Waste Food not Eat: Food Waste Treatment or Obesity - Selection of Sustainable Strategies for Dealing with Food Waste and Obesity

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Research Article

Keywords: environmental impact , food waste , LCA , obesity , waste treatment

Posted Date: April 14th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-418092/v1

Discover Sustainability manuscript No.
(will be inserted by the editor)

Waste Food not Eat: Food Waste Treatment or Obesity - Selection of Sustainable Strategies for Dealing with Food Waste and Obesity

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Received: date / Accepted: date

Abstract This theoretical model-based study is aimed to answer an applied but system-related question, relevant to multiple current studies and general audience: Is it better for human health and the environment to consume extra portion of food or throw it in the garbage (for further treatment)? The question has deep conceptual roots and requires a holistic approach to assessing a few complex systems: food production, food waste treatment and medical treatment activities. According to estimations, there are around 3.05-7.2 Mtonnes of avoidable food waste generated by German consumers at the household level. Simultaneously, high levels of food overconsumption are also observed at the household level. Thus, more than half of all Germans are overweight and obese and a high share of them require additional medical treatment resources. The study compared the environmental impact of treating potentially avoidable food waste with current waste management system in Germany to the hypothetical scenario of consuming such amount of food by the existing population.
The results indicated that current waste management system is more beneficial for the environment than consuming excessive food by German population and requesting related medical services in categories of global warming potential (0.128 versus 0.6-2.4 Mtonnes CO_2 eq.), energy demand (-21 versus 16-66 PJ) and water footprint (-1607 versus 13.2-53 million m^3).However, land use impact allocated to other healthcare due to food consumed by humans is 13-80% lower than current waste treatment. Another danger of consuming excessive food relates to accumulated risks and further increased demand for health services. Following years would worsen the situation, making a choice for "food waste avoided" diet unfeasible. The results received do not allow for a simple

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answer on selecting more sustainable strategies of dealing with an excessive amount of food in every specific case. However, they allow to indicate preferable conditions for dealing with excessive food in model conditions, which account for health status of household members or group of people (population), nutrient density and amount of food, and time frame. Time factor is one of the key factors defining preferences for food-wasting or consumption.

Keywords environmental impact · food waste · LCA · obesity · waste treatment

1 Introduction

One-third of produced food is currently lost or wasted during the various stages of food production and consumption [1]. Food waste is reaching tremendous amounts (only in EU more than 88 Mt of food are wasted), responsible for 15-25% of food system climate impacts [2,3]. In developed countries, the food waste occurs in a great degree at the end of the value chains (at the consumer) [1,4], . The Sustainable Development Goals of the United Nations include a specific target for halving per capita global food waste at the retail and consumption stage by 2030 compared to 2015 (SDG 12.3). The European Commission (EC) also tackles food waste with the Resource Efficiency Roadmap, which contains the goal of reducing the resource input into the food chain by 20% and halving the disposal of potentially edible food waste by 2020 [5]. Therefore, it is impossible to discuss sustainable food systems' progress without tackling food waste at the end of agri-food chains (especially at household level) [4,2,6–8]. Multiple research projects target the issue of food waste reduction, waste treatment improvement [9–11] as well as numerous policies and laws are set in place to deal with the issue on national and international level [12–14].

Germany, in this sense is a country with typical "Western World" food waste problems. There are 9.9 Mtonnes of food (51% of all waste) at the end of the supply chain, which could be annually consumed in Germany, but get to the waste treatment instead [15]. It is necessary to point out that the German food waste treatment system is relatively efficient and food waste is responsible for only around 4% of GHG emissions [16]. Multiple official statistical reports and studies define consumers waste around 7 Mtonnes of food, which can be avoided [15,17]. Such official estimations are highlighted to be excessive [18], and some studies indicate that only half of the mentioned amount of food waste could be avoided [17]. Recently finished study (REFOWAS research project) concluded that around 40% of avoidable food waste in Germany arises in private households [18]. Another study commissioned by BMEL in 2016 examined in a representative manner the compositions and waste treatment routes in Germany through surveys and recordings [19,20]. However, the differences in estimations may be associated with reported and not reported ways to deal with them. Currently, there are mainly six food waste disposal routes at the end of the supply chain, which consist of collection in bin for organic wastes (and further treatment mainly with anaerobic digestion), collection in residual waste bin (further mainly incineration), dumping in the toilet, mostly liquids (for wastewater treatment), composting, application as animal feed (for pets), or other disposal routes [19,20]. Different types of food wastes (fresh fruits and vegetables, meat and fish, dairy, bakery, processed convenience products, beverages, cooked food and other products) have different representation rates in disposal routes. Organic waste bin (anaerobic digestion) is mainly composed of vegetables, fruits and bakery products; composting at the same time almost wholly excludes bakery products. Dairy products and beverages are utilized through toilets as wastewater. Pets are fed with cooked products, meat and fish. Residual waste bins aimed for incineration are composed of diverse groups of foods [19].

