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Characteristics and Determinants of Domestic Food Waste: A Representative Diary Study across Germany

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Abstract: As it is the case in many industrialized countries, household food waste accounts for a large share of total food waste in Germany. Within this study, the characteristics of edible and inedible domestic food waste, the reasons for discarding food and the potential influence of socio-demographic factors on food waste generation are assessed. A data set of 6853 households who participated in a diary study in 2016 and 2017 was analyzed by use of descriptive statistics, parametric tests, and linear regression. The results indicate that perishable products such as vegetables, fruits, and bread are mainly affected by disposal. Moreover, household food waste occurs due to quantity problems at purchase for small households and quantity problems at home for larger households and households with children. Despite statistically significant differences in food waste amounts between household lifecycle stages, age of the head of household, household size, and size category of the municipality, socio-demographic factors have a limited power in predicting a household's food waste level. The study has important implications for food waste policy and research regarding the issues of food waste prevention measures, quantification methodologies, and monitoring implementation.

Keywords: food waste; household; diary study; Germany; food waste behavior; socio-demographic characteristics; consumers

1. Introduction

Domestic food waste is highlighted by Sustainable Development Goal 12.3 as one of the food waste streams which should be reduced by 50% until 2030 [1]. This focus is justified because in industrialized regions households contribute the highest share of food waste in comparison to other stages of the food supply chain (FSC). At the same time, the invested resource input, corresponding emissions, and impacts on the environment until food reaches consumers accumulate along the entire FSC [2,3]. Thus, the prevention of food waste at the very end of the FSC seems to be especially desirable and effective. The design of a proper framework, strategy and prevention measure bundle to tackle household food waste requires comprehensive information on the generation of, characteristics of, and factors influencing domestic food waste. Nevertheless, as households differ in socio-demographic characteristics and behave very differently (due to external framework conditions, past and present experiences, knowledge, motivation, life cycle status, etc.), the collection of representative data sets requires great effort. The first research study on household food waste started in 1895, and the research intensity has increased enormously in recent years [4]. According to Xue et al. [3], up to 2015, 49% of the screened global literature on food loss and waste targeted domestic food waste. Nevertheless, there is still a lack of representative, reliable primary data on the household level related to the generation of food waste and especially to the complex interaction of individuals and existing framework conditions leading to domestic food waste [3]. Thus, research is still necessary to analyze households in order to

identify and design efficient food waste prevention policies applicable for different households and leading to a significant and long-term food waste reduction.

Food waste within households in Germany is an important issue as it is estimated that 52% of all food loss and waste occurs at this stage of the FSC [5]. As a member of the European Union, Germany is obliged to report domestic food waste quantities (among others) to the European Commission from 2020 onwards [6]. In order to ensure proper data collection among Member States, the Delegated decision 2019/1597 provides specific requirements on the methodological issues to be considered. One suggested methodology for food waste quantification at the household level is the use of diaries. Diaries, as a direct method, can cover all disposal of food and drinks and all disposal routes used, whereas indirect collection methods cannot include this information. This self-reporting methodology has been used in several studies, not only for quantification of domestic food waste, but also to collect information on food waste composition. Other factors of interest are root causes, disposal paths, context with socio-demographic characteristics, motivation, and behavioral indicators. Such factors are assumed to add the designing of prevention strategies and measures [7–9]. Nevertheless, the intended and unintended underreporting by respondents has frequently been recognized as a disadvantage of diaries for quantification purposes [10–15].

The obligation to report data was the starting point for the commissioning of a representative diary study among households in Germany. The corresponding data set is the basis of the present paper. It depicts the first representative national data set on the generation of total food waste, including drinks, using direct methodology while covering several disposal routes. The aim of this paper is to gain a better understanding of food waste behavior of households by analyzing the underlying disposal reasons. The paper uses German data to consider disposed product categories, condition at disposal, and disposal routes. Moreover, potential differences in food waste amounts between socio-demographic household characteristics are assessed. The paper presents the results and discusses strengths and weaknesses of the study design to establish a reliable time series towards national and European food waste reporting. This includes the suitability of diary methodology for domestic food waste accounting. Moreover, the study provides implications for policy and future research in the field of household food waste prevention in Germany and other high-income countries.

2. Materials and Methods

A representative self-reporting diary survey was carried out between July 2016 and June 2017 by the German market research institute GfK SE on behalf of the German Ministry of Food and Agriculture (BMEL) [16]. The corresponding data set provides the basis of the present paper.

2.1. Data Set

The sample was drawn from the ConsumerScope Panel of the GfK SE, whose participants are already familiar with the diary reporting procedure. For each month, a representative sample was selected for the Federal Republic of Germany (min. 500 households) according to the criteria of the Federal Bureau of Statistics applied in the frame of the micro-census, namely:

- place of residence within the federal state
- size category of municipality
- age of head of household
- net income of household
- household size
- employment of head of household
- formal education
- number of children in the household
- living circumstances

The necessary material to undertake a diary survey (such as paper and pencil diary, operation instructions and Supplementary Materials) was sent to the selected households. The response rate of the respective households was 85%. The pool of responsive households was again adjusted with regards to the criteria region, age of head of household, and household size to prevent a skewness of the sample.

Each household participating in the survey recorded all food and drink waste (further called "food waste") accruing within the household over a period of 14 days. Each month, a different set of households reported for such a 14-day-period. In total, 6853 households reported their food waste within the study, which means on average 571 households per month. In addition to the mass of the discarded food items, a set of further characteristics of the wasted food, as well as of the household itself, was selected and surveyed for each disposal act (Table 1). For further details on the surveyed socio-demographic characteristics, see also Tables A1 and A2 in the Appendix A.

Table 1. Characteristics of wasted food and socio-demographic characteristics of the households sampled within the survey.

Characteristics of Wasted Food	Socio-demographic Characteristics of Sample Household [1]
Food waste masses per waste act	Household size
Product group	Household lifecycle stage
Disposal route	Age of head of household
Food condition at disposal	Size category of municipality
Disposal reason	

[1] Detailed characteristic values are presented in the results part and in Tables A1 and A2.

