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Food Waste in Healthcare, Business and Hospitality Catering: Composition, Environmental Impacts and Reduction Potential on Company and National Levels

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Abstract: Background: As the reduction of food wastage remains one of our most critical challenges, we quantified the environmental impacts of food losses in the food-service sector in Germany, with a particular focus on the subsectors of business, healthcare and hospitality. Methods: Using the food-waste data of 7 catering companies, 1545 measurement days and 489,185 served meals during two 4–6 week monitoring periods, a life-cycle assessment (LCA) according to ISO standard 14040/44 was conducted. Within the LCA, the carbon, water (blue) and land footprints, and the ecological scarcity in terms of eco-points, were calculated. Results: We show that the waste generated in the food-service sector in Germany is responsible for greenhouse gas emissions of 4.9 million tons CO2-equivalents (CO2e), a water use of 103,057 m^3 and a land demand of 322,838 ha, equating to a total of 278 billion eco-points per year. Subsector-specifically, in hospitality catering: 1 kg of food waste accounts for 3.4 kg CO2e, 61.1 L water and 2.6 m^2 land (208 eco-points); in healthcare: 2.9 kg CO2e, 48.4 L and 1.9 m^2 land (150 eco-points); and in business: 2.3 kg CO2e, 72 L water and 1.0–1.4 m^2 land (109–141 eco-points). Meal-specifically, the environmental footprints vary between 1.5 and 8.0 kg CO2e, 23.2–226.1 L water and 0.3–7.1 m^2 per kg food waste. Conclusions: If robust food waste management schemes are implemented in the near future and take the waste-reduction potential in the food-service sector into account, Target 12.3 of the United Nation's Sustainable Development Goals—which calls for halving food waste by 2030—is within reach.

Keywords: food losses; wastage; life-cycle assessment; LCA; carbon footprint; water footprint; land footprint; ecological scarcity, food-service

1. Introduction

Establishing a valid monitoring architecture to diminish the amount of food wasted across the food sector is one of our most pressing challenges today. Although political, for-profit and nonprofit institutions have defined reduction targets on several levels [1–4] prevailing settings in the single consumer market (food retail) and food-service sector (out-of-home market) do not adequately prioritize or even hinder the systematic reduction of food losses and wastage [5–8]. Therefore, to overcome this challenge in the EU-27, the directive 2019/2000 set into force the "Guidance on reporting of data on food waste and food waste prevention". Based on the Waste Framework Directive (2008/98/EC) the guidance should support member countries in establishing an annual reporting obligation on food-waste generation as of reference year 2020 [9].

To meet this task, the Federal Ministry of Food and Agriculture (BMEL) of Germany implemented five multi-stakeholder dialog forums to discuss and pass appropriate measures to monitor, validate and finally reduce food wastage. The five dialog forums are as follows: #1 agricultural primary production, #2 food processing, #3 wholesale and retail, #4 food-service, and #5 households/consumers [10]. The goal of all dialog forums is to define sector- and subsector-specific guidelines that allow a feasible, continued and quantitative measurement of food waste in practice. In this study, the results of the dialog forum #4 dealing with the food-service sector are presented. In particular, we focus on participating companies that conducted a systematic waste monitoring (during four to six weeks) at the beginning of the project, identified waste hotspots, took measures to reduce their waste and conducted a final measurement (another four to six weeks) to quantify the savings. A further element involved accounting for the environmental impacts of the wasted food and the achieved savings using a life-cycle-assessment (LCA) approach. Hence, the goals of our study are as follows:

- To quantify the environmental impacts of food waste in terms of greenhouse gas emissions, blue water use, land use and eco-points in different food-service subsectors (business catering, healthcare catering and hospitality (hotels/restaurants));
- To quantify corresponding changes after measures have been implemented;
- To quantify the impacts using general waste-composition data vs. meal-specific waste-composition data;
- Compare different datasets regarding the food-waste composition and extrapolate to the national level.

2. Materials and Methods

2.1. Definition of Food Wastage

Not only from a conceptual, but also from a policy point of view, a distinction is made between food loss and food waste. According to FAO [1], these can be defined as:

- Food loss is the decrease in the quantity or quality of food resulting from decisions and actions by food suppliers in the chain, excluding retail, food-service providers and consumers.
- Food waste is the decrease in the quantity or quality of food resulting from decisions and actions by retailers, food-services and consumers.