According to the waste management pyramid, an excessive amount of avoidable food waste should be preferably utilized as food [21]. While for a certain percentage of the population it could make sense, for the largest part of the population it would mean an increase of number of calories consumed. Considering that 54.8% of Germans are overweight and obese, excessive food consumed could lead to severe consequences and many additional resources for the weight management or medical treatment of obesity-associated conditions and diseases. Multiple existing dietary guidelines, aimed for healthier and more sustainable diets, are demonstrated to be inefficient [8,22–25]. Would it be cheaper for the environment and society to waste the excessive food (also considering all the upstream resources used) or consume and treat it as a metabolic waste? The question has deep conceptual roots and requires a holistic approach to assessing a few complex systems: food production, food waste treatment, medical treatment and non-professional sport activities. Simultaneously, the study is not aiming to justify the overproduction rates, neither the known priorities in dealing with food waste (reduce, reuse, recycle etc.) [26]. Instead, it is a search for the guiding sustainability strategies for the consumers, canteens, restaurants, and other end consumers for the dealing with excessive food, not applicable for other purposes.

This theoretical model-based study is aimed to answer an applied but system-related question, relevant to multiple current studies and general audience: Is it better for human health and the environment to consume the excessive portion of avoidable food (e.g. extra cookie, stale bread, etc.) or throw it in the garbage (for further waste treatment)? In this context, we assume for the purpose of this study, that individuals are plate-clearing when they consume this excessive portion. Of course, there are other strategies as e.g., the reutilization of leftovers in subsequent meals [27] but nonetheless plate-clearing for preventing food waste appears to be an obvious as well as an applied strategy. Thus, food waste concerns may encourage people to eat more than they otherwise would be motivated to. Research revealed that individuals may consume less when food waste concerns are reduced [28,29], and other studies proposed a link between surplus food, food waste and overeating [30,31]. In her PhD-thesis Sheen [32](Sheen 2020) found that individuals who are concerned about wasting food and habitually clear their plate may be at risk of overeating, especially when faced with larger portions. Her research provides evidence that food waste concerns are associated with plate-clearing tendencies. Her developed new scale for measuring food waste concerns in an eating context revealed that higher scores on this scale are connected to a higher degree of self-reported plate-clearing. Likewise, Robinson and Hardmann [33] stated that clearing one's plate when eating is associated with heavier body weight, and the prevalence of this behavior may depend on parenting practices and concerns about food waste. In the framework of a regression analysis, they found that concerns over food waste ($\beta=0.474$, $p<0.001$) were predictive of plate clearing. Furthermore, some individuals experience an inner conflict that revolves around finishing all the food provided on their plate to reduce food waste on the one hand, and avoiding eating too much to maintain a healthy, slim body on the other hand [34,35]. Also, the meta-analysis by Zlatevska et al. [36] highlights that the influence of plate-clearing and food waste concerns on actual intake from larger portions may be underestimated. Compared to plate-clearing there are of course more effective strategies for reducing food waste as e.g., to train people to prepare and select less food (portion and meal size reduction [37]. Nonetheless, there is to our knowledge no data available that compares the real extent of household's different food waste avoidance strategies (e.g., plate-clearing, select less food, eating leftovers in subsequent meals, etc.) to each other. Thus, it is unknown which strategy dominates in the population. For carrying out the calculations we assume that only plate-clearing is applied for food waste avoidance. Of course, this assumption is unrealistic, but by focusing only on plate-clearing and waste treatment a direct comparison of these avoidance strategies becomes possible.

In order to create a basis of comparing different scenarios of food end-of-life treatment versus consuming for food and determine the potential reduction in environmental impact, the study is designed to reveal three main steps. The first step is to quantify the status quo of food waste amount and composition on household level in Germany. The analysis of the amount and composition allows for estimating the calorific value of avoidable food waste. Second step includes quantification of environmental impacts of dealing with excessive amount of avoidable waste at household level by combining the mass flows with life cycle assessment (LCA) results of relevant waste-treatment methods. The third step consolidates healthcare scenarios of consuming excessive avoidable waste by the German population, followed by the comparative analysis of potential environmental benefits or drawbacks for different waste treatment or food consumption scenarios. The study is finalized with discussion and recommendations for policymakers, society and private households.

2 Material and Methods

The study relied on published and statistical data sources to analyze food waste amounts at household level in Germany. While statistical data on general amount of food waste allowed for the approximation on the overall amount at the end of the chain [15,17], such data were not well stratified for a more detailed analysis. However, a recent study of GfK SE allowed creation and stratification of a more detailed picture of consumer food waste according to the main food groups and main management routes [19,20]. More detailed and more in-depth analysis of food waste use and impact was performed in the scope of the REFOWAS project [17], which defined the amount of food waste in Germany being equal to around 12.7 million tonnes (with 7.05 million tonnes theoretically avoidable). Similarly, to other estimates, the study allocated most of the food waste to the end of the supply chain. The estimates defined that consumers at household level were responsible for around 55% (6.96 million tonnes) of all food waste. These quantities included liquid food waste and drinks [17]. The data from the indicated sources allowed to define an upper (7 Mtonnes) and lower (3 Mtonnes) boundary for the theoretically avoidable food waste amount in Germany [17]. Relative distribution of food waste and related waste treatment scenarios were based on the study of GfK SE [19].