Moreover, all food waste had to be classified as edible or inedible in the sense that for example the peel of certain fruits and vegetables, such as banana or watermelon, is generally presumed to be inedible. However, the classification of food waste as edible or inedible took place without any clear definition and hence was at the participants' discretion. For simplification of the classification, examples of inedible food fractions were listed in the diary material, including peels and cores of fruit and vegetables, bones, skin, cheese rinds, coffee grounds, and tea bags. To determine the mass of food waste per disposal act, the participants could decide for themselves whether to measure or estimate the mass or volume or indicate the number of pieces discarded. A conversion sheet (piece to mass) was provided with the survey diary for estimation. In the case of piece indication, the respective mass was calculated subsequently by GfK SE with the aid of a conversion table. The final data set was provided by BMEL to the authors.

2.2. Extrapolation

An extrapolation to national scale is valid since the sample households were selected representatively based on the mentioned criteria and the extrapolation was carried out according to Equation (1). Based on the assumption that the 14-day sampling period can be seen as representative for the respective month, the total mass of food waste in the Federal Republic of Germany was calculated per year. To enable this assumption, the sampled households were asked to select a 14-day period which represents a common behavior of their household. The individual weighting factor (f, Equation (1)) enables the multiplication of each household according to the respective characteristic values of the representative criteria mentioned above. This means that households which more accurately represent the population than others are assigned a higher weight. The weighting factor was based on the household characteristics presented in Table S1. Although there are indications of underreporting, no arithmetical adjustment of the data was made for this paper apart from extrapolating the reported data to annual waste quantities. The problem of underreporting will be discussed further in Section 4.

$$\mathrm{M} = \sum_{k=1}^{n} m_k \times f_k \frac{d \times 12}{14}, \quad (1)$$

M = total food waste mass of all households in Germany (kg/year)
k = sample household
m = actual mass of food waste of respective household [kg]
f = individual weighting factor of household according to characteristic values
d = number of days of the respective sampling month
n = total number of sampled households

2.3. Statistical Analysis

The statistical analysis was carried out in three subsequent steps. In a first step, a descriptive analysis of the data set was carried out to get a general overview of characteristics, such as edibility, product group, condition at disposal and disposal route.

In a second step, the reasons of households for discarding food were examined with regard to product groups, household size groups and lifecycle stages. This focus was selected because the disposal reason has major implications for potential prevention actions. The first two steps were carried out with the edible fraction of food waste only, which is of specific interest regarding potential policy and prevention measures.

The third step was undertaken with the whole data set, including the edible and inedible fraction of food waste, following the guidelines for food waste monitoring set by the European Commission. Potential drawbacks of the monitoring methodology suggested by the European Commission may thus be detected. Within this step, an explorative analysis (boxplots) was applied in the statistical software R Studio (R) to get an overview on food waste masses of households with regard to the sampled socio-demographic household characteristics. Subsequently, inductive statistics were applied in R to test for statistically significant differences in food waste levels between

- household lifecycle stages,
- age of the head of the household,
- household size (number of persons),
- size category of municipality, and
- level of education

by carrying out an analysis of variance (ANOVA). For statistically significant variables, as suggested by the omnibus test ANOVA, the post-hoc Tukey-Kramer test was applied to detect significantly different means between all pairs of groups. The Kramer multiple comparison procedure can be used for unequal sample sizes, as is the case for all variables in this study.

In a final step, potential dependencies of the amount of food waste (dependent variable) on other variables were examined by the aid of weighted multiple linear regression. For both analyses, the specific weighting factors of each household (f, Equation (1)) were applied to ensure an inference on the parent population. As both tests demand normal distribution, the original data was transformed by use of Box-Cox power transformation (Figure S1 in Supplementary Materials). Normal distribution of residuals and homogeneity of variances of the transformed data as well as of residuals were given for all variables.

3. Results

The distribution of food waste amounts per household and 14-day-period is right-skewed (Figure 1a) indicating that many households reported smaller amounts of food waste, and a smaller number of households reported comparably large amounts. A total of 5% of all households reported no food waste at all and a further 12% only inedible food waste (Figure 1b). Another 8% of the sample households indicated having discarded only edible food waste, while the majority of 75% reported both types. Those 346 households reporting no food waste were excluded from the investigation for any further analysis. The reason was that it was assumed to be very unlikely to have no food waste at all within a period of 14 days, particularly as households on vacation were excluded in advance. A sample

of 6507 households remained. The food waste amount per household and 14-day-period (excluding households reporting no food waste) ranged up to 37.8 kg, with a mean of 3.4 kg and a median of 2.7 kg. After extrapolation to national scale, the data accumulate to a total amount of household food waste of about 3.7 million tons within the study period of one year. With a total number of 41.3 million households and 82.8 million inhabitants in Germany [17], household food waste sums up to 89.5 kg per household and year and 44.6 kg per person and year, respectively.

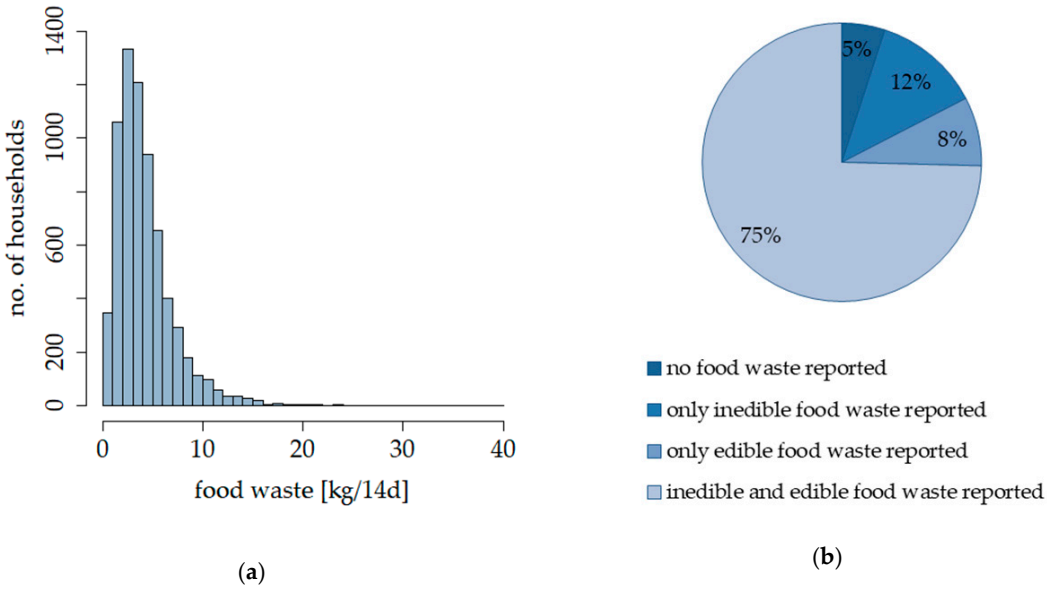

Figure 1. Number of households per total food waste amount category in kg per 14 day period (**a**) and shares of household food waste reporting (**b**).