Further, on both levels a distinction is made between "avoidable/edible" and "not avoidable" food loss and waste. However, depending on the cultural context, the differences between the two can be seamless.

2.2. Scope of the Study

Seven catering companies were involved in the project (3 business, 3 healthcare, and 1 hospitality), comprising 24 measurement locations (central kitchens, dining rooms and stationary serving areas), which recorded their food-waste totals on 1545 measurement days (759 in the first and 786 in the second period). A full list of the participating companies can be found in the supplementary material. Whereas the lunch was solely included in the business-sector assessment, the hospitality sector also included breakfast, while in the healthcare sector, breakfast, lunch and supper were monitored (Figure 1).

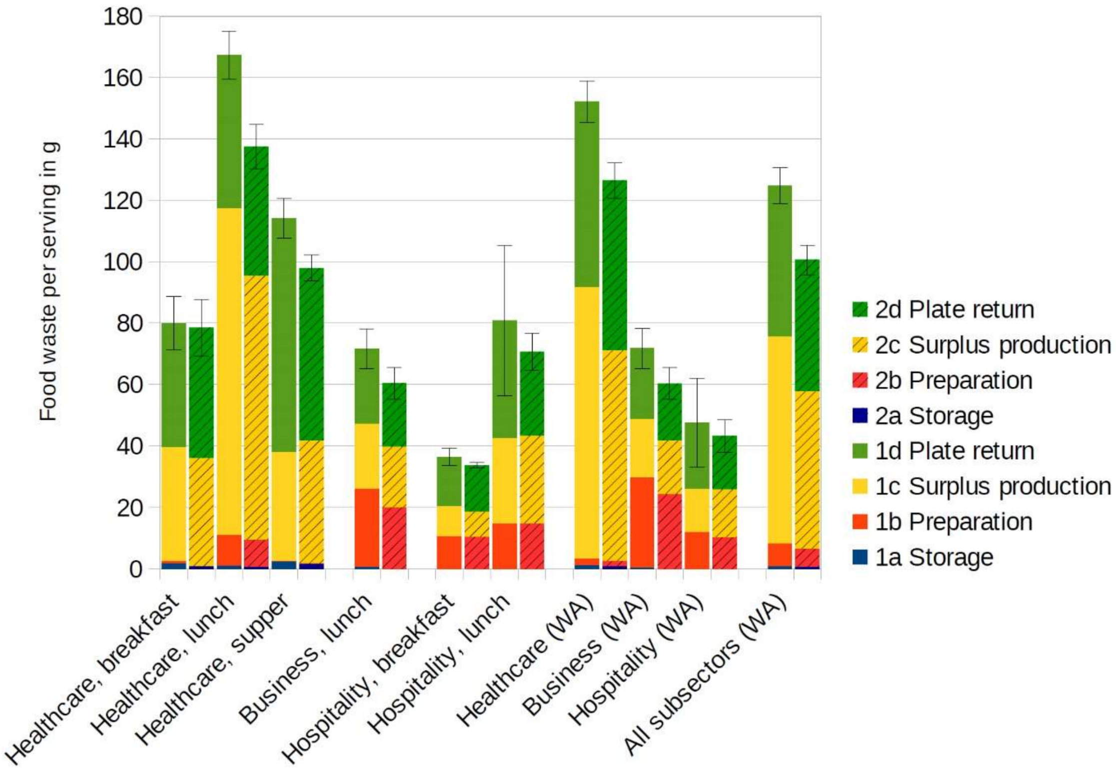

Figure 1. Food-waste quantities per serving recorded by the catering companies during the first (1) and second (2) monitoring periods. The whiskers reflect the 95% confidence interval (95% CI). WA = weighted average.

The food waste generated by these companies was collected daily and sorted into four transparent collection containers. These containers represent the following kitchen processes: (i) waste from storage by expiration of the best-before date, (ii) preparation waste during processing (peeling of carrots, etc.), (iii) surplus production and (iv) plate return. The waste volumes of the four containers were separately weighed and documented daily. Then, the daily results and the number of produced dishes were transferred to the online-based waste-analysis tool [11]. Coffee and tea residues as well as oil waste (grease traps) were not collected in this project. Whereas the first measurement period was conducted in the year 2019, the second measurement period covered 2019 and 2020—depending on the participating partner, both study periods lasted from four to six weeks.

