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The Environmental Footprint of Available Food Waste in Young Households: A Diary Case Study of Schleswig-Holstein (Germany)

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Abstract: As households contribute significantly to food waste, it can be assumed that they bear considerable responsibility for the environmental footprint of it. In Germany, household food waste comprises over half of all food loss and waste, with a notable share attributable to young people. To explore their environmental footprint, data from fifty young households in Schleswig-Holstein, northern Germany, is analyzed using the Food Loss and Waste Value Calculator with an integrated life cycle assessment. We evaluate the environmental footprint of animal and plant food waste across five categories: climate change, water scarcity footprint, soil quality index, phosphorus and nitrogen eutrophication. Surprisingly, animal food waste, though representing only 18% of the total volume of all available food waste in our study, exhibits a more substantial impact in all categories except water scarcity. Specifically, animal food waste is found to be an important factor in soil degradation. Our results generally indicate an inverse relationship between the volume of animal-based and plant-based food waste in young households and its environmental footprint. However, the case study highlights a troubling connection between plant food waste and significant water scarcity issues in European agriculture.

Keywords: Food Loss and Waste Value Calculator, Life Cycle Assessment, Climate Change, Water Scarcity, Soil Quality, Eutrophication

1 Introduction

In 2015, the United Nations Sustainable Development Goals (SDGs) outlined the target of achieving a 50% reduction in per capita global food waste at both retail and consumer levels by 2030, as articulated in Goal 12, which focuses on ensuring sustainable consumption and production patterns.[1] Nevertheless, in 2019, a global total of approximately 931 million tons of food waste occurred, with 61% originating from households (UNEP, 2021: 70). In Germany, an annual amount of approximately 11 million tons of food waste is reported, with 6.68 million tons accounting for household food waste (Hafner et al., 2012: 8, 16). Considering that households are significant contributors to food waste, one might argue that they carry a substantial share of responsibility for its environmental footprint. With approximately 12 million tons of food waste per year (BMEL, 2019), 52% of which is generated in private households (Schmidt et al.,

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[1] https://champions123.org/target-123, last accessed on December 8, 2023

2019: i), direct food related greenhouse gas emissions (GHG) (caused by production, processing, and food preparation) are estimated at roughly 21.8 million tons $C0_2$ equivalents (eq) (Noleppa and Cartsburg, 2015: 8).

It can be suggested that the waste produced at each stage of the food life cycle incurs noteworthy environmental costs, depleting resources earmarked for food production and acquiring a distinct moral aspect. Food Loss and Waste (FLW) is purported to significantly contribute to the aggravation of three global crises: climate change, loss of nature and biodiversity, and pollution and waste (UNEP, 2021: 4). Poore and Nemecek (2018: 987) find that global food production contributes to 26% of global GHG emissions and is responsible for 13.7 billion tons of CO_2-eq, 32% of global acidification and 78% of eutrophication, while 43% of the planet's ice-free and desert-free land is occupied by an extremely resource- intensive agricultural system. Of the 26% of GHG emissions from food production, Ritchie (2020) estimates that food losses along the food supply chain and food waste from consumers account for 24%, while retailers and consumers account for 9%. In total, 6% of global GHG emissions come from FLW (Ritchie, 2020).

Jepsen et al. (2014) conduct the first study to estimate the environmental impact of food waste in Germany for the Environmental Research Plan of the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV).[2] They suggest that the final environmental impact of food waste can only be assessed through a life cycle assessment (LCA) of the consumed food, which starts at the production stage. It shows that the cumulative GHG emissions are 0.5 tons CO_2-eq per inhabitant per year in Germany and about 38 million tons CO_2-eq for the whole country (Jepsen et al., 2014: 40). Nevertheless, to the best of our knowledge, there are no scientific case studies yet that contribute to the complexity of the environmental footprint of FLW from specific regions or groups of people. We present a pioneering exploration by analyzing young households in Schleswig-Holstein, marking one of the initial research endeavors employing the FLW Value Calculator developed by a consortium of top-tier experts in the field.[3]

Our case study delves into the avoidable food waste data from 50 young households in the Schleswig-Holstein region in Northern Germany. The data was collected over a two-week period using a diary study (Reinhold, 2018), and their environmental footprint was calculated using the FLW Value Calculator. The primary research questions addressed include: (1) To what extent does avoidable food waste occur among the 50 sampled young households in Schleswig-Holstein? (2) What is the environmental footprint of avoidable household food waste among the 50 sampled young households, as assessed by the FLW Value Calculator? (3) How are the values obtained through the FLW Value Calculator interpreted in the context of the study? (4) In evaluating the environmental footprint of avoidable household food waste, what is the efficacy of the FLW Value Calculator as a reliable tool according to the research findings?

Our main findings suggest that, although animal food waste accounts for only 18% of the total volume of avoidable food waste, it has a greater impact in all environmental categories (climate change, soil quality, eutrophication) except for water scarcity. This indicates an inverse relationship between the composition of food waste in young households and their environmental footprint. Notably, animal food waste significantly contributes to soil degradation. Conversely, the case study reveals a strong relationship between plant-based food waste and the issue of water scarcity in European agriculture.

The article is structured as follows: it begins with background information on avoidable household food waste, followed by an explanation of the conceptual framework and details on the use and assumptions of the FLW Value Calculator. Next, it describes the data on avoidable

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[2] Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz (in German)

[3] https://flwprotocol.org/, last accessed on December 9, 2023

household food waste and its environmental footprint and presents the results. Finally, the article ends with a discussion and conclusion section.

2 Understanding Avoidable Household Food Waste and its Environmental Footprint

As we delve into the concept of avoidable household food waste, it is essential to clarify the terminology surrounding “food loss” and “food waste”, which are often used interchangeably. Commencing with a definition of avoidable household food waste, the broader perspective encompasses “food that reaches the consumer in a satisfactory state and fit for consumption but is not consumed and is discarded before or after it spoils and deteriorates” (Yahia and Mourad, 2019: 1). This phenomenon originates at the retail level and extends to the consumer due to various factors, including choice, poor stock management, negligence leading to spoilage or expiration, and failure to consume after preparation (Searchinger et al., 2019: 53). The phenomenon of food waste is further influenced by a variety of factors, including consumer preferences for freshness and quality, perceptions related to health, and the attraction of low pricing. These factors can lead to suboptimal purchasing and consumption decisions. For example, the preference for fresh food items may result in the discarding of still-consumable, though less fresh, products. Similarly, misconceptions about food quality and health impacts can lead to the premature disposal of edible food. Economic considerations, such as the appeal of low-cost goods, often result in over-purchasing, subsequently leading to waste due to inadequate consumption planning. It is critical to note that not all instances of food waste are a result of irrational behavior; they can also occur in scenarios where the products are still fit for consumption. A narrower definition of food waste includes both consumable items and associated inedible parts removed from the human Food Supply Chain (FSC) in retail, food service, and household sectors (Forbes et al., 2021: 9). In contrast, food loss encompasses the departure of food from the FSC during production, handling, storage, and processing (Forbes et al., 2021: 19).

Focusing on “avoidable” food waste enables further categorization, distinguishing between (optional) avoidable and unavoidable food waste (Hafner et al., 2012: 4). Avoidable food waste pertains to items fit for human consumption at the time of disposal or would have been if consumed promptly. Partially (optional) avoidable food waste results from varying consumer habits and encompasses a blend of avoidable and unavoidable waste, such as cutting off bread crusts or peeling apples, as well as leftovers. Unavoidable food waste occurs when prepared food is discarded, encompassing both edible elements like potato peelings and non-edible components like bones and eggshells (Hafner et al., 2012).