Of all food waste generated, 56% was classified as inedible and 44% as edible by the participating households (Figure 2a). Figure 2b–d provides more detailed information on the edible section of reported food waste. With respect to the product categories (Figure 2b), fresh fruit and vegetables clearly represent the main disposed food categories (both 17.1%), followed by cooked and prepared food (16.2%). Bread and baked goods also represent a product group disposed in large amounts with 13.8% of all food waste. Animal products such as dairy (9.4%) and meat, fish, and eggs (3.7%) were discarded to a smaller extent. When looking at the condition of edible food at disposal, more than half of all discarded food was described as loose/unpacked, while another 21% was prepared or cooked and 13% in opened packaging. Only 6% was still in its original unopened packaging. The major disposal routes of the participating households were the organic waste bin used for 34% of all edible food waste, and to a similar extent, the residual waste bin with 33%. Another 14% of edible food waste was discarded into the sewer while 9% and 6% were recycled for home composting and reused as animal feed, respectively. The underlying data regarding absolute numbers of food waste masses are provided in the supplement (Table S2).

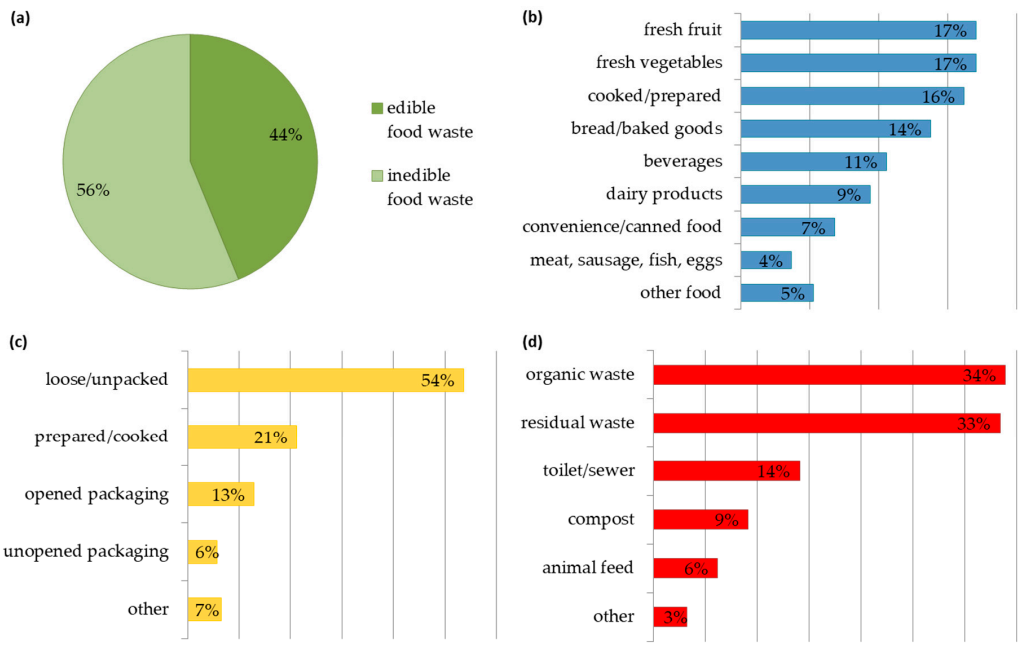

Figure 2. (**a**) Share of edible and inedible food waste reported by households; (**b**) shares of product groups; (**c**) condition at disposal and (**d**) disposal route of edible food waste reported by sample households.

3.1. Reasons of Disposal in Relation to Socio-Demographic and Food Characteristics

An important indicator for the identification of potentials for action is the reason for disposal (Figure 3). Classes and answer options were predefined by GfK SE within the diary and could be answered by the households by indicating their main and sub-reason for the disposal of the respective food item. The vast majority of edible food stuff (57.6%) was disposed due to the durability of the product as indicated by the participants. Most of these products were apparently spoilt while only 5.8% were disposed as a consequence of an expired best-before date. 21.3% of all food waste was discarded due to a quantity-related problem at home, e.g., too much food had been cooked or prepared within the household. Another 11.9% was wasted as a result of a quantity-related problem at purchase such as too big packaging sizes. Only 1.7% of the households indicated that a too big packaging size was bought because it was cheaper or on offer. Other reasons such as bad taste, wrong preparation, and storage play a minor role for the disposal of recorded food products.

A detailed look at the disposal reasons with respect to household size and structure (see also Table S3) shows that especially small households, such as one person and older single households (both ca. 16%) discard food products as a result of quantity-related problems at purchase (Figure 4b,c). Moreover, households without children indicate in around 13% of all cases quantity-related problems at purchase as the disposal reason while only 8% to 9% of households with children listed this as the main reason. Larger households of three persons or more, as well as households with small children, indicate disproportionally often quantity-related problems at home as a major reason for disposal. Single households and young households without children seem to be less affected by this category of disposal reasons. The overall main reason recorded is durability with relevance of 54% to 62%, which can be explained by the product types wasted (Figure 4a).

The identification of the main disposal reasons by product group revealed that particularly fresh fruit and dairy products are affected by a limited durability, followed by bread and baked goods and fresh vegetables. Quantity-related problems at home occur mainly for cooked and prepared food as well as for beverages, such as coffee and tea. Quantity-related problems at purchase, for instance large packaging or portion sizes, result disproportionally often in the disposal of convenience products (including canned food) but also of bread and baked goods. Convenience products are moreover often

discarded for "other reasons" which can be traced back to an "accident" (32% of other reasons), such as a freezer defect or infestation, and needed shelf space (25% of other reasons).