It was assumed that food waste at household level was treated (managed) in one of the ways indicated in the study [19]. Quantification of environmental impacts was performed for four impact categories (global warming potential, land use, water footprint and energy demand). Calculations were based on average values from numerous LCA studies performed for food waste treatment with anaerobic digestion [38–50] , composting [45,49,51–57], incineration [38, 45,47,48,50], wastewater treatment [58–61], feeding to pets [62–64] and other methods which represent average impact values of all other waste treatment methods. Calculated average LCA impacts were multiplied by the relevant mass flows of avoidable food waste at household level to determine the overall effect of avoidable food waste treatment with current technologies.

Accounting of approximate composition of avoidable food waste at household level allowed estimation of its calorific value. The wasted food's calorific content was accounted from approximate composition in published studies [17, 19,65,66] and relevant calorific values from USDA National Nutrient Database for Standard Reference [67]. Accounting of calorific content of potentially avoidable food allowed the estimation of overall excessive fat weight each representative of the German population in general or for specific groups will gain annually. To calculate the German population's weight gain, the study relied on the equation (1) developed by Swinburn et al. [68] for the population with constant height and age. German population was divided into groups with similar average age and size, and weight gain was calculated.

$$\left(\frac{W_2}{W_1}\right) = \left(\frac{EnFlux_2}{Enflux_1}\right)^{0.712} \tag{1}$$

Where, W_1 – initial weight of a person, kg; W_2 – resulting weight of a person in one year, kg; $EnFlux_1$ – initial energy flux, amount of energy consumed daily to maintain the bodyweight W_1, MJ; $EnFlux_2$ – changed energy flux, amount of energy consumed daily to maintain the bodyweight W_2, MJ. Next, it was necessary to assess the potential change in the health-related issues along with comparing the food waste and excess food consumption of the German population if all the avoidable food is consumed.

The analysis of potential changes accounted for demographic structure [69] and current state of obesity and overweight rates in Germany [70]. However, current obesity levels themselves do not indicate the changes in healthcare system, neither the environmental impact of such changes. Therefore, it was necessary to identify the environmental impact of current healthcare system and share of the healthcare related to overweight and obesity states. It was one of the most challenging parts, and it is necessary to highlight a lack of such studies in this field. Large-scale healthcare LCA studies have only been conducted for a few countries like USA [71], the United Kingdom [72], Australia [73], and Canada [74] and results are limited to "carbon and water footprints" mostly [75, 76]. This study relied on the estimates of carbon footprint available in literature [77, 75]. At the same time, for other impact categories, it was assumed that the share of healthcare impact was the same as the ratio of spending for the healthcare system to the national GDP. The ratio in Germany is 11.45% [78]. The healthcare causes global environmental impact ranges between 1% and 5% of the total global impacts and more than 5% for some national impacts based on Eora multiregional global supply-chain database contain detailed information on healthcare sectors that use to quantified the direct and indirect supply-chain environmental damage driven by demand for healthcare [79]. Similarly, obesity is associated with 20% greater GHG emissions relative to normal weight and 700 megatons per year of CO_2 equivalent which is about 1.6% of global GHG emission because of increase in oxidative metabolism, food intake, and fossil fuel use for transportation [80]. Using estimated impact values per capita for water footprint, land use, fossil energy use [77, 81–83], it was possible to define German healthcare system impacts.

Further, it was assumed that the current share of healthcare impacts in developed countries is in the range of 5% [84] and according to OECD [85] the health expenditure associated with overweight per year in Germany will be 441,2 USD PPP per capita and percentage of healthcare expenditure average 2020-2050 will be 11% of total health expenses. Therefore, it was hypothesized that adding extra weight would result in an additional increase in 1-4% for low and high-impacting scenarios. Similar results shown by another study that extra 1% to 4% CO_2 emission produced, if we consider normal weight, obese and overweight to analyses additional burden on global and national emission due to increase in prevalence of obesity [80]. The study's final step included comparing LCA results of conventional food waste treatment methods and using the food directly as food.

3 Results

The distribution of potentially avoidable food waste indicated that most significant amounts (weight) were associated with treatment through dumping to residual wastes, organic waste bins and toilets (Table 1).

Table 1 Potentially avoidable food waste composition according to the main types and treatment routes (Mtonnes, composed after [19])

	Total food waste	**Fruits (fresh)**	**Vegetables (fresh)**	**Meat/fish (fresh)**	**Dairy**	**Bakery**	**Processed convenience foods**	**Beverages**	**Cooked dishes**	**Other**
Residual waste (bin)	2.376	0.3303	0.3231	0.1307	0.2614	0.3469	0.2566	0.0879	0.4467	0.1925
Organic waste (bin)	2.52	0.6401	0.6275	0.0983	0.0781	0.4133	0.1285	0.0554	0.3830	0.0958
Compost	0.648	0.2119	0.2022	0.0078	0.0227	0.0525	0.0285	0.0311	0.0680	0.0233
Toilets	1.008	0.0006	0.0071	0.0002	0.2490	0.0010	0.0242	0.5201	0.1552	0.0433
Feed pets (animals)	0.432	0.0328	0.0557	0.0264	0.0130	0.1711	0.0229	0.0056	0.0942	0.0104
Other	0.216	0.0181	0.0225	0.0052	0.0467	0.0127	0.0235	0.0510	0.0207	0.0156
Total	7.2	1.2338	1.2380	0.2685	0.6708	0.9975	0.4843	0.7512	1.1679	0.3808
%	1	0.17	0.17	0.04	0.09	0.14	0.07	0.10	0.16	0.05