In the context of household food waste, research underscores that private households contribute significantly to this issue. A report conducted by the FAO (2011: 5) reveals that consumers in Europe and North America produce 95 to 115 kg/year of food waste per capita, primarily attributed to consumer abundance and attitudes. Parfitt et al. (2010) identify four main socio-economic factors influencing household food waste: household size and composition, household income, household demographics, and household culture. The study indicates that, in terms of composition, adults waste more food than children, and households with children tend to waste more than those without. Interestingly, one-person households waste the most food per capita, while low-income households generate less food waste than high-income households. Additionally, the study suggests that younger people waste more food than older individuals. All these aspects are crucial considerations when addressing the avoidable household food waste of young people.

In Germany, an accurate assessment of the extent of food waste is made difficult by a lack of reliable statistics, which are often based on extrapolations from non-representative samples, as shown in the Thünen Institute’s 2015 baseline report (Schmidt et al., 2019). Commissioned by the Federal Ministry of Food and Agriculture (BMEL), this report is widely regarded as the most precise data available on household food waste. The estimated annual food waste in Germany stands at approximately 11 million tons, with households contributing approximately 6,263,775 tons annually, equating to 75 kg of food waste per capita (UNEP, 2021: 67). In terms of percentage, household food waste constitutes 52% of the total, amounting to an average of 2.69 million tons of avoidable food waste (Schmidt et al., 2019: XIX).

A pivotal household survey conducted by the market research company GfK SE from July 2016 to June 2017, on behalf of the BMEL, sought to address these gaps. This survey involved 6853 German households participating in a 14-day diary study, recording their food waste practices. The study delves into the specifics of discarded foods, quantities, reasons for disposal, and the subsequent disposal methods. Additionally, social, demographic, geographic, and behavioral factors within households are considered to discern the underlying reasons for food waste, incorporating variations in household size, age, and region. Notably, this study is deemed the first “representative” examination of food waste in German households, aiming to encompass the diversity of the entire German population (Schmidt et al., 2019a: 3).

The study reveals the composition of avoidable food waste from households by product group, indicating percentages as follows: fresh fruit 17%, fresh vegetables 17%, cooked/prepared food 16%, bread and bakery products 14%, beverages 11%, dairy products 9%, convenience/frozen and canned products 7%, meat/sausage/fish (fresh) 4%, and other food 5% (Schmidt et al., 2019a: 14). The survey estimates that 3.7 million tons of food waste occurred during the study, acknowledging potential under-reporting due to social desirability bias and the relatively brief survey duration. Adjusting for these factors, the study posits the actual amount of food waste in households at 4.4 million tons, representing a discrepancy compared to the 2015 baseline report (Schmidt et al., 2019a: 11).

To enhance our comprehension of the environmental footprint stemming from food waste, Noleppa and Cartsburg (2015) aggregate data from various studies, elucidating the distribution of emissions across different stages of the supply chain within the food sector. Their findings underscore that agriculture, encompassing its inputs, constitutes the predominant contributor to greenhouse gas (GHG) emissions in the realm of food-related environmental impact, accounting for a substantial share ranging from approximately 45% to 60% of the total emissions. Delving into specific regional contexts, Meier and Christen (2012) and Nieberg (2009) focus their studies on Germany, while SWC (2012) and Audsley et al. (2009) concentrate on the United Kingdom. Meanwhile, the global scope is taken by Garnett’s studies (2008, 2011). Across these diverse studies, a consistent pattern emerges, with GHG emissions from agricultural production consistently ranging from 45% to 60% of the overall emissions.

In contrast to the globally impactful carbon footprint, the water scarcity footprint primarily exerts a local influence, as highlighted by Erickson (2021). This implies that the environmental burden is predominantly borne by the region where agricultural production occurs. According to Dräger de Terrain (2021), Germany’s analysis in 2021, plant-based food was responsible for a staggering 96% (1,384 m^3 world eq per year) of the water scarcity footprint, while a mere 4% (59 m^3 world eq per year) was attributed to the production of feed for animal-based food in Germany (Dräger de Teran, 2021: 26). Notably, Germany itself has a water scarcity footprint of 1.443m^3 (Dräger de Teran, 2021: 26). A key finding from the study by Dräger de Teran (2021) is that 99.7% of Germany’s water scarcity footprint originates outside the country’s borders. This phenomenon is closely linked to the country’s dependence on fruit, vegetable, and grain imports, while a significant proportion of domestic agricultural land is used to produce animal products, including animal feed (Dräger de Teran, 2021: 35). This highlights the interconnectedness of water scarcity on a global scale, with Germany’s consumption patterns having a significant impact on water resources in the regions from which the country sources its agricultural products.

Quantifying the environmental footprint of avoidable food waste on soil quality is a complicated task that remains largely unexplored in the existing literature. The lack of relevant studies in this area could be attributed to the inherent difficulties arising from the spatial and temporal variability of soil properties in different geographical regions. Efforts to develop a single indicator to measure soil quality are complicated by the nuanced and dynamic nature of soil properties. This complexity arises, as explained by De Laurentiis et al. (2019: 63), from the challenges associated with accounting for the heterogeneous and time-dependent properties of soils in different locations.

Similarly, when it comes to estimating eutrophication associated with household food waste, there is a lack of studies that specifically analyze this relationship. Although existing literature provides evidence of significant nitrogen (N) and phosphorus (P) surpluses contributing to severe eutrophication issues in several regions of Germany (e.g., Haeussermann et al., 2020; Castro Campos and Petrick, 2023), an analysis of the connection between household food waste and eutrophication appears to be a gap in research.

3 Conceptual Framework and Food Loss and Waste (FLW) Value Calculator

The FLW calculator, developed by Quantis within the framework of the FReSH program initiated by the World Business Council for Sustainable Development (WBCSD) and supported by the World Resources Institute (WRI), serves as analytical instrument for analyzing FLW based on its environmental and nutritional footprints (FLW, 2019). Following the guidelines in the publication "Food Loss and Waste Accounting and Reporting Standard" by Hanson et al. (2016: 1), the calculator sets a global benchmark by introducing standardized requirements and guidelines for the systematic quantification and reporting of FLW.

The conceptual framework employed in this study is shown in Figure 1, presenting a fusion of two components: one showing the process of data collection and the other showing the structure, origin, and footprint of avoidable household food waste. Avoidable household food waste goes through different disposal routes, and the same type of food may be subject to different disposal methods. Subsequently, these values are input into the FLW Value Calculator, initiating the environmental footprint assessment, with a particular focus on plant and animal food waste. Although a comprehensive discussion of every assumption exceeds the scope of this article, readers seeking detailed information can find complete documentation on the FLW Value Calculator's webpage.[4]

In particular, the calculator's integrated methodology encompasses the full spectrum of FLW by addressing food category, life cycle stage, geography, and organizational parameters (FLW, 2019). The FLW Value Calculator employs the methodology of life cycle impact assessment (LCIA) to calculate the environmental footprint of FLW. Although our study focuses only on the consumption phase, the integrated assumptions of the FLW Value Calculator, which are based on sophisticated underlying models, expert knowledge, and databases, consider all cumulative impacts from production to disposal.