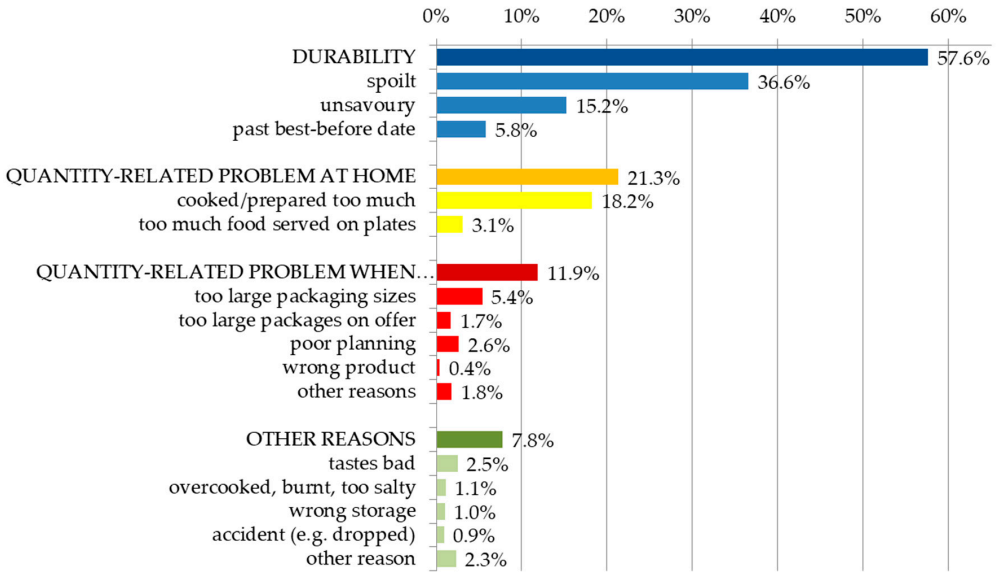

Figure 3. Disposal reasons of edible food waste reported by sample households.

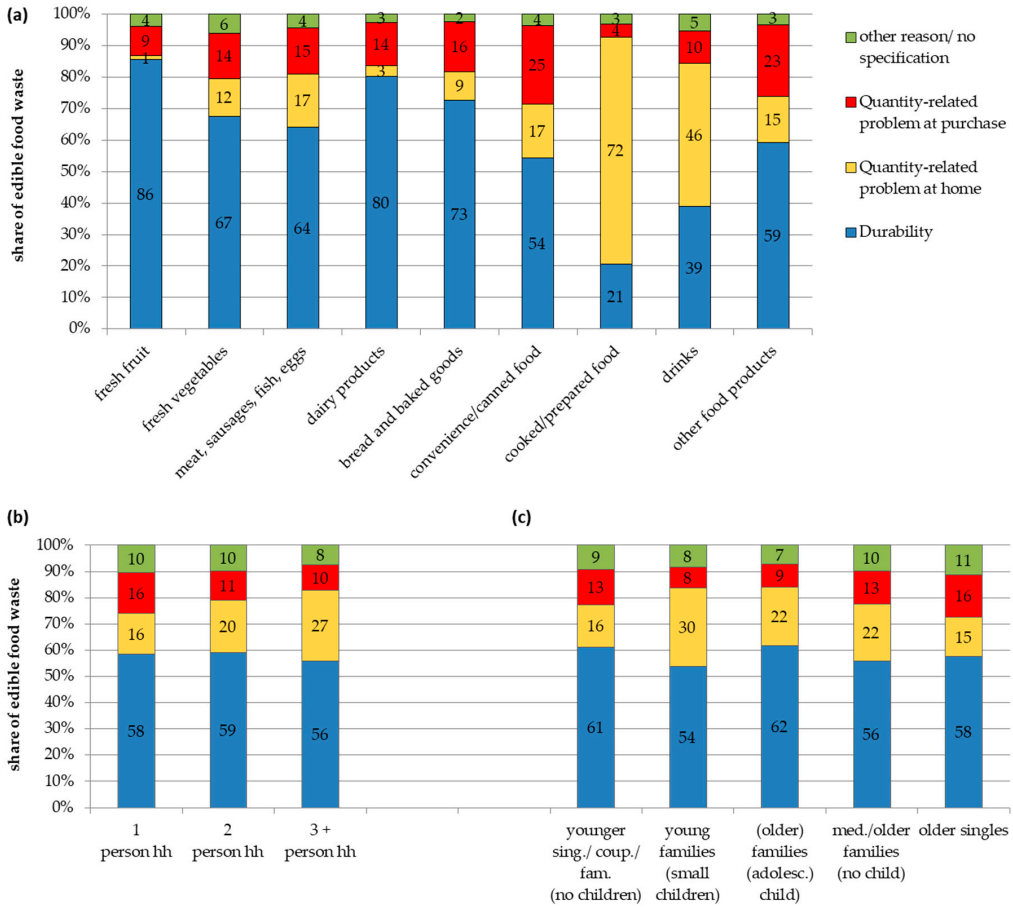

Figure 4. Indicated reasons for disposal of edible food waste (**a**) by type of food product; (**b**) by household size group; (**c**) by household lifecycle group.

3.2. Differences in Food Waste Amounts between Socio-Demographic Household Characteristics

A weighted analysis of variance (ANOVA) was performed to test for significant differences in food waste amounts (edible and inedible) between households with distinct socio-demographic characteristics. The individual weighting factors of households according to the characteristic values (*f*, Equation (1)) were applied within the analysis. This enables the transfer of results from the sample to the whole population of the Federal Republic of Germany. The Boxplots (Figure 5) seem to indicate that between-group differences with respect to household lifecycle stage, age of the head of the household, household size, size category of municipality, and level of education are often negligible in absolute terms. Substantial differences become only visible for household lifecycle stage and household size. Nevertheless, according to the ANOVA, statistically significant differences in the amount of food waste exist between factor levels of all tested groups (Table 2).