Table 2 Calorific energy included in potentially avoidable food waste according to the main types and treatment routes in Germany (in GJ unless specified)

	Fruits (fresh)	**Vegetables (fresh)**	**Meat/fish (fresh)**	**Dairy**	**Bakery**	**Processed convenience foods**	**Beverages**	**Cooked dishes**	**Other**	**Total**
Residual waste (bin)	825660	517018	1710471	1960200	4856544	1898899	114286	3305491	1096999	16285567
Organic waste (bin)	1600200	1003968	1286387	585900	5785920	951048	72072	2834496	545832	14665823
Compost	529740	323482	101780	170100	734832	210989	40435	503496	132970	2747823
Toilets	1512	11290	2639	1867320	14112	179021	676166	1148717	247061	4147837
Feed pets (animals)	82080	89165	344921	97200	2395008	169430	7301	696902	59098	3941105
Other	45360	35942	67853	349920	178416	174226	66269	153446	88646	1160079
Total, GJ	3084552	1980864	3514051	5030640	13964832	3583613	976529	8642549	2170606	42948235
Calorific energy, MJ per capita annually	38.56	24.76	43.93	62.88	174.56	44.80	12.21	108.03	27.13	536.85
Calorific energy, kcal per capita annually	9207.39	5912.88	10489.44	15016.46	41685.02	10697.08	2914.94	25798.01	6479.26	128200.5

While residual wastes and organic waste bins were composed almost evenly with various food wastes, composting was applied mostly to fresh fruits and vegetables. Toilet dumping (wastewater treatment) was related to beverages, dairy products and cooked dishes. Pets (animals) mainly were fed with bakery products. Analyzing from food waste group perspective fruits and vegetables were treated through residual, organic waste bins and composting. Meat and fish (fresh) were wasted through residual waste bin and minor degrees through organic waste and pet feeding. Dairy products ended up in residual waste bins and toilets. Bakery foods were allocated to residual and organic waste bins and pet (animal) feeding. Processed convenience foods got in residual and organic waste bins. Beverages were almost entirely poured in the toilets. Cooked dishes got to residual and organic waste bins and toilets. Representation of potentially avoidable food waste distribution with embodied calorific value indicated that highest portions of energy (more than 2 million GJ annually) was wasted with bakery products (in residual and organic bins and pets/animals) and cooked dishes (residual and organic bins) (Table 2). They were followed

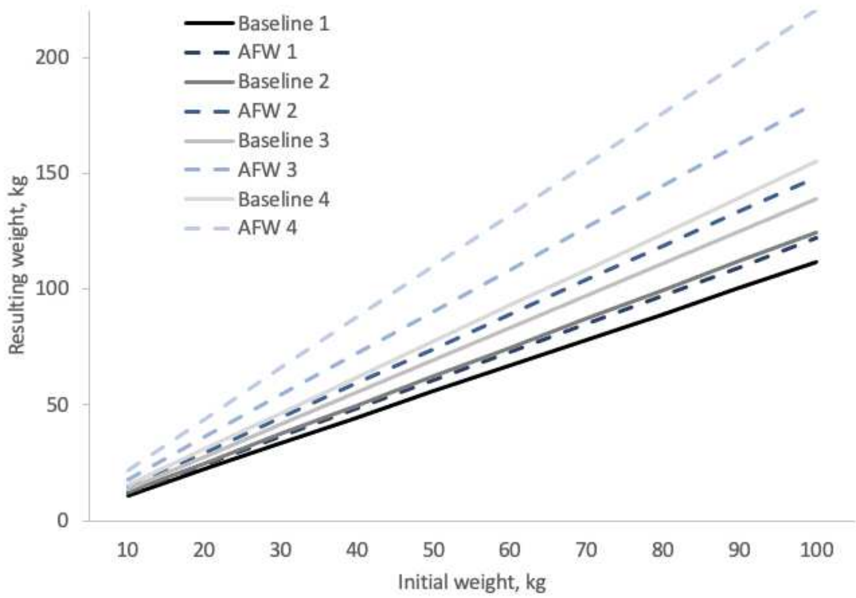

Fig. 1 Weight gain model of a person in a four-year period, baseline scenarios include current rate of calorific consumption (3500 kcal daily per capita), AFW – avoided food waste scenarios additionally include calories from potentially eatable food waste at household level (350 kcal); 1-4 – years of relevant diet; model based on [68]

by fresh meat/fish, processed convenience foods and dairy products dumped in residual waste bins with values close to 2 million GJ annually. Similar energy amount went through the toilet with wasted dairy products. Somewhat lower amount of energy (around 1 million GJ for each product category) ended up with fresh fruits, vegetables and meat/fish, and processed convenience products in organic waste bins. Similar calorific values were allocated to wasted cooked dishes through toilets and other foods through residual waste bins.

