case of M_USES, a sharp increase in the blue water footprint of 'Nuts & seeds'. For the female population, we observe a likewise, however, slightly less pronounced tendency for 'Meat' and 'Nuts & seeds', with women of lower-middle socio-economic background forming an outlier. The consumption of 'Fruits, vegetables & legumes' contribute to a substantial share of the total blue water requirement for both male and female consumers across different socio-economic strata.

4. Discussion

Our findings address the research question: *what are the environmental foodprints of German consumers by gender and socio-economic status?* The results reveal differences in environmental impacts across these groups: (i) High socio-economic standing is associated with lower carbon, land and green water foodprints among male consumers, while (ii) females exhibit no significant discrepancies in the distribution of carbon, land and green water foodprints across different socio-economic strata (Fig. 3–5); (iii) blue water foodprints increase with higher socio-economic background among both male and female consumers (Fig. 6).

4.1. New foodprint evidence using physical IO tables

Our findings contrast previous results for Australia, where the carbon and water foodprints of high-income households are estimated to exceed those of less well-off households by almost three times (Reynolds et al., 2015). Similarly, Franco et al. (2022) find affluent Chileans to cause almost twice the amount of carbon emissions and water use than their low-income counterparts. In the case of the UK and the Netherlands, evidence suggests diets from high SES consumers to cause only slightly higher CO_2e (3–5 %) than individuals from low/medium SES (Reynolds et al., 2019; van Dooren et al., 2018). Diverging results may originate from: (a) Differences in data sources (e.g. micro-census based vs interview/observation based, monetary vs physical); (b) variations in consumption profiles and supply chain structures of Australia and Chile compared to Germany; (c) different system boundaries, which not only include direct emissions and resource use in agricultural production, but also indirect emissions and inputs along the upstream supply chain; and (d) methodological differences, such as using a life-cycle assessment approach (Franco et al., 2022; Reynolds et al., 2019; van Dooren et al., 2018) or monetary (Reynolds et al., 2015) versus physical IO tables (this study).

A major limitation of monetary input-output tables revolves around the failure to account for price inhomogeneity within homogenous item categories, leading to biased estimations of foodprints. This bias occurs due to the assumption of fixed environmental impacts per monetary unit spent, resulting in an overestimation of environmental impacts associated with affluent socio-economic groups, as their absolute spending on food products tends to exceed that of low-income households (Reynolds