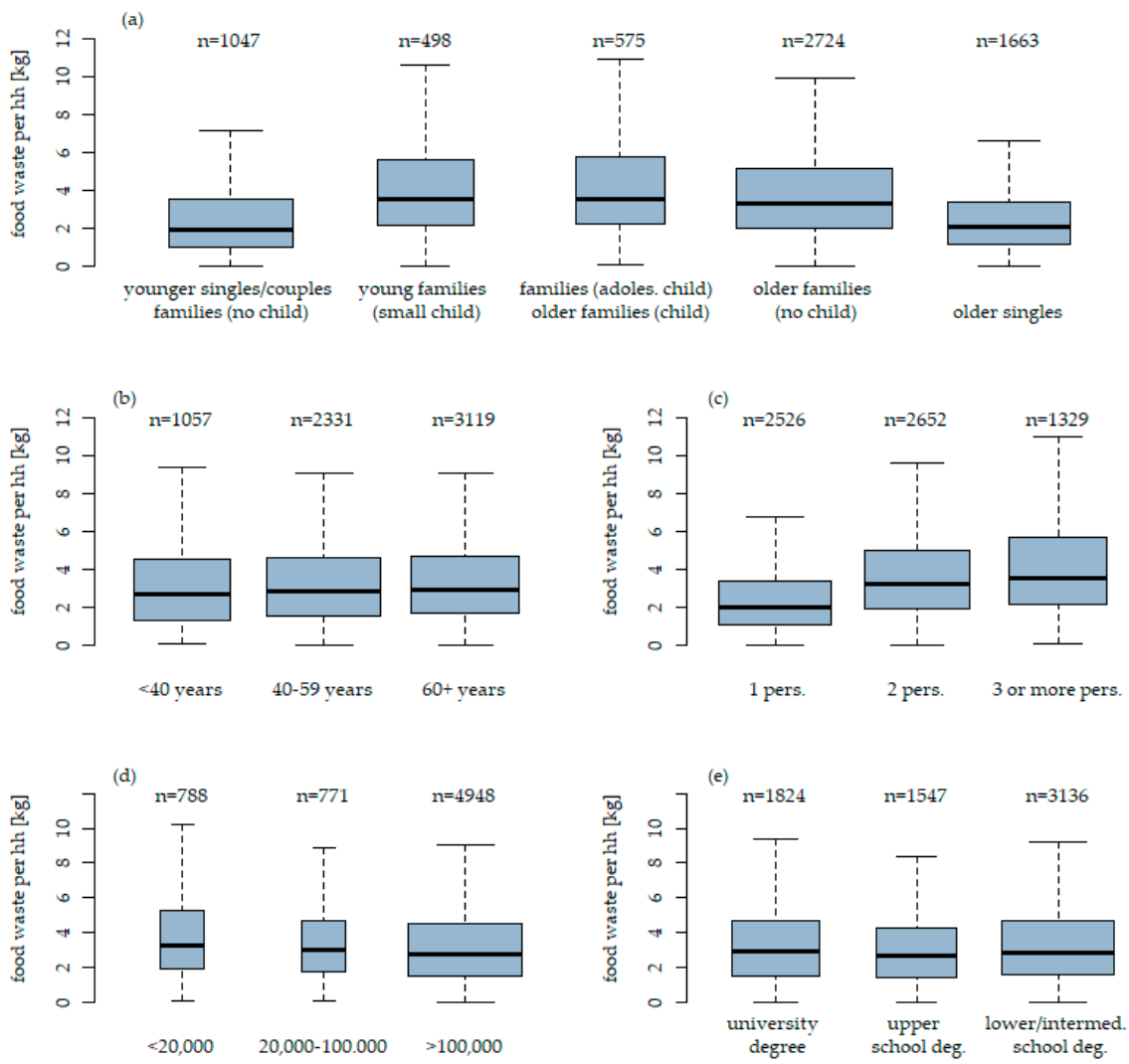

Figure 5. Total amount of household (hh) edible and inedible food waste within 14 days per (**a**) household lifecycle stage, (**b**) age of the head of the household, (**c**) household size, (**d**) size category of municipality, and (**e**) level of education (n indicates sample sizes; outliers are excluded).

Table 2. Results of statistical analysis: average food waste masses per household, *p*-values of ANOVA results of Tukey-Kramer post-hoc test, and r^2-values of linear regression models.

Groups and Characteristic Values	Avg. Mass of Food Waste (kg/14d)	*p*-Values (ANOVA)	Group Differences (Tukey-Kramer) [1]	Adjusted r^2 (Linear Regression)
household lifecycle stage				
younger singles/young families and couples without children	2.55		a	
younger families with small and school children	4.17	2×10^{-16}	b	0.086
families with adolescent children/older families with children	4.24		b	
older families without children	3.97		b	
older singles	2.56		a	
age of head of household				
<40	3.20		a	
40–59	3.35	0.00214	ab	0.002
60+	3.54		b	
household size				
1 person	2.52		a	
2 persons	3.86	$<2 \times 10^{-16}$	b	0.088
3+ persons	4.25		c	
size category of municipality				
<20,000	3.86		a	
20,000–100,000	3.62	2.32×10^{-9}	a	0.006
>100,000	3.32		b	
level of education				
university degree	3.46		a	
upper school degree	3.31	0.00286	a	0.001
lower and intermediate school degree	3.45		a	

[1] Characteristic values with distinct letter differ significantly from each other.

The post-hoc Tukey-Kramer test revealed that significantly less food waste occurs in the group of "younger singles; young couples; young families (without children)" and in the group of "older singles" than in all other groups with a *p*-value of the ANOVA below 0.001 (Table 2). The household lifecycle groups with children as well as the older families without children reported average food waste levels between 3.97 and 4.24 kg per 14 days while the younger group without children and the older singles reported only about 2.6 kg within the period of two weeks (Figure 5). For head of household age groups, only the youngest (up to 39 years) and the oldest group (60 years and older) are significantly different from each other with regard to the amount of household food waste they produce ($p < 0.01$). The older household age group however, discards with 3.54 kg/14d on average only 340 g more than the youngest age group. It should be noted here that the medium age group disposes about 10% and the oldest age group about 20% more inedible food than the youngest age group. An analysis of edible food waste only led to a noticeably different outcome concerning age and lifecycle groups (see also Figures S2 and S3), which will be discussed further in Section 4. With respect to household size groups, all factor levels differ significantly from each other ($p < 0.001$). Unsurprisingly, more food waste accrues in larger households. However, the difference between 2-person (3.9 kg/14d) and 3+-person households (4.3 kg/14d) is rather small, although 3+-person households with an average of 3.61 persons per household are almost twice as large as a 2-person household. This shows that the average per capita mass of food waste decreases with increasing household size. The post-hoc test for the size categories of municipality led to the finding that households in cities of more than 100,000 inhabitants waste with an average of 3.32 kg/14d significantly less than households in rural areas and smaller municipalities (<20,000 inhabitants, $p < 0.001$) with an average of 3.86 kg/14d and households in medium sized municipalities (20,000–100,000 inhabitants, $p < 0.01$) with an average of 3.62 kg/14d. With regard to the level of education groups, the post-hoc test, as opposed to the ANOVA, indicated that none of the groups differ significantly from each other. The boxplots and average values also reveal quite small differences between groups of education level within the sample which only become significant in the ANOVA after the implementation of weighting factors. This means that a