Recalculation of wasted calorific energy per capita in Germany (Table 2) indicated the highest values allocated to wasted bakery products (around 174 MJ) followed by cooked dishes (about 108 MJ). Total energy per capita wasted with potentially avoidable waste in Germany is more than 128 000 kcal annually. Such amount of energy could transform in additional 6.29-13.6 kg of weight gain annually if consumed in addition to the current level of consumption. It should be noted that the current level of calorific load for German population could result in baseline weight gain in the range of 9.26-12.87 kg / annually (average 10.2 kg annually). Joined calorific impact of current level of food consumption with consumption of potentially avoidable food could result in tremendous weight gain in the range of 15.5-26.5 kg annually (Fig. 1).

On the other hand, waste treatment of avoidable food waste resulted in very diverse environmental impacts (Table 3).

Table 3 Environmental impact of treating avoidable food waste (annual values, GWP – global warming potential, ED – fossil energy demand, LU – land use, WF – water footprint)

Current waste treatment	GWP, kg CO_2eq	ED, MJ	LU, m^2a	WF, m^3
Residual waste (bin)	-184080600	-1453320000	-2993760	-816156000
Organic waste (bin)	-76622000	-19308193200	11531492431	-704697504
Compost	162921650	539400384	181920	-42541200
Toilets	6596856	18317759	32472	-13751472
Feed pets (animals)	192956000	9288000	339991200	18216
Other	25977726	-319747725	231640935	-30343336
Total	127749632	-20514254783	12100345198	-1607471296

Thus, average values of residual food waste incineration, available from literature, indicated a high level of avoided impact by producing energy (heat / electricity), which resulted in the overall positive environmental impact of all four categories. Anaerobic digestion applied to organic waste, similarly, resulted in the production of biogas, burned for energy purposes. This process allowed to "justify" organic waste treatment with positive impacts on the environment except for the category of land use, where it was responsible for more than one million ha lands occupied. Other waste treatment technologies had rather negative impact on the environment. Composting was the most impacting treatment technology applied to avoidable food waste in terms of energy demand for the total amount of waste treated (around 539 million MJ). Feeding of pets (animals) had the highest contributions in global warming potential (more than 190 000 ton of CO_2eq.), land use (around 34 000 ha) and water footprint (about 18 000 m^3). Cumulated results on treatment of avoidable food waste resulted in positive environmental impacts for energy demand and water footprint and negative for global warming potential and land use.

Identifying the potential connection between excessive food consumed and environmental impact of such metabolic waste required the estimation of the current allocation of German healthcare resources to the treatment of overweight and obesity-related conditions. It was possible through relation to the literature resources [75–77] and assumptions on the applicability of defined healthcare resources for treating conditions related to overweight and obesity [70, 86, 87]. German healthcare system therefore was responsible for more than 60 million tons of CO_2eq. of GHG emitted; 1.6 billion GJ of energy used; 265 000 km^2 of land used; and 1.3 km^3 water depleted (Table 4). Such massive amounts were in the range of values reported in the literature for other countries [71, 72, 74]. Considering high levels of overweight and obesity in Germany [88] , 5% of healthcare resources can be allocated to the current treatment of overweight and obesity-associated conditions. Interesting that environmental impact of healthcare allocated to overweight and obesity-related activities was much lower than the metabolic waste [89, 65] calculated for the German population for carbon water footprints and higher for land use.

Table 4 Environmental impact of German healthcare (HC) system and share of impact associated with treatment of overweight and obesity related conditions (reference year 2017, annual values, GWP – global warming potential, ED – fossil energy demand, LU – land use, WF – water footprint)

	GWP, ktons CO_2eq	ED, TJ	LU, km^2a	WF, km^3
Total impact German HC	60,919	1,639,399	265,003	1.325
5% of impact associated with overweight and obese treatment	3,046	81,970	13,250	0.066
Scenario (plus 1%)	609	16,394	2,650	0.013
Scenario (plus 4%)	2,437	65,576	10,600	0.053
Metabolic waste of German population*	10,723,874	n/a	175	15,151.0
Potential increase in metabolic waste (plus 1% scenario) *	2,144,775	n/a	35	3,030.4

Note: * - calculated after [65]

Increasing Body Mass Index of German population [88] with additional 15.5-26.5 kg of weight gain per person annually (on average 10.2 kg due to current rate of overconsumption and 9.0 kg due to potential consumption of avoided food waste) indicated a rapid shift of German population, including undernourished part (1.8%) to extreme obesity and overweight rates from 18.1% to 54.0-65.4% and 35.9% to 22.05% respectively. In the case of even consumption by the entire German population of potentially avoidable food waste, the overweight and obesity rates would reach 76-95% within 3-4 years. Such a rapid weight gain is associated with additional calories gained through consumption of potentially avoided food waste (plus 350 kcal daily) and existing overconsumption of calories (around 500 kcal daily).