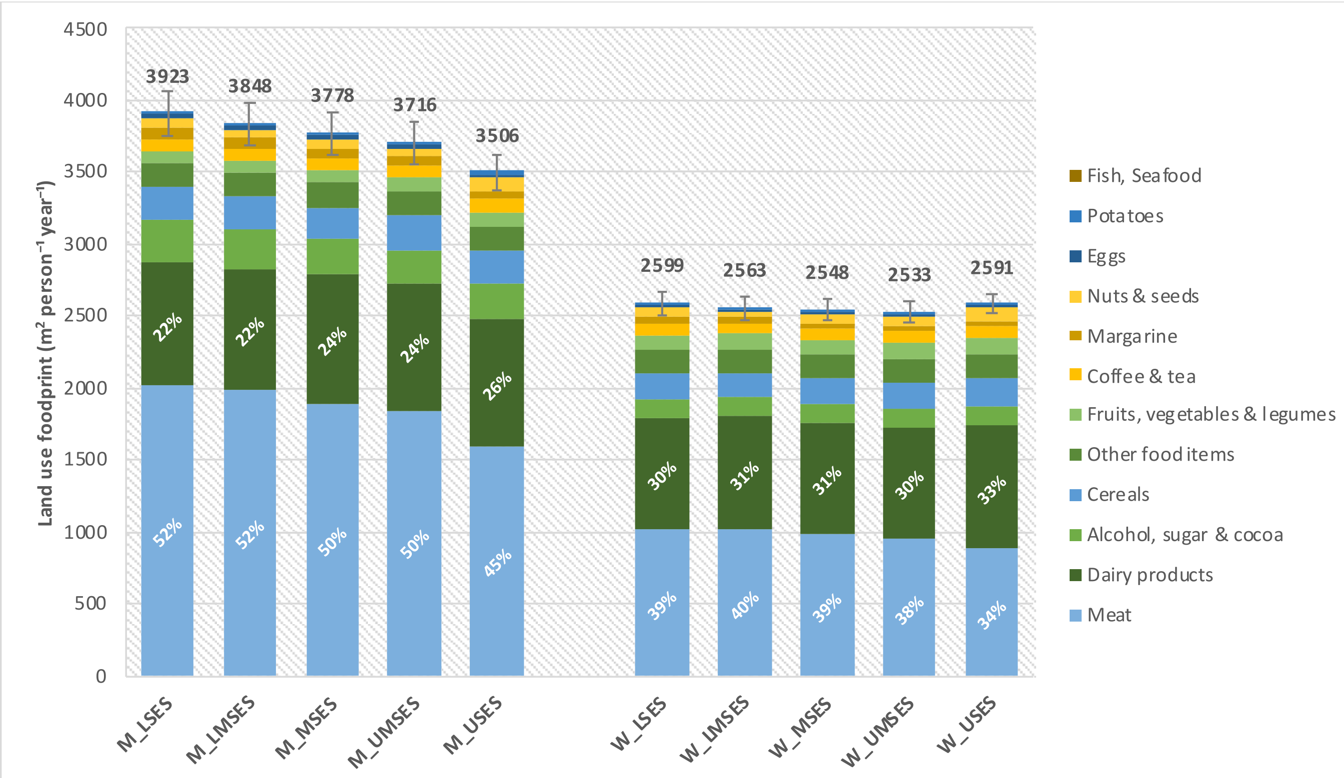

Fig. 4. Land foodprint in m^2 $person^{-1}$ $year^{-1}$ by gender and SES. The error bars indicate the results from the uncertainty analyses. The numbers above each bar indicate the total land use foodprint. For visualisation purposes, diverse food items were aggregated into broader categories, namely 'Alcohol, sugar & cocoa' and 'Fruits, vegetables & legumes'.