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[4] https://flwprotocol.org/wp-content/uploads/2017/05/FLW_Standard_final_2016.pdf#page=114, last accessed on December 12, 2023

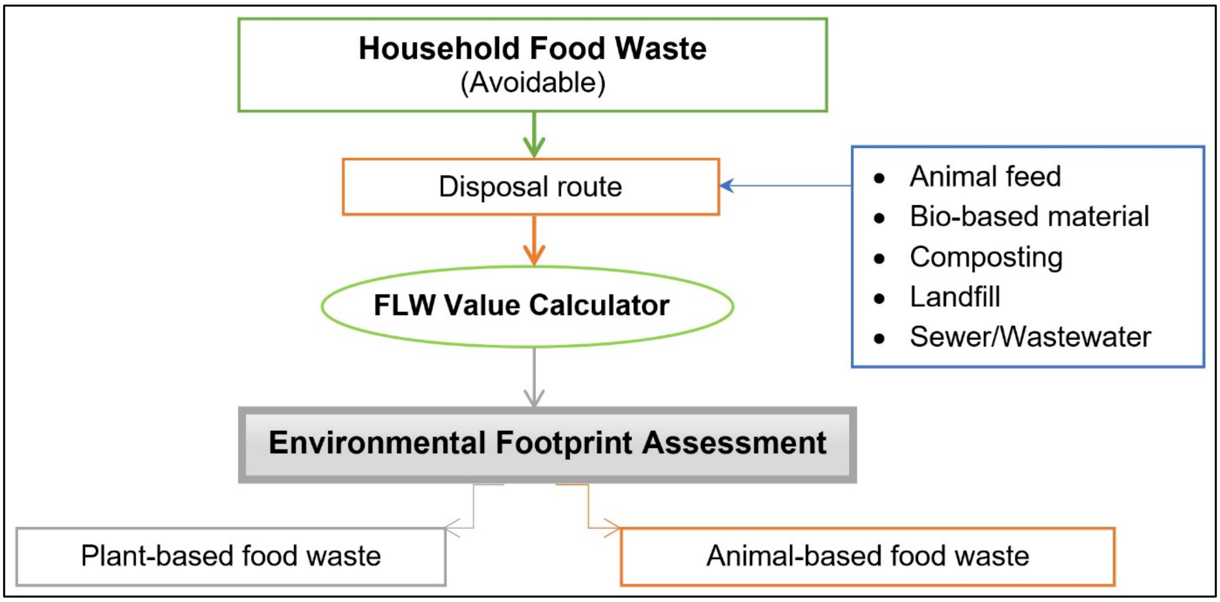

Figure 1. Conceptual framework of the study

Source: authors

Figure 2 presents the four-step process used in LCA, which evaluates the environmental impact of a product or service throughout its life stages. This approach aligns with the guidelines set by the International Organisation for Standardisation (ISO) in the ISO 14040 standard. The calculator's foundation is built on the methodologies and assumptions detailed in the 2018 Technical Report of the Joint Research Centre (JRC) of the European Commission (Sala et al., 2018). It focuses on four specific impact categories: climate change, water scarcity footprint, soil quality index (SQI), and eutrophication:

- For climate change impact assessment, the calculator employs a model adapted from the IPCC's (2013) Climate Change report, utilizing the Global Warming Potential for a 100-year time frame (GWP100) to quantify the carbon footprint of FLW attributable to greenhouse gas emissions.
- The water scarcity footprint is determined using the AWARE model, which assesses the relative Available Water Remaining (AWARE) per area in a watershed after fulfilling human and aquatic ecosystem demands. The indicator, "scarcity-adjusted water use," is based on the principle that diminishing water availability per area increases the likelihood of deprivation for other users (WULCA, 2015).
- Soil quality is measured through the LANd use indicator value CAlculation (LANCA®) model developed by the Fraunhofer Institute for Building Physics in Stuttgart. This model evaluates soil quality based on erosion resistance (ER), mechanical filtration (MF), groundwater regeneration (GR), and biotic production (BP), with the exclusion of physiochemical filtration (PF) from the SQI calculation (Beck et al., 2010: 3).
- Aquatic eutrophication (freshwater and marine) is assessed using the ReCiPe2008 (EUTREND model). This LCIA model considers nutrient limitations on aquatic biomass, particularly phytoplankton and duckweed, using P equivalents and N equivalents as indicators for measuring eutrophication (Struijs et al., 2009: 59).

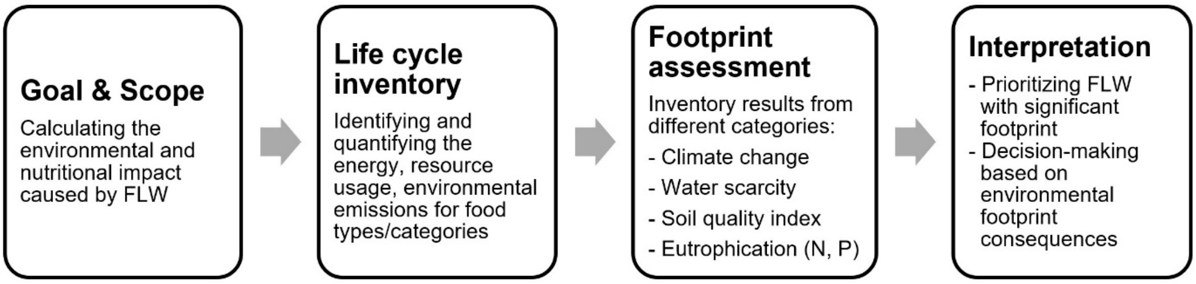

Figure 2. The four steps of a life cycle assessment according to the ISO 14040 framework for life cycle assessments

Source: authors based on Whitehead et al. (2015)

The calculator obtains the environmental footprints of production from the Quantis World Food LCA Database.[5] Regional prototypes are used in the production phase, as there is a lack of data for all individual production countries. This takes into consideration the per-country production volume in the specific regions of (i) Europe and Russia, (ii) Industrialized Asia, (iii) Latin America, (iv) North America, (v) South and Southeast Asia, (vi) Sub-Saharan Africa, and (vii) North Africa, West, and Central Asia. For example, Spain is taken as a proxy in determining the volume of tomato production in Europe.

Currently in its beta version, the calculator does not provide detailed calculations for different locations, as local technologies vary. The underlying assumptions made by its developers focus on the environmental impact offset by four main destinations of FLW: animal feed, bio-based materials/biochemical processing, co-digestion/anaerobic digestion, and composting/aerobic processes, including land application. Specifically, FLW directed towards animal feed, bio-based materials/biochemical processing, and land application is believed to completely neutralize impact across all environmental categories (climate change, water scarcity footprint, soil quality index, and eutrophication). In contrast, co-digestion/anaerobic digestion, and composting/aerobic processes are thought to only mitigate the carbon footprint.

These assumptions used in the current version of the FLW value calculator are not entirely accurate in representing the complex underlying processes that occur and require critical examination. First, the assertion that FLW directed towards animal feed, bio-based materials/biochemical processing, and land application completely neutralizes impacts across all environmental categories is overly optimistic and lacks nuance. While these methods can certainly offer environmental benefits compared to landfilling or incineration, they still have associated environmental costs. For instance, land application of organic waste can contribute to eutrophication if not managed properly, leading to nutrient runoff and water quality issues (e.g., Haeussermann et al., 2020). Additionally, transportation and processing of waste for animal feed or biochemical processing entail energy consumption and emissions, which contribute to the carbon footprint and may have other environmental consequences. Second, suggesting that co-digestion/anaerobic digestion and composting/aerobic processes only mitigate the carbon footprint oversimplifies their environmental impact (e.g., Liu et al., 2018). While it is true that these processes can effectively reduce GHG emissions by capturing and utilizing methane produced during decomposition, their benefits extend beyond carbon sequestration. For example, anaerobic digestion can also help manage waste volume, reduce odor, and produce biogas for energy generation. Similarly, composting not only mitigates carbon emissions but also improves soil quality, enhances nutrient cycling, and reduces the need for synthetic fertilizers. Nonetheless, a useful theory must be concise and reduce complex evidence to key variables that determine patterns (e.g. Gereffi, 2005: 82). Our intention is to apply the FLW

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[5] World Food LCA Database (WFLDB) is a project launched in 2012 by Quantis and Agroscope. Additional life cycle impacts assumptions are adapted from Product Environmental Footprint (PEF) guidance documents through the European Commission and are intended as rough estimates.

calculator to household data of young people for getting at least a rough understanding of their environmental impact based on the currently established assumptions.