Such rapid increase in obesity rates was assumed to increase demand for healthcare resources in the scope of 1% (conservative case) to 4% (extreme case). According to the results from the population based KORA studies in Germany, the direct and indirect healthcare cost with increasing obesity varied from factor 1 to 4 [90]. Therefore, human consumption of potentially avoidable food waste could result in additional environmental impacts: 0.6-2.4 Mtonnes CO_2eq. for global warming potential; 16-66 million GJ for energy consumption; 2650-10600 km^2 for land use; 13.2-53.0 million m^3 for water footprint (Table 4). The comparison of environmental impacts of treating the avoidable food waste with current waste treatment technologies versus consuming it by Germany's population indicated that current waste treatment technologies were more beneficial for the environment in categories of global warming potential, energy demand, and water footprint (Table 5). Consuming potentially avoidable food waste by German population would result in increased GHG emissions (additional 0.48-2.3 million tonnes CO_2eq.), energy use (additional 36.9-86.1 million GJ) and water depletion (additional 1.62-1.66 billion m^3). At the same time, conventional waste treatment requires 1.14-4.57 times more land resources when treating potentially avoidable food waste at the end of the chain (Table 5).

It is to highlight that the above calculations are made under the quite strict

Table 5 Environmental impact of treating potentially avoidable food waste with current treatment technologies in comparison with human consumption in Germany (reference year 2017, annual values, GWP – global warming potential, ED – fossil energy demand, LU – land use, WF – water footprint)

	GWP, tonnes CO_2eq	**ED, GJ**	**LU, km^{2}a**	**WF, m^3**
Current waste treatment	127750	-20514255	12100	-1607471296
Consume and gain weight (LOW)	609192	16393991	2650	13250143
Consume and gain weight (HIGH)	2436770	65575963	10600	53000572

assumption that all excessive food is eaten (plate-clearing). It is unknown, how intense this strategy is used under real conditions if e.g., communication measures (e.g., in canteens, schools, media) are launched with the aim to point out the food waste problem. Research suggests that such a trigger could lead to an increase of this consumer behavior, but it is unclear to what extent this strategy is used in comparison to other more efficient strategies in such a situation. Nonetheless, by focusing only on the two analyzed food avoidance strategies the superiority of waste treatment compared to plate-clearing behavior could be demonstrated.

4 Discussion

The results on the weight gain calculated for the German population, correspond well to the models and recommendations on the dietary approaches presented in literature [91, 92]. Moreover, the results of the current study correspond well to the findings of studies, dealing with the assessment of food system environmental impacts. Thus, several studies indicate the impact of Germany's whole food system in the range of 85-260 Mtonnes CO_2eq.; 38 million ha of agricultural lands, and 3727 PJ of cumulative energy expenditure [17]. Mentioned study indicated that if environmental impact were allocated to waste by mass, all agri-food waste in Germany would be responsible for 8 million ha of land use (current study 1.2 million ha for the treated avoidable food waste) and 33 million tonnes of CO_2eq. (current study 0.128 million tonnes CO_2eq. for the treated avoidable food waste). The analysis of environmental impact of reducing overweight and obesity rates based on data from 150 countries, concluded that a complete normalization among all individuals with excess weight would reduce GHG emission by 10% to 15% [93]. At the same time the study [17] indicates the negative impact of food waste on energy demand (733 PJ). In contrast, with treatment of waste, our study demonstrated the possibility to avoid such impact. Another study indicated that utilization of avoidable food waste from complete value chain in Germany could save 2.6 million ha and 21.8 million tonnes CO_2eq. [15]. The impacts of potentially avoidable food waste (without treatment) are much higher than those with waste treatment. At the same time, avoiding food waste by consuming extra portion does not seem to be a good strategy. With high severity of weight gain, the annual impact of potentially avoidable food waste consumption by German population could result in as high environmental impact as those of wasting avoidable food waste without treatment (2.4 million tonnes CO_2eq.; 65.6 PJ; 1.1 million ha and 53 km^3 of water depleted). Accumulation of avoidable food waste in fat tissues accumulates huge environmental impacts [89,65], but also increases risks of health problems and demand for health resources [86]. Due to such issues, it is not recommended to rely on consuming extra portion as a waste treatment technology for avoidable food waste management. Even, under the more realistic assumption, that plate-clearing in only one out of several food waste avoidance strategies, the figures demonstrate impressively the disutility of this approach respectively consumer behavior. It is much better to apply waste treatment instead of plate-clearing when the focus is set only on this both options.

There are several points which should be thoroughly discussed before making the final conclusions in the study. First, it should be noted that there was an extreme lack of data and trustable studies, which can be used for calculations. Therefore, the study relied on number of approximations, based on the most recent published data.