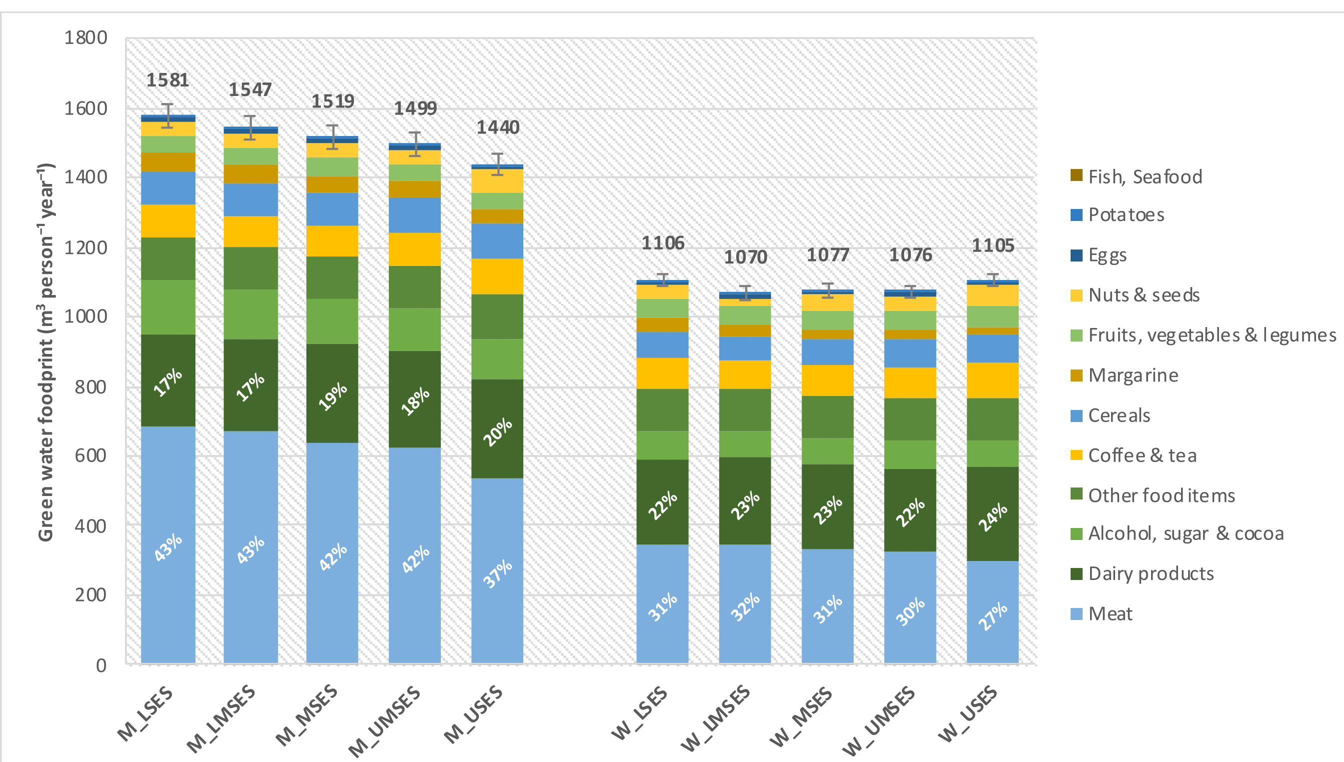

Fig. 5. Green water foodprint in m^3 $person^{-1}$ $year^{-1}$ by gender and SES. The error bars indicate the results from the uncertainty analyses. The numbers above each bar indicate the total green water foodprint. For visualisation purposes, diverse food items were aggregated into broader categories, namely 'Alcohol, sugar & cocoa' and 'Fruits, vegetables & legumes'. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