4 Data Description and Application

The empirical data are collected by Reinhold (2018) through a two-week diary study conducted from June 25 to July 8, 2018, involving 50 households in Schleswig-Holstein (Germany). In Reinhold's 2018 study, the survey of participants reveals a diverse demographic profile. The majority, 68%, are from Northern Germany, particularly from postal code areas beginning with 24, while others are from North Rhine-Westphalia, Baden-Württemberg, and Bavaria. The age range of these participants varies from 17 to 65 years, with an average age of 26.68 years (SD = 9.65 years). The gender distribution is predominantly female, constituting about 71%, with males making up 27%, and less than 2% identifying as other.

When it comes to dietary habits, just over 20% of the respondents are vegetarians, contrasting with the 80% who do not follow a vegetarian diet. The survey also sheds light on household compositions: the average household size is 2.31 people (SD = 1.14), slightly larger than the German national average (McCarthy, 2019). Living arrangements among the participants are varied, with 46% living in shared housing, 16% alone, 9% with parents, and others in different family setups. About 82% of the respondents are the primary household managers.

Financially, the survey participants' household incomes vary, with 58% earning between 0 and 1000 Euros monthly. A smaller percentage earns more, with 15% between 1,000 and 2,000 Euros, and others in higher income brackets. The majority spend between 100 and 500 Euros monthly on groceries, while the average personal expenditure on food and drink is approximately 200 euros. Educationally, the participants are highly educated, with 55% holding a bachelor's or master's degree, and a significant number having completed high school or vocational training. The data suggests a high likelihood of many participants being students, highlighting a youthful and educated demographic.

For the dietary study, participants are specifically asked to record avoidable food waste, including edible food and beverages, and the disposal route of each food item. Five disposal routes are available for selection: (i) residual waste (Restmüll) (ii) organic waste (Biotonne) (iii) compost (Kompost) (iv) sewers (Kanalisation), and (v) animal feed (Tierfutter).[6] The diary study is organized by household, where participants accurately monitor the quantity of avoidable food waste they discard, measured in grams, during the study period. Additionally, they note the specific disposal methods used for this waste within their household. The participants were explicitly requested not to account unavoidable food waste such as shells, peels, bones etc. A manual was given to each participant that contained a glossary and clear instructions on how to fill the diary (Reinhold, 2018).

Subsequently, the collected data is input into the FLW Value Calculator, as detailed in the previous section, to quantify the environmental impact (refer to the results in section 5). The compiled values of avoidable food waste from the 50 young households in Schleswig-Holstein are presented in Table 1, categorized into eight main groups.

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[6] The aggregated data are available in appendix A1.

Table 1. Food waste in tonnes from 50 young households in Schleswig-Holstein in 2018

	Tonnes
Vegetables	0.01522
Fruits	0.008485
Cereals	0.008542
Pulses and seeds	0.00086
Dairy products	0.010135
Meat	0.002875
Beverages[a]	0.00594
Other[b]	0.017942
Total	0.069399

[a] Beverages (except for milk included in dairy) were not used in the calculations as the calculator does not provide “Beverages” as a food category option.
[b] Refer to Appendix 1 for the complete list of food items used in this study under the mentioned food categories.
Source: authors based on Reinhold (2018)

In the surveyed 50 households, a total of 69.39 kg (almost 70 kg) of food waste is documented during the two-week diary study. Figure 3 shows all the food waste from these households, as detailed in Table 1. Plant-based food waste, encompassing vegetables, fruits, grains, pulses, and seeds, constitutes the majority at 47%, while animal-derived food waste (meat and dairy products) comprises less than a quarter, totaling 18% of the overall avoidable food waste.

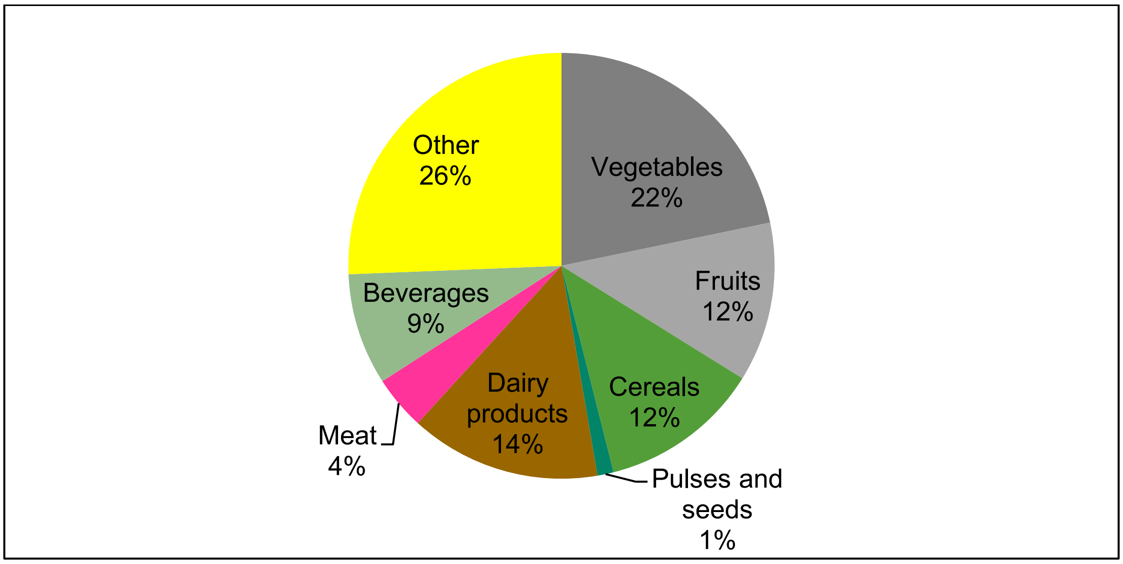


Figure 3. Share of household food waste of 50 young households in Schleswig-Holstein

Source: authors

While acknowledging the limitations, the extrapolation of data to an annual scale is crucial for the effectiveness of the calculator. The diary study indicates that, on average, each household generates 1.38 kg of avoidable food waste over a two-week period, derived from a total of 69.39 kg across 50 households. By extending this average to a monthly estimate, we arrive at 2.76 kg per household (calculated as 1.38 kg multiplied by 2 (persons)). Subsequently, extrapolating this monthly figure over a year results in an estimated annual food waste of 33.12 kg per household (2.76 kg multiplied by 12 months). This method of extrapolation, despite its simplicity, is a common practice in such studies and provides a necessary framework for assessing long-term food waste trends in households.

In the final stage, the categorized food waste items, as detailed in Table 1 and Figure 3, are entered into the FLW calculator. This process adheres to the procedures and assumptions discussed in the previous section. Recognizing that almost every food item can be directed to at least two different disposal routes (as elaborated in Appendix 1), attention is paid to the calculation and data entry to minimize the risk of inaccuracies.

5 Results

This section presents the key findings from the FLW calculator, as illustrated in Figures 4 to 10. Figure 4 displays the breakdown of food waste generated by 50 households, categorized into six groups: Fruit and Vegetables, Cereals, Pulses and Oilseeds, Meat, Dairy, and Other, as detailed in Table 1. Notably, the data reveals that a significant portion of the food waste in our study originates from plant-based sources. Subsequent Figures 5 to 10 delve into the various environmental footprint categories associated with household food waste. These categories include climate change, water scarcity footprint, soil quality index, and eutrophication. The data presented in these figures summarize a range of assessments, including those at the destination of the waste (e.g., landfill and animal feed), other life cycle stages (e.g., processing and transport) and the stage of agricultural production.