correlation between formal education and household food waste mass cannot clearly be drawn from this analysis.

3.3. Multiple Dependencies between Waste and Household Characteristics

Weighted linear regression models were created with the transformed data of food waste amounts as dependent variable and f (Equation (1)) as weighting factor. First, the regression was carried out for all independent variables separately before implementing all variables into one weighted multiple linear regression model. The analysis aligns with the ANOVA by indicating that the considered independent variables indeed show significant differences among characteristic values. Nonetheless, the selected variables are not sufficient to predict the amount of household food waste as indicated by the low adjusted r^2 values below 0.1 (Table 2). The weighted simple linear regression with lifecycle stage and household size as independent variables resulted in the highest adjusted r^2 values of 0.086 and 0.088, respectively. The weighted multiple linear regression model resulted in an almost as low adjusted r^2 value of just above 0.09 indicating that the addition of more independent variables does not lead to a markedly better fit of the regression model. It could be shown that the individual as well as the combination of socio-demographic household characteristics predict less than 10% of the variance of the dependent variable.

4. Discussion

4.1. Design and Realization of the Survey

The data set showed that 5% of the households did not record any food waste within 14 days, although the households were asked to select a representative period. It must be asked whether it is realistic that neither edible nor inedible food waste occurs in these households within 14 days. Corresponding information from literature suggests that between 15% and 40% of respondents to questionnaires stated not wasting any food or edible food within a regular week or during the previous week [18–20]. In contrast, household food waste collection in Denmark led to the finding that only 3% did not have any food waste in the bag [21]. In Spain, 20% of all households did not record any food waste in diary surveys [20]. The Netherlands Nutrition Centre [22] compared food waste generation self-assessments from Dutch households with waste sorting analyses and summarizes that "every household throws things away." The methodological procedure applied here should be better reflected within scientific literature in order to gain more experience on "zero food waste" households.

Methodological questions arise with regard to the extent of underreporting of diary studies as well as to whether all respondents conduct underreporting in the same way, and if specific food waste fractions are more or less affected. For the present data set, GfK SE [16] estimates an underreporting of 18% by comparing the reports with panel data on daily shopping behavior. They assume that all food waste is underreported in the same way by all respondents. Findings from the literature show that this might not be the case. According to Hoj [12], the unavoidable food waste fraction was not statistically underreported by all respondents, while the avoidable and possibly avoidable food waste fraction was underreported to a huge extent by households with multiple members. A smaller extent of underreporting was detected by Giordano et al. [23] who report a lack of 23% for edible food waste on average. Quested et al. [15] compared the diary methodology with waste collection at the example of five studies in the UK, Saudi-Arabia, and the US and came to the conclusion that the underreporting of diaries lies between 7% and 40%. The main reasons for the underreporting of diary studies according to Quested et al. [15] are behavior change resulting from the reporting, misreporting, measurement bias (if not all items are weighed) and self-selection bias. In the present paper, the primary data set was not corrected, but for future use of such diaries more research needs to be carried out on the level of under coverage for distinct product groups and different behavior of respondent groups. The German baseline-2015-study by Schmidt et al. [5] derived household food waste mainly from official waste statistics, the underlying data set of GfK SE to consider relevance of

disposal paths and waste composition analyses of bins. The study suggests a food waste amount of 75 kg per person, which represents 1.7 times the mass of the diary study presented here and 1.3 times the mass of the correction methodology using the panel data of daily shopping behavior described above.

Furthermore, other methodological questions arise, for instance concerning the impact of the independent categorization of edible and inedible food waste by the participants themselves. However, the perception of edibility of a product can vary between households (e.g., for peels of different vegetables) which complicates a clear categorization of edible and inedible food products in advance. Moreover, participants were allowed to weigh or estimate the mass of food waste in grams or liters or indicate the number of pieces, leading to further uncertainties. Conversion tables were provided, but it was not recorded which households weighed and which estimated the food waste mass. This information could support assumptions on uncertainties of the reported data. Additionally, the prior aggregation of the data by GfK SE, e.g., for household size and lifecycle groups complicated the statistical analysis. For future surveys, a more detailed household characterization, such as the exact number of household members, would be desirable.

4.2. Product Characteristics

Unsurprisingly, perishable products such as fruit, vegetables and bread are mainly discarded which could be shown in previous studies [13,24]. In addition, the study was able to show that cooked/prepared and loose/opened food products range among the main discarded food products. Our findings indicate that beverages contribute to a major extent of domestic food waste and should not be excluded from quantification methodology, as it is quite common in current literature on household food waste; for example [9] or [18] or [20]. The relevance in terms of the environmental impact should not be underestimated as liquid waste streams consist of coffee, tea, fruit juices, alcohol or soft drinks. These may have a major impact during production related to the use of fertilizer, pesticides, water demand, etc. Findings from Schmidt et al. [25] showed that the environmental impact of domestically wasted beverages is considerable in Germany.