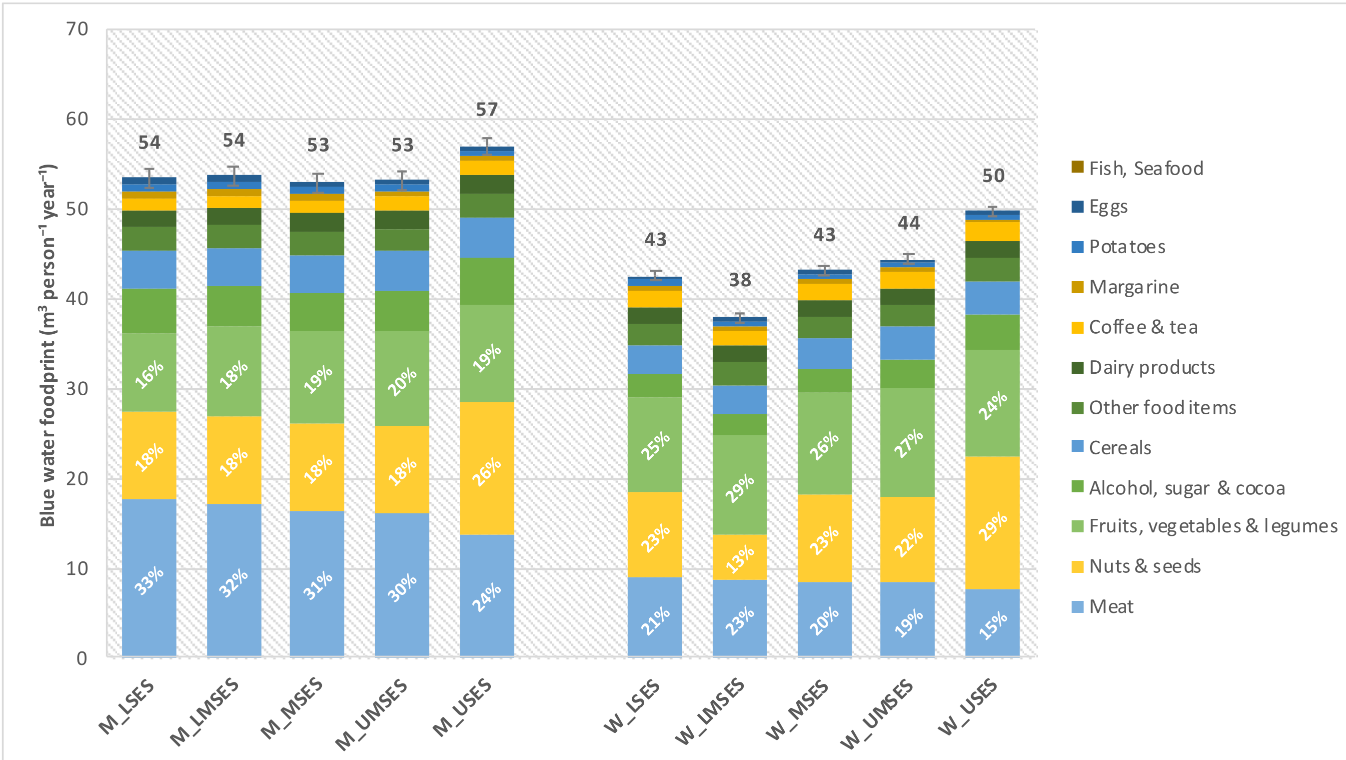

Fig. 6. Blue water foodprint in m^3 person^{-1} year^{-1} by gender and SES. The error bars indicate the results from the uncertainty analyses. The numbers above each bar indicate the total blue water foodprint. For visualisation purposes, diverse food items were aggregated into broader categories, namely 'Alcohol, sugar & cocoa' and 'Fruits, vegetables & legumes'. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

et al., 2015; Theine et al., 2022). As a consequence, numerous scholars have argued for the use of physical accounting frameworks (Bruckner et al., 2019; Heun et al., 2018; Kovanda, 2019; Merciai and Heijungs, 2014). By focusing on actual consumption quantities rather than monetary values, physical IO analysis facilitates a more accurate assessment of environmental foodprints across different socio-economic strata by mitigating the influence of variations in purchasing power on foodprint estimates. Our results thus enable a more nuanced analysis and deliver new insights into the relationship between socio-economic standing and environmental foodprints.

4.2. *Uncertainties & limitations*

The final results depend on a variety of underlying assumptions. (1) To match the two datasets, aggregated food categories from the NNSII needed to be translated into the more detailed item classification of FABIO. Consumption of 'Meals on the basis of meat', for instance, is a highly diverse NNSII category for which no additional information on the respective proportions of ingredients is given. Based on Meier and Christen (2012), we allocated 67 % by weight of this particular multi-ingredient dish to the FABIO item group 'Meat', while neglecting potential other ingredients. This procedure was applied to a set of 8 NNSII food categories. In other cases, data unavailability necessitated the application of recipes to detangle compound items, as in the case of the category 'Lemonade'. Foodstuff that lacked corresponding NNSII intake data (e.g. fermented beverages, spices, etc.) as well as 75 % of overall 'Vegetable oil' consumption was attributed to the category 'Other food items' and assumed to be equally consumed by each socio-economic group. It is important to highlight that within this particular category, vegetable oils account for as much as 92 % of total consumption, 92 % of carbon emissions, 95 % of land requirements, 92 % of green and 68 % of blue water use. We acknowledge that different assumptions on the proportions allocated to individual food categories may influence the results. It is therefore that we determine the mismatch in the level of detail of the datasets and the use of assumptions that are consequently required to be a source of uncertainty.