The results of the study depend on the assumption on the overall amount of avoidable food waste at the end of the chain (at consumer or household level). The study relied on the value of around 7 Mtonnes as a basis value for overall avoidable food waste in Germany at the end of the chain [15]. Other sources approximate indicate the values of around 4 Mtonnes annually. However, a recent study revealed that the lowest value of 3.05 Mtonnes allocated to potentially avoidable food waste at household level [17]. Such reduction of waste treated would not change the proportional values of environmental impact. However, it could change the amount of weight gained annually to around 3.8 kg on average in the first four years. In this case the tendency to the rapid switch of German population to more overweight and obese options will not be observed within one year, but rather in 2-3 years, especially if current tendency for overconsumption would not change. In case of lower avoidable food waste consumed (3.05 MTonnes annually) the lower additional healthcare impact case is more applicable (1% additional impact).

The study also relied on the established distribution among food types and waste treatment routes in literature studies [17,19]. However, the studies do not give the complete distribution image within groups. In some cases, it was possible to estimate to approximate composition of fresh fruits, vegetables and bakery products [19]. In other cases, additional calculations and sources were used. For meat products, the distribution of wastes was assumed according to the consumption distribution [94], where 60% were pork products, 21% poultry, 17% beef and veal, 2% other meats. Similarly, fish products were allocated according to the consumption rates: 60% sea fish (Alaska pollock 18.4%, Herring 13.6%, Salmon 15.4%, Tuna fish 14.4%, Pangasius 5%), 27.8% freshwater

fish and 7.4% shrimps [95], with total consumption of 14.1 kg per capita[96]. Following average values were set up as the basis for calorific content of 1 kg of food waste: fresh fruits – 2.5 MJ; fresh vegetables – 1.6; fresh meat/fish – 13.1 MJ; dairy – 7.5 MJ; bakery – 14 MJ; processed foods – 7.4 MJ; beverages – 1.3 MJ; cooked dishes – 7.4 MJ; other foods – 5.7 MJ. As part of sensitivity analysis, all the values were increased and decreased by 10%. 10% increase in energy content respectively increased the number of calories which could be consumed and increased potential amount of fat by 15.7 kg per capita. 10% decrease of energy content would reduce the potential amount of fat to 12.8 kg per capita. Even though such changes are quite considerable, they do not change the overall conclusions about the shift of BMI indices.
Food waste was also assumed to be treated with specific technologies such as incineration for residual waste, anaerobic digestion for organic waste, composing, and wastewater treatment for toilet dumped wastes. While such distribution reflects the waste treatment distribution in Germany [19], each of the specific technologies has quite a variation of cases and scales. To account for those current study relied on several LCA studies performed for relevant treatment technologies on food waste. Up to the authors' best knowledge currently, there is no systemized avoidable food waste treatment study, which could more precisely reflect on the impacts. Moreover, sensitivity analysis, which included a check for the change of results by ±10% did not demonstrate considerable changes, which could affect conclusions.
The most crucial assumption in the study was associated with the allocation of 5% of healthcare system impacts to treating overweight and obesity-related conditions [84]. While such assumption was based on the single publication, it was backed up by other publications, which estimated the real cost of overweight and obesity. Thus, a study performed for Germany indicated that 3.27% of healthcare resources in 2008 were allocated to the treatment of overweight and obesity-related issues [86]. Application of this value in our study did not change the relative conclusions (higher impact for avoidable food waste consumptions by humans in GWP, ED, WF; and lower for LU). Considering complete life cycle perspective, the overweight and obesity states was responsible for 1-2% of GDP (equal to around 17% of healthcare resources) [87].
Similarly, such values neither changed the relative results of our study. There is a great variety of studies indicating approximate values to the one chosen for the current study. Despite the robustness of our research results, it is still necessary to highlight the need for more precise analyses of the environmental impact of the German healthcare system. Moreover, more studies are needed to define the allocation of healthcare resources more accurately to the treatment of overweight and obesity conditions in Germany and other countries. Similar study argues that over-nutrition - the consumption of food beyond that which is necessary can be regard as food waste. In this study, the quantity of food hidden in over-nutrition to create overweight and obese Italians is estimated by calculating the total excess calories consumed by overweight and obese people that is corresponding to 2.67 trillion kcal per year. By converting this value into food quantity based on a typical Italian diet, it was estimated

that 2.28 million tons of food is wasted annually. This figure is comparable to the quantity of food waste generated at the household level, as estimated by previous research quantifying food waste, thus confirming that policies focused on the promotion of sustainable consumption styles are crucial to address both the challenges of food waste and unhealthy food styles as it generates the same economic, social and environment impact as does food waste along the different stages of food chain [97].
Current study also has some limitations, mostly connected with several factors affecting human metabolism (and weight gain) through increased activities (sport) or uneven distribution of food energy within the population. Further studies should consider these factors. Even with such limitations, the study achieved defining the best of two options: waste food, not eat.
The study results are not aimed to argue the priority of waste management hierarchy to avoid overproduction (and thus wasting or overconsumption) [26, 98]. However, they revealed that in specific cases (overweight population), it is better to treat food waste with existing waste treatment methods than reuse (consumption of excessive amount) from environmental perspective. The results of the study are relevant for the populations with high levels of produced avoidable food waste at household level and high overweight and obesity rates. It does not allow for a simple universal answer on the selection of more sustainable strategies of dealing with excessive amount of food for all the cases (countries). However, the study indicates preferable conditions for dealing with excessive food in model conditions, which account for the health state of household members or groups of people
(population), nutrient density and amount of food, and timeframe. Time factor is one of the key factors defining preferences for food-wasting or consumption. Furthermore, the findings of this study suggest that policy had to create a food environment in which plate-clearing would no longer constitute a maladaptive behavior. Despite benefits for the environment, this could induce widespread reductions in food intake. As mentioned, there is a research gap concerning consumer studies with focus on plate-clearing behavior in the context of food waste concerns. Such studies should measure on a representative level the extent of this behavior in a population and how individuals react to different food waste avoidance campaigns/measures. It is to hypothesize that certain well-intentioned measures and policy campaigns represent triggers for an undesirable plate-clearing behavior. Research has to identify effective measures without causing this side effect.