With respect to disposal paths, the results show that toilet or sewer represents the 3rd relevant disposal option. The present findings are less than for Dutch households who dispose nearly 30% of their total food waste (including e.g., yogurt, soup, dairy drinks, coffee, tea, soft drinks, fruit juices, milk, wine, beer) into the toilet or sewer which ranks this disposal option in 2nd place [26]. With the background of such findings, it seems to be critical that sewer/toilet disposal is excluded in current EU legislation [6]. Moreover, the alternative disposal ways of home composting and feeding to animals should not be neglected. Although the waste compositional analysis can be referred to as the more accurate methodology, it is a drawback that the disposal ways sewer, home composting, and animal feed cannot easily be captured by it [15,27].

The residual waste bin is used almost as often as the bio waste bin, which underlines the importance of taking into account both of these disposal options for any household food waste survey. The fact that separate bio-waste collection is not available everywhere should also be taken into account when comparing (inter)national food waste amounts.

4.3. Disposal Reasons

The respondents chose durability or spoilage as the main reason for edible food wastage within their homes, which corresponds well with other literature; for example [9] or [13] or [28]. This result should be interpreted rather as perceived reason than as actual reason for disposal, as spoilage arises due to poor planning or wrong storage in the first place rather than due to poor quality of food produce.

The relevance of the quantity-related problems at home is quite similar to other studies [9,13,19]. Quantity-related problems at purchase play a greater role for smaller households within the present study. Here, the offer of smaller packaging units, re-sealable packaging, or piece-by-piece withdrawal for small households could contribute to prevention, especially for canned food and convenience products.

In contrast to other studies [9,18,19,28], the best-before date, with less than 6% of all wasted items, was not highly ranked as reason for disposal. This finding aligns with Schmidt et al. [25] who found that 88% of their participants in Germany check the edibility of the particular product after expiry of the best before date. Only 7% of the participants usually discard all products after expiry of the best-before date. Moreover, the present respondents presume not to waste a high share of food due to too large packages being cheaper or on offer, which is supported by other authors as well [3,9,19].

4.4. Socio-Demographic Characteristics

The inedible fraction was included in the analysis of socio-demographic characteristics due to the legal requirements within the European Union to report the total food waste masses from 2020 onwards. It represents a different approach to most of the already available literature which is often dedicated to edible domestic food waste only. The findings on the dependency of generated domestic food waste on age and lifecycle stage of participants differ within the literature. Koivupuro et al. [9] could not find any significant connection between food waste level and age. However, most studies found that older households waste less than younger households [18,20,29–32]. In contrast to these studies, the present results indicate that older age groups and lifecycle stages account for a relatively high share of food waste. The reason is that the inedible fraction of food waste is much higher for older households than for other age groups (Figure S2) which raises specific implications for the monitoring. First, it makes a noticeable difference if one targets edible or inedible domestic food waste. Therefore, both fractions should be reported separately with clear indication on what is covered. Second, the shares of edible and inedible food waste vary between household types, making a more specific addressing of prevention measures necessary. At present, the European legislation asks for separate reporting of edible and inedible fraction on voluntary basis only.

Many studies suggest that food waste amounts are lower in smaller households than in larger households and that the amount of waste per person decreases with increasing household size [9,13,28,29,31,33]. This result was also found within our data set.

Families with children within this study waste significantly more which is in line with findings of other household surveys [28,32]. Parizeau et al. [28] offer the explanation of time and money constraints with children in the household while Neff et al. [34] suggest that eating behavior of children is not always predictable resulting in too much food served on the plate. Since too much food served on the plate was not a major disposal reason in our study, this explanation seems unsuitable in this context. Taking into account the assumed underreporting of a diary study, the impact of household composition on the recorded food waste should be considered as well. According to Hoj [12], households with children and multiple adults provided substantial underreporting in diaries by 40% of the total food waste (wasted into municipal waste collection), whereas single occupancy households recorded the same amount of food waste as parallel conducted compositional analyses found for them. This puts the comparably high per capita mass of food waste of small households somewhat into perspective.

The present findings concerning food waste in rural and urban areas seem to be contrary to other studies. Neff et al. [34], who conducted an online survey which did not actually aim at food waste quantification, found few differences in reported food waste amounts between rural and urban status. Koivupuro et al. [9] did not find a significant correlation for avoidable food waste to all disposal paths. Secondi et al. [30], who statistically analyzed survey data of telephone interviews within the EU, found that households living in towns indicate they produce more food waste than those living in rural areas. This is supported by Schneider and Obersteiner [35] as well as Lebersorger and Schneider [27], who conducted waste sorting analysis covering residual waste only. These apparent differences may be grounded in the coverage of disposal options surveyed. All disposal paths were covered in the present study, whereas the latter two mentioned studies included residual waste only. This means that according to the present results, nearly two thirds of the food waste was not covered within these studies. The findings of Neff et al. [34] and Secondi et al. [30] rely on questionnaire and telephone surveys which do not represent an adequate method to draw exact figures on food waste quantities

from. The comparison of the different coverage of disposal paths and domestic food waste generation may suggest that in rural areas, non-residual waste disposal paths such as separate collection of bio waste (municipal collection or home composting) or animal feeding are more relevant than in urban areas. This issue should get more attention by future research.

Similar to our study, Cecere et al. [36] cannot draw clear findings on the correlation between education and household food waste. Also Neff et al. [34] found few differences in reported food waste amounts between differently educated groups. Visschers et al. [32], who analyzed a much smaller sample of less than 900 households, did not find a correlation either. Similarly, in Finland, Koivupuro et al. [9] did not find any significant correlation between food waste amount and educational level of the householders who filled in the diary. Only Secondi et al. [30] found that less educated individuals state to waste less than more educated ones. As mentioned above, the study by Secondi et al. [30] relies on own estimations of food waste amounts by use of questionnaires and hence on a completely different methodology compared to the one of the underlying study.

4.5. Prediction of Food Waste Amounts through Socio-Demographic Variables

In the present study the tested independent variables of the regression only explain a very small share of food waste emergence. Similar results were found by Giordano et al. [13], as the included socio-demographic characteristics within their study as for instance household size and food related habits such as shopping and eating behavior, could only explain about 30% of the variation in food waste quantities within the regression random forest. In a similar way, Grasso et al. [20] stated that their findings "underscore the modest role of socio-demographic characteristics in predicting food waste behavior in Europe".