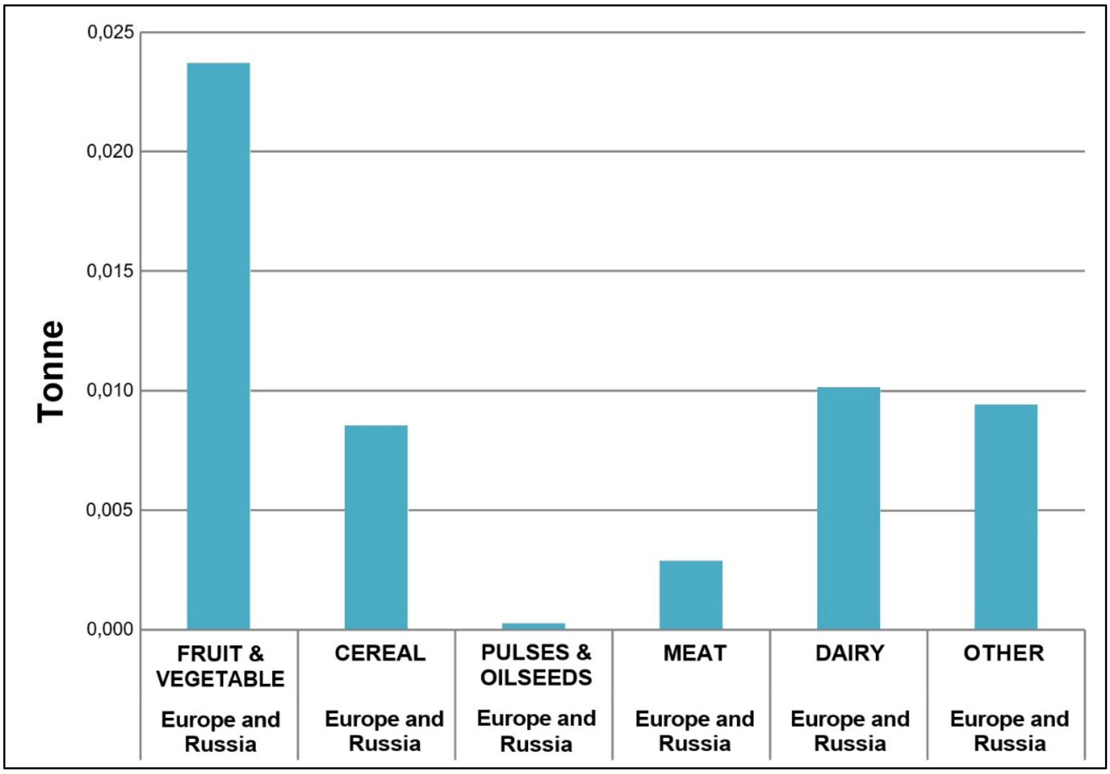


Figure 4. Total avoidable FLW amount for selected food categories and regions across the life cycle

Note: the life cycle stage refers to the stage of consumption.
Source: authors’ calculation with the FLW calculator

5.1 Climate Change Impact

The climate change impact is measured by the quantity of GHG emissions released across various stages of the life cycle, measured in kilograms of CO_2-eq. The LCIA reveals that the foremost contributors to climate change are the impacts arising from landfills and agricultural production, both significantly influencing GHG emissions.

Figure 5 shows the proportional distribution of emissions during the LCIA, underscoring the substantial impact of these specific stages on climate change. The results suggest that a substantial proportion, approximately 90%, of total greenhouse gas emissions emanate from two primary sources—agricultural production, which takes place at the very beginning of the LCIA, contributing 46% and landfilling that happens at the end of the LCIA as a destination impact accounting for 44%. A minor proportion, constituting 3% of household food waste, contributes to the climate change footprint through its association with animal feed and bio-based materials (also destination impacts of household food waste).

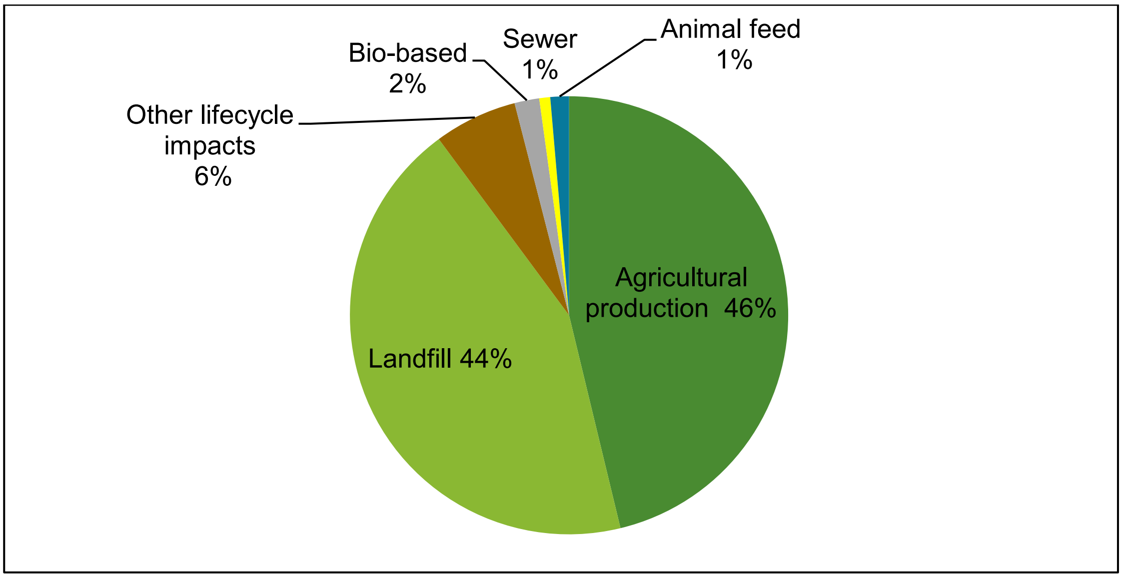
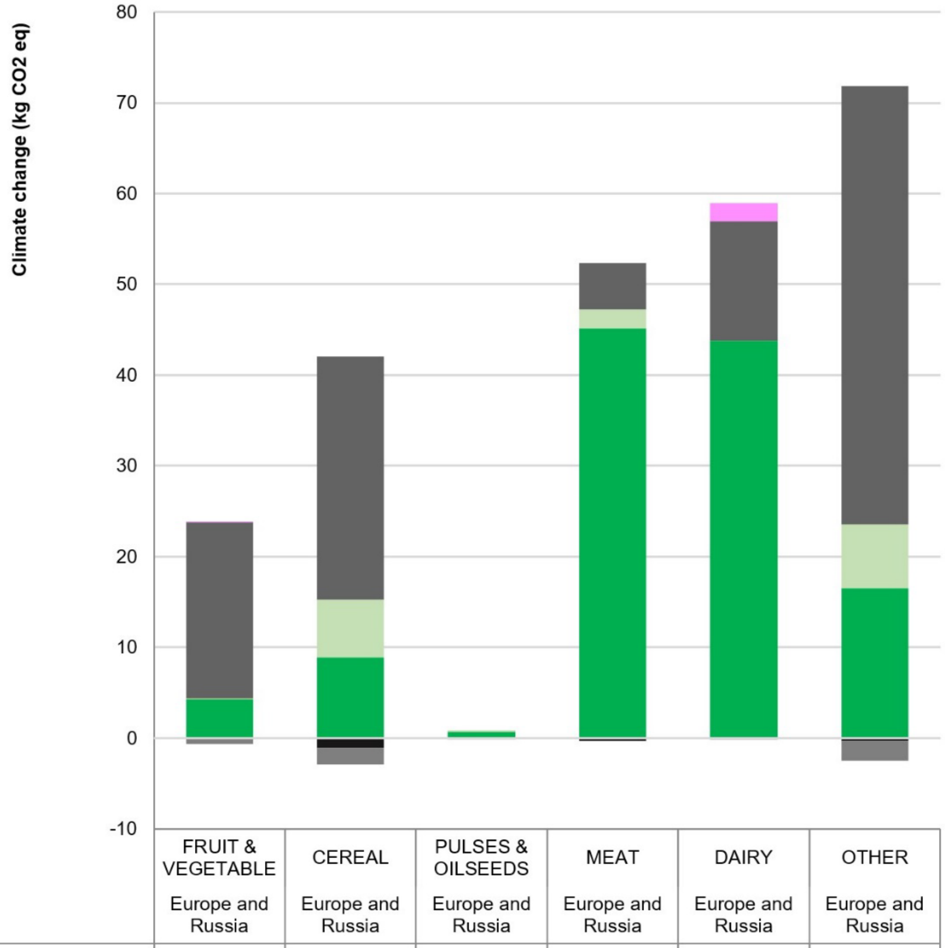