(2) Furthermore, as a result of the NNSII not providing meat intake data on a more detailed level, we assumed the consumption of different meat types to be equally distributed among all socio-economic groups. Numerous studies, however, have scrutinised socio-demographic and economic indicators to be a strong predictor of meat selection and consumption (Anyiro et al., 2013; Carrie et al., 2011; Einhorn, 2020a, 2020b; Phuong et al., 2014). Einhorn (2020b), for instance, find educational attainment to be correlated with an increased propensity to follow a vegetarian diet and lower levels of red and white meat consumption. While these studies point towards differences in meat consumption behaviour in absolute terms, questions on the relative composition of meat consumption behaviour between individuals of varying socio-economic backgrounds remain unaddressed. Against the background of meat consumption being one of the largest contributors to environmental impacts, we pursue an uncertainty analysis by setting a lower and upper uncertainty boundary while keeping the overall amount of meat consumption as indicated within the NNSII constant. Thus, for the lower bound, the assumption of +20 % poultry requires a decrease in bovine meat consumption of the same size in absolute terms. For the upper bound, we assume +20 % in bovine consumption to be met by an equal decrease in the quantity of poultry. The error bars are calculated by multiplying the adjusted emission intensities for the minimum and maximum uncertainty boundaries with the amount of food consumed by gender and SES (see SM I, J, K, L).

(3) FABIO lacks data on environmental inputs for fish and seafood. As shown in Fig. 1, the intake of 'Fish, Seafood' increases with rising SES, moving from 7.6 kg person^{-1} year^{-1} for M_LSES to 10.4 kg person^{-1} year^{-1} for M_USES (37 % increase) and from 6.5 kg person^{-1} year^{-1} for W_LSES to 7.9 kg person^{-1} year^{-1} for W_USES (23 % increase). Considering fish products' relatively low environmental impacts

at the production stage in comparison to other animal-based products like meat and cheese (Meier and Christen, 2012), we believe this to only marginally influence our results.

(4) Another aspect that was not considered is the potential variation in survey-based under- and overreporting, as well as food waste behaviour. Reporting biases in dietary surveys can lead to significant discrepancies between reported and actual consumption, thereby complicating efforts to accurately assess dietary patterns and associated environmental impacts. To address this, food intake data are commonly scaled using macro-supply data (e.g. FAOSTAT, 2023). This approach helps to correct for both reporting inaccuracies and FWL occurrence. In our study, we complemented NNSII intake data with macro-level FAO Food Balance Sheets, assuming that reporting biases and food waste behaviour are evenly distributed across genders and socio-economic groups. To the best of our knowledge, there is no clear evidence of the distribution of under- and overreporting across socio-economic strata. However, women have been found to slightly underreport their dietary intake more frequently than men, with a negligible difference of approximately 4 % (Macdiarmid and Blundell, 1998). Reporting biases furthermore vary by food type, with unhealthy items (e.g., sweets, snacks, alcohol) being typically underreported, while healthier items (e.g., fruits, vegetables) tend to be overreported (e.g. Kilian et al., 2020; Straßburg et al., 2019). With regard to food waste behaviour, the influence of various socio-demographic and economic characteristics is highly contested. While a number of studies outline a relationship between rising income and higher waste levels (Koivupuro et al., 2012; Setti et al., 2016; Stancu et al., 2016), Di Talia et al. (2019) conclude that affluence does not affect individual food waste behaviour. Likewise, results on the link between educational attainment and food waste are diverging (Di Talia et al., 2019; Herzberg et al., 2020; Neff et al., 2015; Secondi et al., 2015). In terms of the relationship between gender and food waste, we can observe similar ambiguities. Several studies find women to generate less food waste than men (Cecere et al., 2014; Di Talia et al., 2019; Secondi et al., 2015). Conversely, some scholars ascertain males to waste less than females (Kuo and Shih, 2016). Other factors that explain individual food waste behaviour are age, employment status and household size, to only name a few (Cecere et al., 2014; Neff et al., 2015; Secondi et al., 2015; Stancu et al., 2016). Research simulating the impacts of household composition, demography and food practices on food waste is still in its infancy, as each food product must be simulated individually, e.g. in the case of Milk (Kandemir et al., 2022) and Chicken (Guo et al., 2024). In light of SES being specified as an index incorporating educational qualification, occupational status of the main earner and household net income, and since food waste practices develop as a complex interplay between various socio-demographic and economic factors, it is not possible to draw a final conclusion on the potential correlation between SES and food waste behaviour.