2.3. Data Sources, Data Harmonization and Calculation

As the individual food components (amount of pasta, rice, carrots, meat, etc. in the waste) were not monitored in this project, representative sector-specific composition data was used from UAW [11] and Leanpath [12].

2.3.1. Average Composition of Food Waste

The data from UAW [11] was generated on the basis of 269 measurement periods in different business restaurants in Germany. The data from Leanpath [12] is based upon 487,000 measurements across Europe (EU14 + Norway) in the business-catering sector (corporate dining, B&I), in healthcare catering and hospitality catering (hotels, restaurants) in 2019. The composition of these standard wastes by sector and food components is shown in Figure 2 (Section 3).

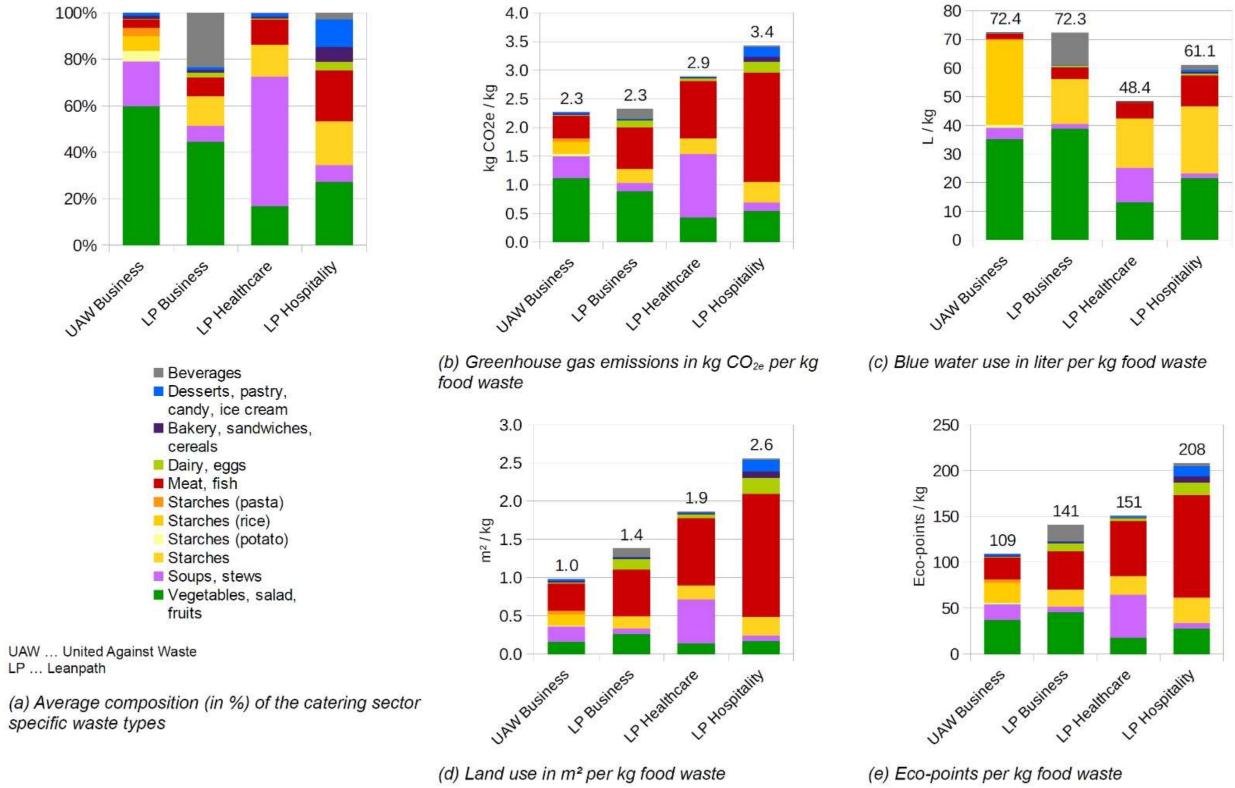

Figure 2. Average composition (**a**) and environmental burdens of catering-sector-specific food waste—greenhouse gas emissions (**b**), blue water use (**c**), land use (**d**), and eco-points (overall environmental indicator) (**e**).