5 Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

6 Author Contributions

SMS, VH contributed conception and design of the study; SMS performed literature review and data analysis, SMS, AP wrote the first draft of the manuscript; VH, AB performed manuscript proofreading and editing. All authors contributed to manuscript revision, read and approved the submitted version.

7 Acknowledgments

The authors acknowledge the support of DIL e.V. (German Institute of Food Technologies) for the implementation of the study.

8 Data Availability Statement

The raw data supporting the conclusions of this manuscript will be made available by the authors, without undue reservation, to any qualified researcher.

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Figures

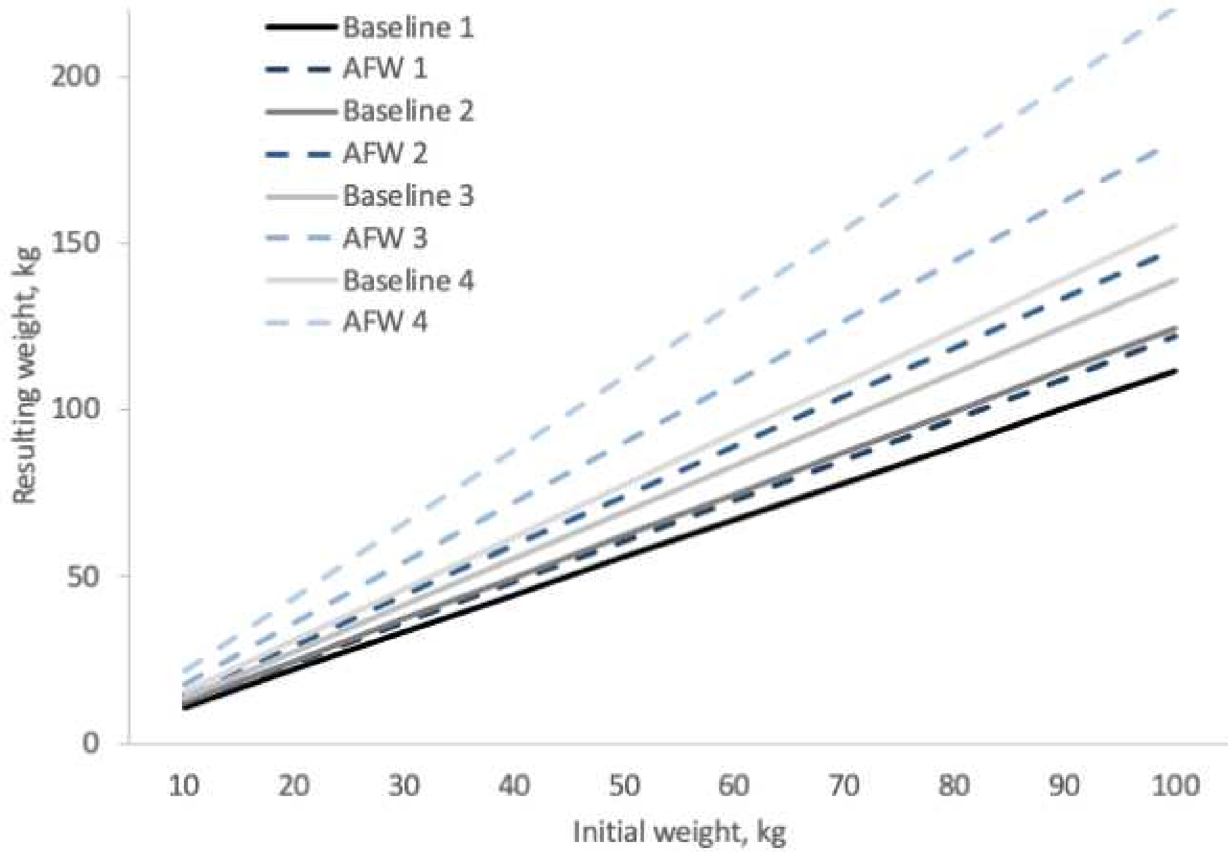

Figure 1

Weight gain model of a person in a four-year period, baseline scenarios include current rate of calorific consumption (3500 kcal daily per capita), AFW – avoided food waste scenarios additionally include calories from potentially eatable food waste at household level (350 kcal); 1-4 – years of relevant diet; model based on [68]