Figure 5. Climate change impact (GHG emissions) during different lifecycle stages of household food waste

Source: authors' calculation with the FLW value calculator

Figure 6 illustrates the climate change footprint of the six food categories, focusing on GHG emissions. The figure reveals a total impact of agricultural production on climate change as 119.33 kg CO_2-eq, while emissions from landfills are quantified at 112.65 kg CO_2-eq. Notably, our analysis highlights that food of animal origin, despite constituting a smaller proportion of total avoidable household food waste, has a significantly higher impact on climate change. This is predominantly due to emissions occurring upstream in the food supply chain, particularly during the agricultural production phase.



	FRUIT & VEGETABLE Europe and Russia	CEREAL Europe and Russia	PULSES & OILSEEDS Europe and Russia	MEAT Europe and Russia	DAIRY Europe and Russia	OTHER Europe and Russia
■ Unknown (assumed to be landfill)	-	-	-	-	-	-
■ Sewer/wastewater treatment	0,10	-	-	-	1,98	-
■ Refuse/discards/litter	-	-	-	-	-	-
■ Landfill (no gas capture)	19,42	26,78	-	5,08	13,13	48,24
■ Not harvested/plowed in	-	-	-	-	-	-
■ Land application	-	-	-	-	-	-
■ Controlled combustion with energy recovery	-	-	-	-	-	-
■ Composting/aerobic processes	0,01	-	-	-	-	-
■ Codigestion/anaerobic digestion	-	-	-	-	-	-
■ Bio-based materials/biochemical processing	(0,61)	(1,81)	(0,14)			(2,15)
■ Animal feed	(0,01)	(1,08)	-	(0,31)	(0,05)	(0,34)
■ Additional relevant life cycle impacts	0,07	6,41	0,20	2,16	0,03	7,05
■ Agricultural production impacts	4,32	8,87	0,70	45,11	43,81	16,52

Figure 6. Absolute climate change impacts for the different contributions (agricultural production, life cycle and destination)

Note: the dash means that the category is not applicable.
Source: authors' calculation with the FLW Value Calculator

5.2 Water Scarcity Footprint

Figure 7, which explores the environmental footprint in terms of water scarcity, suggests a tendency in our case study: plant-based food waste from households appears to have a greater impact than animal-based waste. In our sample of 50 households, plant food waste contributes to 62% of the water scarcity footprint, while animal food waste accounts for 34%. While these findings are indicative, given the limited scope of our study, they do point towards the potential significance of plant food waste in contributing to water scarcity issues. This observation highlights the value of a regional approach and suggests that, at least in this case, household plant food waste could play a notable role in water scarcity challenges.

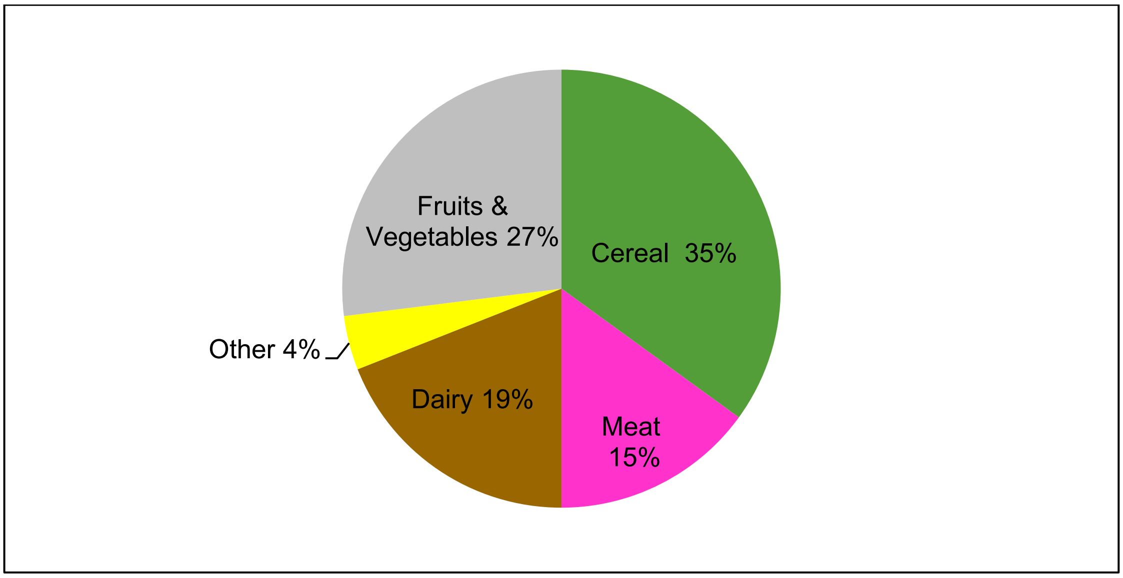
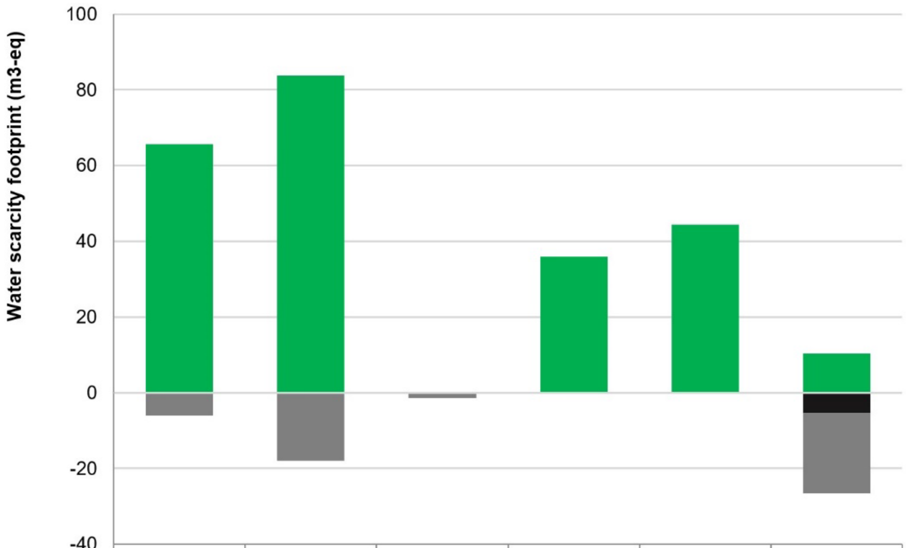


Figure 7. Water scarcity footprint during agricultural production accrued by different food categories

Source: authors' calculation with the FLW Value Calculator

Figure 8 provides a tentative look at the overall impact of household food waste on the water scarcity footprint, considering the entire life cycle of the waste. The data indicates a notable contribution to water scarcity during the agricultural production phase, with a combined footprint for all food categories amounting to 240.12 m^3-eq. It is interesting to note that the environmental impact seems to be mitigated in other destinations, such as bio-based materials/biochemical processing and animal feed, which show negative values. However, these findings require careful interpretation. While the values may indicate reduced impact compared to other destinations, potential trade-offs and hidden environmental costs could be linked to these processes. These might include the use of land and water resources, energy consumption during processing, or emissions associated with transportation. Additionally, hidden environmental costs, such as impacts on biodiversity or ecosystem services, could influence the overall sustainability.