(5) Finally, differences in environmental intensities between conventional and organic food production processes were not taken into account. This may be of particular relevance for the comparison of consumption patterns across individuals of different SES. Seufert et al. (2012), for instance, find organic yields to be on average 25 % lower than their conventional alternatives. Consequently, organic products generally require 20–110 % more land (Meemken and Qaim, 2018), with land use of organic beef and pork production exceeding conventional alternatives by up to 85 % (Treu et al., 2017). In contrast, evidence on the carbon intensity of organic agriculture is mixed. While several studies suggest that carbon emissions of organic foods are on average 0–10 % lower (M. Clark and Tilman, 2017; Mondelaers et al., 2009; Tuomisto et al., 2012), others find that organically produced pork and poultry (Treu et al., 2017) as well as rice (Arunrat et al., 2022) may actually result in higher carbon footprints. This consideration, however, is only relevant if a correlation between income or education and the purchase of organic food products exists — an issue that remains contested in the literature. While higher income and education levels are generally linked to a greater likelihood of purchasing organic products — due to increased health and environmental awareness and the financial capacity to afford premium prices (Dimitri and Dettmann, 2012; Hughner et al., 2007; Zepeda and Li, 2007) — this relationship is not consistently observed. Motivational factors such as ethical values or environmental concerns can also lead to organic food consumption among individuals with lower income or education levels (Einhorn, 2020a). Against this background and given the considerable difference in land use intensities, we expect distinguishing between organic and conventional food consumption habits to mainly affect the robustness of our land use foodprint results. Specifically, land-use may be underestimated for high-income groups, who are more likely to consume more land-intensive organic foods.

4.3. Implications for policy and practice

Our findings offer valuable insights into the distribution of environmental burdens across different socio-economic groups, highlighting the need for a comprehensive and coordinated approach to sustainable food production and consumption within Germany and the EU. This is acknowledged by the EU's long-term *Farm to Fork* strategy, which seeks to accelerate the transition towards a sustainable food system encompassing production, processing, distribution, consumption, and food waste management (European Commission, 2020). While the strategy primarily focuses on supply-side strategies, such as improving the energy efficiency and emission intensity of food production and livestock farming (B. Food production objective), it also endeavors to steer demand towards more environmentally sustainable products via initiatives such as nutrition labelling and favourable tax incentives (D. Food consumption objective). Complementing efforts at the EU level, Germany adopted its own National Nutrition Strategy, known as *Good Food for Germany,* on January 17, 2024 (BMELH, 2024). The strategy outlines 90 measures, including the implementation of a Protein Crops Strategy aimed at increasing legume production and consumption, initiatives to reduce food loss and waste, and the development of evidence-based dietary guidelines for adults, infants, children, and adolescents.

In this national and EU policy context, our findings emphasize the importance of policies aimed at reducing meat and dairy consumption, as these are the primary contributors to environmental foodprints in Germany and average EU food consumption in general (Notarnicola et al., 2017). Pull-measures, such as front-of-pack nutrition labelling, encourage consumers to make healthier food choices (Vecchio and Cavallo, 2019). However, recent evidence suggests nutrition and sustainability labels to likely be insufficient to achieve healthy food outcomes and drastically reduce environmental foodprints (Brown et al., 2020). Another pull-measure proposed by the EU is the exemption of VAT for plant-based foods to enhance their relative economic attractiveness compared to animal-based products, thereby promoting a shift towards more environmentally sustainable alternatives. Additionally, the EU could introduce push-measures to address the overconsumption of animal-based products, such as expanding the European Emission Trading System to the agricultural sector (Bognar et al., 2023) or introducing a meat tax (DW., 2019; Perino and Schwickert, 2023; Roosen et al., 2022; TAPPC, 2022; Van Loo et al., 2017). Our analysis, however, unveils that push-measures are likely to disproportionately affect households of low socio-economic status due to their higher consumption levels of animal-based products compared to more affluent households. Policies aimed at increasing the price of meat and dairy products should thus be accompanied by measures to ensure the affordability of alternative sources of protein. Given that food habits are deeply internalised routines being shaped by cultural and social norms, policies need to be carefully crafted to promote inclusivity and equity in line with the EU's aspirations of leaving no one behind. One potential approach could involve using revenue generated from a meat tax to subsidize healthier food options, such as fruits, vegetables, and plant-based protein sources, thereby making them more accessible to low-income individuals (Klenert et al., 2023). This could also be deployed in the form of direct financial support or food vouchers for low-income households to help them afford sustainable food choices (Verdeau et al., 2025).