De Hooge et al. [37] showed that besides demographics, waste behavior is influenced by personality characteristics, such as value orientation, commitment to environmental sustainability, and perceived consumer effectiveness in saving the environment and by individual waste aspects, such as perceived food waste of the household, perceived importance of food waste and engaging in shopping and cooking. Visschers et al. [32] performed a Tobit analysis on self-reported household food waste and also found that personal attitudes and norms such as perceived behavioral control and good provider identity are important influencing factors. Parizeau et al. [28] observed that food and waste awareness in general as well as family and convenience lifestyles are connected with food waste behavior.

Food waste is a multi-dimensional problem which is influenced by purchasing behavior, general waste prevention habits, as well as the importance of materialistic and environmental values [38]. Stancu et al. [31] strengthen this view on food waste generation by showing that psychological factors and household-related routines perform better in explaining food waste behavior than socio-demographic factors. Therefore, food waste can be described as an unintended result of several practices in a broader context of values and factors and should, with regard to domestic food waste reduction, also be addressed as such a multi-faceted issue [39].

5. Conclusions

The study presents for the first time findings on household food waste behavior and characteristics in Germany in a representative way and grounded on a quantitative statistical analysis. It is able to show that levels of household food waste indeed differ between distinct socio-demographic factors which has not become clear in previous studies with smaller sample sizes. Nonetheless, the socio-demographic factors considered in the analysis explain only a small share of households' variance in food waste levels, which must substantially be affected by parameters not taken into account in the frame of this study. Food waste not only depends on selected socio-demographic characteristics of households but also on many other conditions that relate to behavior, routines, lifestyles, attitudes, and norms. This implies that policies targeting certain population groups such as single, young, or households with children might be limited in their effectiveness. As the comparison with other research on household food waste showed, a focus on overall consumer behavior, waste prevention habits, daily routines and

environmental values could be more accurate. More quantitative research on potential influencing factors of household food waste should be carried out as a scientific basis for targeted prevention policies. The results on disposal reasons indicate that food waste prevention measures should not solely rely on information provision regarding the best-before date and perishability but rather focus on adequate packaging sizes for smaller households, especially of canned foods and convenience products, and better meal planning options for larger households and households with children as well as re-use ideas for surpluses.

Regarding the monitoring of household food waste, further issues need to be taken into account. The disposal path sewer/toilet should not be neglected as it represents a major disposal path, particularly for beverages. The present dataset show a survey methodology for households that integrates this component in a consistent way. Further, the disposal options composting and animal feed and the different use of these paths between regions must also be taken into consideration.

With regard to the recent EU requirements for food waste monitoring, the problem of distinct shares of inedible fractions between households must be discussed in further detail. Differences in the share of edible and inedible food waste among age groups may result in distortions if indication on the potential edibility of the food product is not provided during reporting.

From a methodological viewpoint, it is challenging to compare existing studies and make clear assumptions on food waste masses, behavior, and the influence of socio-demographic factors. The existing studies apply different methodologies and rely partly on households' own perceptions and estimations of food waste levels. Moreover, the studies differ in their inclusion of distinct disposal routes, liquid products, and inedible food waste. Future research should focus more on adequate methods to quantify domestic food waste and to better estimate potential underreporting and negligence of certain food waste fractions. Particularly methodologies for measuring wasted beverages and the disposal path sink should be discussed. Research on household food waste quantities should moreover clearly unveil and reflect on the advantages and disadvantages of their applied methodologies to facilitate a comparison between studies. Furthermore, the phenomenon of "no food waste at all"-reporting should be investigated with respect to methodological interpretation, impact on results, and proceedings for other households. Recent literature already states the disadvantages of diary studies for quantifying household food waste [5,13,15]. Nonetheless, our study could show that particular information on all relevant disposal paths can easily be captured by use of food waste diaries. Thus, a combination with other methodologies should be applied for a proper assessment. Finally, time series should be established to capture potential trends in the development of food waste, which are as yet unclear for households in Germany.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/12/11/4702/s1, Figure S1: Histogram (left) and QQ-Plot (right) showing the normal distribution of transformed data on food waste masses by use of Box-Cox transformation, Figure S2: Total amount of edible and inedible food waste by age group of head of household per household and year [kg], Figure S3: Total amount of household (hh) edible food waste only (in contrast to Figure 5 addressing total food waste) within 14 days per (a) household lifecycle stage, (b) age of the head of the household, (c) household size, (d) size category of municipality, and (e) level of education (n indicates sample sizes; outliers are excluded), Table S1: Criteria for calculation of the weighting factor (f) for each household by GfK SE, Table S2: Underlying data of descriptive statistics concerning edibility, food product types, condition of disposal and disposal routes in percentages and absolute annual numbers (absolute numbers are extrapolated to the whole population of Germany), Table S3: Underlying data of descriptive statistics concerning disposal reasons by product group, household size group, and lifecycle group in percentages and absolute annual numbers (absolute numbers are extrapolated to the whole population of Germany).

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Appendix A. Specifications of Surveyed Socio-Demographic Characteristics

Table A1. Characteristic values of observed socio-demographic characteristics.

Socio-Demographic Characteristic	Characteristic Values	Group Number
lifecycle stages	younger singles/young families and couples without children	1
	younger families with small and school children	2
	families with adolescent children/older families with children	3
	medium aged and older families without children	4
	older singles	5
age of head of household	<40 years	1
	40–59 years	2
	60+ years	3
household size	1 person	1
	2 persons	2
	3+ persons	3
number of inhabitants of municipality	<20,000 inhabitants	1
	20,000–100,000 inhabitants	2
	>100,000 inhabitants	3
level of education	university degree	1
	upper school degree	2
	lower and intermediate school degree	3

Table A2. Detailed specifications of the socio-demographic characteristic "lifecycle stage".

Lifecycle Stages	Further Specifications	Group Number
younger singles	49 years or less	1
young families and couples without children	head of household 34 years or less	
younger families with small children	head of household 44 years or less; oldest child 6 years or less	2
younger families with school children	head of household 44 years or less; oldest child between 6 and 14 years	
families with adolescent children	head of household 44 years or less; oldest child between 15 and 19 years	3
older families with children	head of household 45 years or more; children between 0 and 19 years	
medium aged families without children	head of household between 35 and 49 years; no child below 20 years in hh	4
older families without children	head of household 50 years or more; no child below 20 years in hh	
older singles	50 years or more	5

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