Figure 8 further suggests that plant food waste appears to have a larger footprint in agricultural production (149.46 m^3-eq) than animal food waste (80.3 m^3-eq). However, these findings should be interpreted cautiously due to the study's limited scale. The results suggest that water use and pollution, critical factors in water quality and scarcity, are particularly significant in the agricultural production of cereals, fruits and vegetables, and pulses. This insight, while derived from a small sample, may provide a preliminary understanding of the potential impacts of different types of plant food waste on water scarcity.



	FRUIT & VEGETABLE Europe and Russia	CEREAL Europe and Russia	PULSES & OILSEEDS Europe and Russia	MEAT Europe and Russia	DAIRY Europe and Russia	OTHER Europe and Russia
■ Unknown (assumed to be landfill)	-	-	-	-	-	-
■ Sewer/wastewater treatment	-	-	-	-	-	-
■ Refuse/discards/litter	-	-	-	-	-	-
■ Landfill (no gas capture)	-	-	-	-	-	-
■ Not harvested/plowed in	-	-	-	-	-	-
■ Land application	-	-	-	-	-	-
■ Controlled combustion with energy recovery	-	-	-	-	-	-
■ Composting/aerobic processes	-	-	-	-	-	-
■ Codigestion/anaerobic digestion	-	-	-	-	-	-
■ Bio-based materials/biochemical processing	(5,99)	(17,87)	(1,35)			(21,30)
■ Animal feed	(0,00)	(0,04)	-	(0,01)	(0,00)	(5,34)
■ Additional relevant life cycle impacts	-	-	-	-	-	-
■ Agricultural production impacts	65,62	83,81	0,03	35,96	44,34	10,36

Figure 8. Absolute water scarcity impacts for the different contributions (agricultural production, life cycle and destination)

Note: the dash means that the category is not applicable.
Source: authors' calculation with the FLW Value Calculator

5.3 Soil Quality Index

Figure 9 illustrates the breakdown of household food waste across various categories and their relative impacts on soil degradation. Figure 10 further delves into this by showing the Soil Quality Index (SQI)[7] linked to each type of food waste. In line with broader research findings, our study indicates that the agricultural production stage is a critical contributor to soil deterioration. This is particularly true for food waste from meat and dairy products.

Specifically, in our sample, food waste from animal sources shows a notable impact on soil quality, accounting for 7,384.22 points or 75% of the overall effect on the SQI. In comparison, plant-based food waste contributes 1,633.21 points, making up 16% of the total impact. It is worth emphasizing that animal food waste, which forms 18% of the total avoidable food waste in our study, is identified as a major factor in the degradation of soil quality.

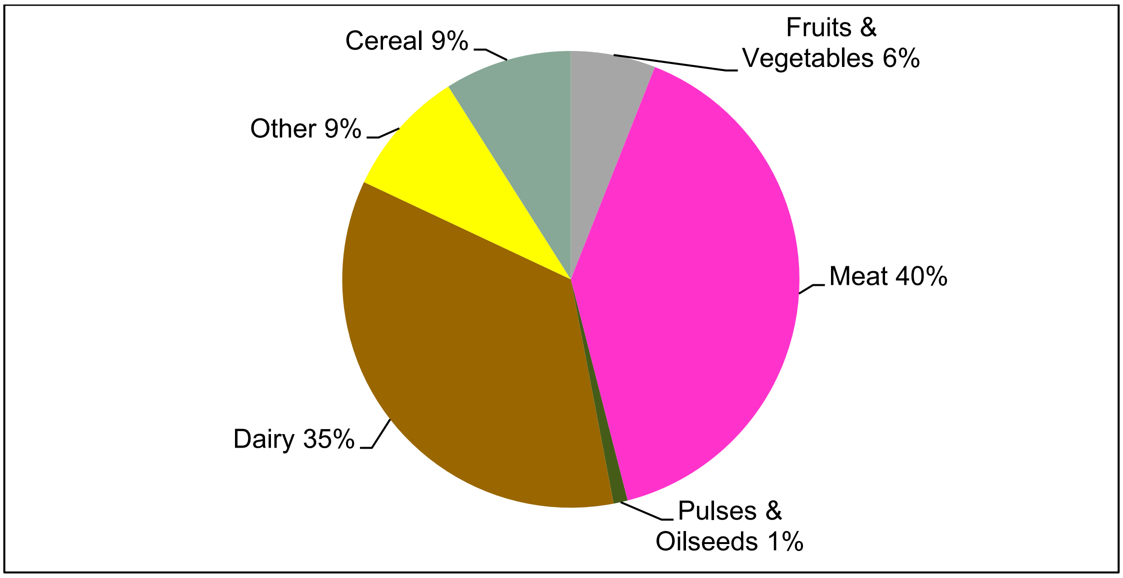


Figure 9. Percentage of soil that is deteriorated by each household food waste category

Source: authors

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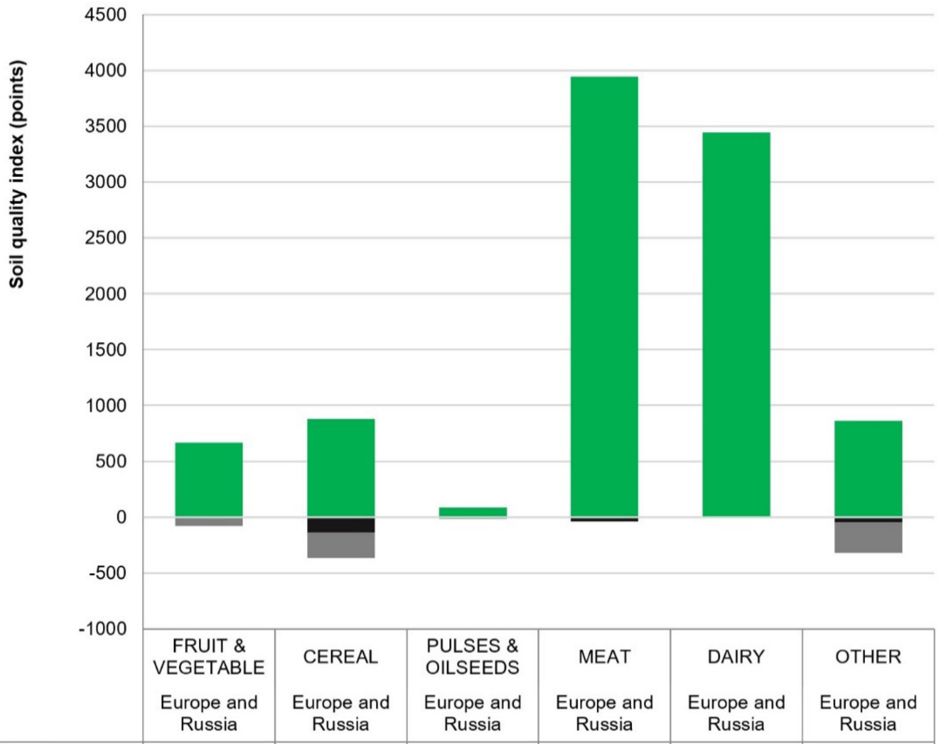
[7] The soil quality index, otherwise known as “land use” in the product environmental footprint of the European Commission, indicates the deterioration of soil quality, where the higher the points the worse the soil quality. This impact is measured in points, which are a relative indicator aggregating impacts on land related to biotic production capacity, erosion, mechanical filtration of water, and groundwater replenishment (definition as it appears in the ‘impact descriptions’ of the FLW Value Calculator).