Furthermore, our research suggests that policies promoting socio-economic equality could yield positive environmental outcomes. For instance, the German government could further explore measures to increase access to healthy, affordable food in low-income neighborhoods or provide incentives for sustainable food production and distribution that benefit marginalized communities. At a minimum, dietary advice, such as in the National Nutrition Strategy, could be further tailored to different demographics based on their consumption habits and cultural contexts (beyond the currently proposed age based guidance). Any new initiatives should continue to employ community consultations and participatory approaches with diverse stakeholders to ensure that the needs of all socio-economic groups, and any power imbalances within food systems are considered.

5. Conclusion

In order to tackle the multiple environmental challenges associated with the predominance of high caloric intake diets in Europe, the EU advanced its *Farm to Fork* strategy as part of the *European Green Deal*. The aim is no less than transforming the food system towards having a neutral or positive environmental impact, reverse biodiversity loss and ensure public health by facilitating access to healthy and sustainable foods (European Commission, 2020). To achieve its goals, the EU will require some fine craftsmanship to design and orchestrate effective environmental policies that take into account the multitude of material and non-material spheres in which individuals maneuver (Einhorn, 2020a). Against this background, our results offer interesting insights into the distribution of environmental burdens across different socio-economic realities. Our findings indicate that policy must be designed and implemented that consider SES and gender contexts in both the National Nutrition Strategy and wider policy.

We find carbon, land and green water foodprints to decrease with SES for the male population. Women, in contrast, do not exhibit a clear correlation between foodprints and SES with regard to the environmental indicators named above. Our results on the magnitude of environmental impacts of animal-based products echoes that of other studies (Meier and Christen, 2012; Tilman and Clark, 2014). Interestingly, meat and dairy products demonstrate a converse pattern: While the share of foodprints originating from meat consumption decreases with SES, impacts associated with dairy consumption increase. As a result, we observe the share of animal-based products to total foodprints to remain more or less stable across all socio-economic groups. Blue water foodprints diverge from the other environmental indicators, with individuals of upper instead of lower SES causing the greatest foodprint. This may be explained by a relatively low blue water intensity for meat, especially in comparison to the item category 'Nuts & Seeds', for which individuals of upper SES exhibit substantially higher consumption levels.

Finally, it is important to emphasize that in light of the scarce evidence and the numerous limitations outlined above, further research will be needed to improve our understanding of the environmental impacts of food consumption of different socio-economic groups. First, providing more detail on the types of meat consumed would enhance the accuracy of the results and allow for a more nuanced picture of the environmental consequences of meat consumption across different SES. Second, the lack of available data concerning out-of-home consumption and food waste behaviours across different SES impedes a thorough analysis of their respective contributions to individual foodprints. Moreover, further exploration in the direction of comparing the environmental impacts (especially blue and green water foodprints) of conventional vs organic food choices is much needed. Last but not least, qualitative research could unveil the underlying mechanisms and motivations behind varying food consumption patterns across different socio-economic backgrounds.

CRediT authorship contribution statement

Simon Grabow: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Conceptualization. **Elisabeth Laa:** Writing – original draft, Conceptualization. **Jasmine MacLean:** Writing – original draft, Conceptualization. **Christian Reynolds:** Writing – review & editing. **Martin Bruckner:** Writing – review & editing, Supervision, Software, Methodology, 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.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolecon.2025.108908.

Data availability

Data will be made available on request.

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