	FRUIT & VEGETABLE Europe and Russia	CEREAL Europe and Russia	PULSES & OILSEEDS Europe and Russia	MEAT Europe and Russia	DAIRY Europe and Russia	OTHER Europe and Russia
■ Unknown (assumed to be landfill)	-	-	-	-	-	-
■ Sewer/wastewater treatment	-	-	-	-	-	-
■ Refuse/discards/litter	-	-	-	-	-	-
■ Landfill (no gas capture)	-	-	-	-	-	-
■ Not harvested/plowed in	-	-	-	-	-	-
■ Land application	-	-	-	-	-	-
■ Controlled combustion with energy recovery	-	-	-	-	-	-
■ Composting/aerobic processes	-	-	-	-	-	-
■ Codigestion/anaerobic digestion	-	-	-	-	-	-
■ Bio-based materials/biochemical processing	(77,95)	(232,47)	(17,62)			(277,03)
■ Animal feed	(0,65)	(135,89)	-	(38,63)	(6,31)	(43,40)
■ Additional relevant life cycle impacts	-	-	-	-	-	-
■ Agricultural production impacts	664,46	879,97	88,78	3.941,56	3.442,66	864,03

Figure 10. Absolute soil quality impacts for the different contributions (agricultural production, life cycle and destination)

Note: the dash means that the category is not applicable.
Source: authors' calculation with the FLW Value Calculator

5.4 Eutrophication

In this study, household animal food waste stands out as the principal source of phosphorus discharge, contributing 0.61 kg P-eq to freshwater bodies. The impact of plant food waste on eutrophication is minimal, so much so that it is assessed as practically negligible. However, it is important to interpret these findings with caution, considering they are derived from a relatively small sample size. For eutrophication from nitrogen, the findings, aligning with general scientific understanding, show a total marine eutrophication value of 0.49 kg N-eq. Notably, food waste from households, particularly meat and dairy products, constitutes a significant portion of this, amounting to 0.29 kg N-eq. The observed environmental impact in marine eutrophication also primarily originates from agricultural production activities associated with the life cycle of avoidable household food waste. Within this context, the contribution of animal food waste to marine eutrophication substantially exceeds that of plant food waste. While these findings are consistent with broader knowledge on the topic (e.g., Haeussermann et al., 2020), the limited scope of the study needs further research to validate and expand upon these initial insights.

6 Discussion and Conclusions

Our exploratory case study, conducted in 2018 with 50 young households in Northern Germany using a two-week diary method (Reinhold, 2018), provides valuable insights into the environmental footprints of avoidable household food waste. The findings from this study deepen our understanding of how various types of avoidable food waste contribute to environmental degradation from a life cycle perspective. Moreover, the study aligns with and contributes to the existing literature in several key areas, particularly by quantifying the environmental footprint of household food waste.

We explored key environmental indicators including GHG emissions, water scarcity, soil quality, and eutrophication. We find that the GHG emissions from household food waste observed in our study confirm previous findings, such as those by Noleppa and Cartsburg (2015), which show a significant proportion of food sector emissions arising from agricultural production. Our results support this, showing that nearly half of GHG emissions are attributable to agricultural production associated with corresponding animal food waste.

In terms of the water scarcity footprint, our findings are in line with those of Erickson (2021) and Dräger de Teran (2021), who highlight the predominantly localized effects of this footprint and its significant attribution to plant-based foods in Germany. In our study, 62% of the water scarcity footprint is linked to plant food waste, underscoring the role of plant-based food in water scarcity, though not as pronounced as the 96:4 ratio seen in broader German studies (Dräger de Teran, 2021).

Our study highlights the significant impact of animal food waste on soil quality, revealing that it accounts for 75% of soil degradation during agricultural production. This substantial contribution adds to the existing literature by illustrating the specific role of animal food waste in soil degradation. Additionally, our findings align with the broader challenges in assessing soil quality, as discussed by De Laurentiis et al. (2019), which emphasize the complexity due to its spatial and temporal variability.

Regarding eutrophication, a significant environmental issue in Germany (Haeussermann et al., 2020; Castro Campos and Petrick, 2022), we found that animal food waste is the major contributor to phosphorus-induced eutrophication and surpasses plant food waste in marine eutrophication by nitrogen. These findings suggest the importance of implementing efficient fertilizer and wastewater management strategies in agriculture. Additionally, they call for a deeper comprehension of the various agricultural practices and limitations faced by farmers, as detailed in Castro Campos's (2022) study.

In conclusion, our study’s findings suggest that while animal food waste generally has a larger environmental footprint, the significant contribution of plant food waste to water scarcity, especially among young consumers in Germany, cannot be overlooked. These insights emphasize the urgency of rethinking and adopting sustainable dietary practices and improving food waste management strategies. The results also highlight the need for further research to validate and expand upon these initial insights, particularly in the context of environmental sustainability and efficient resource utilization.

Our research has several limitations. Reporting inaccuracies in the diary study, including potential underreporting and estimation errors, present challenges. Another important limitation is the extrapolation of two-week diaries to the calculations for one year. Assumptions about food origin, due to the broad regional categories in the FLW Value Calculator, also limit the precision of our findings. The FLW Value Calculator, still in beta, lacks specific country values and nuances, with limited considerations for different production processes or supply chain losses. Additionally, the tool does not consider the costs incurred by households in avoiding food waste, such as time, energy, and utility loss. These limitations highlight avenues for future research in this field and underscore the need for continued refinement of the FLW value calculator. Moreover, exploring specific policy measures, such as implementing taxes or eco-labelling schemes, could prove instrumental in achieving a reduction in food waste and mitigating its environmental impact.

Nevertheless, the FLW Calculator represents a significant advancement in the field of food waste research, offering novel insights into the environmental footprints of avoidable food waste. Despite its limitations, it serves as an excellent starting point for collaborative research endeavors. By enhancing our understanding of how food waste affects various environmental indicators, the FLW Calculator provides a foundation for improving the comparability of data across different case-studies. Furthermore, it fosters interdisciplinary and transdisciplinary efforts to refine the assumptions underlying the calculator, thereby contributing to more accurate and comprehensive assessments. The benefits of this tool for future research are substantial, as it encourages a more unified and detailed approach to addressing the environmental challenges associated with food waste from a life-cycle perspective.

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We would like to thank James Galloway for his literature suggestions on how to analyze food waste and loss in terms of their environmental footprint. Our thanks also go to Sabine Reinhold for conducting the survey as part of her bachelor thesis at the University of Kiel. Lastly, we express our gratitude to the two anonymous reviewers for their constructive feedback, which has substantially enhanced the quality of this manuscript.

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Appendix

Table A1. Avoidable household food waste data aggregated according to food category and its final destination

Destination	Grams
VEGETABLES	15220
Landfill	10725
Bio-based materials/biochemical processing	4165
Sewer	250
Animal feed	80
FRUITS	8485
Landfill	4625
Bio-based materials/biochemical processing	3610
Compost	230
Animal feed	20
CEREALS	8542
Landfill	3217
Bio-based materials/biochemical processing	3525
Animal feed	1800
PULSES & OILSEEDS	260
Bio-based materials/biochemical processing	260
DAIRY	10135
Landfill	5610
Bio-based materials/biochemical processing	1790
Sewer	2665
Animal feed	70
MEAT	2875
Landfill	1485
Bio-based materials/biochemical processing	1090
Animal feed	300
OTHER	17942
Landfill	5160
Bio-based materials/biochemical processing	3740
Animal feed	500

Source: authors based on Reinhold (2018)