2.3.2. Data Harmonization

To ensure the comparability of the different data sets provided from UAW and Leanpath and proper matching with corresponding LCA processes (see Section 2.4), a data segregation and aggregation process was conducted comprising 49 predefined allocation rules (see Supplementary material, Table S2). After harmonization of the data sets, the amounts of food waste and corresponding environmental impacts were calculated using the following formulas:

$$\overline{FW}_i = \sum_{i=3}^{n} FW(MP)_n / \sum_{i=3}^{n} m(MP)_n \quad (1)$$

where $\overline{FW}_i$ = food waste per serving (weighted average) in subsector i, $FW(MP)_n$ = total amount of food waste in monitoring period, and $m(MP)_n$ = number of served meals in monitoring period; and

$$EI_i = \overline{FW}_i \times EF_i \quad (2)$$

where EF_i = environmental factors (greenhouse gas (GHG) emissions, water use, land use, eco-points) per kg waste in subsectors i, and EI_i = environmental impacts of food waste in subsectors i.

2.4. *Life-Cycle-Assessment (LCA) Approach and System Boundaries*

In accordance with the ISO standard 14040/44 [13], life-cycle inventory data were calculated by attributive modeling and mass allocation. The system boundaries were defined in this project from cradle-to-fork, i.e., all environmental impacts along the food chain from the primary agricultural production and processing to the use of the products in the canteen kitchens, including transport, packaging and preparation, were considered.

Credits or additional environmental burdens from the recycling of food and packaging waste (in biogas or waste incineration plants, APOS modelling) were not included.

2.4.1. Functional Unit

As basis, 1 kg of food waste was set as the functional unit.

2.4.2. Greenhouse Gas Emissions (Carbon Footprint)

The accounting of the carbon footprint (greenhouse gas emissions) is based on the ISO standard 14067 [14], IPCC [15] and the greenhouse gas protocol [16]. Product-specific emissions from land use and land-use change were included based upon Blonk [17].

2.4.3. Water Footprint

The accounting of the water footprint is based on the ISO standard 14046 [18]. Accordingly, only blue water is considered. This includes water used in agriculture, food industry and gastronomy, which is used via channels and pipelines for watering animals, for irrigating vegetables in greenhouses and in open fields, for cleaning in the food industry or for cooking, etc. Green water (direct precipitation) and grey water (sewage) are not considered in the method.

2.4.4. Land Footprint

The accounting of the land footprint is based on statistically recorded yields (t/ha) on a three-year-average basis (2014–2016), which were converted into corresponding area factors (m^2/kg) [19,20]. A distinction is made between several types of land (arable land conventional/organic, grassland conventional/organic, permanent crops conventional/organic, forest area).

2.4.5. Overall Environmental Indicator: Environmental Impact Points (Eco-Points)

The method of ecological scarcity used here considers 15 different environmental indicators (emissions of CO2, CH4, N2O, NH3, NO, NMVOC, SO2, H2S, HCl, N-surplus, P-surplus, use of blue water, use of pesticides, primary energy demand and land use), reflecting different environmental impact indicators (Table 1). As 15 different environmental impacts cannot be communicated in a practicable way, these are weighted using the method of ecological scarcity [21]. To this end, indicator-specific environmental impact points (eco-points) were derived on the basis of official material flows (reference year 2010) and corresponding political targets in Germany. The carbon, water and land footprints are part of the overall indicator.

Table 1. Environmental indicators considered for the calculation of the environmental impact points (eco-points) and the subindicators of carbon footprint, water footprint and land footprint.

	Environmental Indicator	Effect	Footprint
1	CO_2 (Carbon dioxide) emissions	Greenhouse effect	Carbon footprint according to [14,17]
2	CH_4 (Methane) emissions	Greenhouse effect	
3	N_2O (Nitrous oxide) emissions	Greenhouse effect	
4	NH_3 (Ammonia) emissions	Acidification, air pollution, greenhouse effect, eutrophication (as NH_4^+)	
5	NO (Nitrogen monoxide) emissions	Air pollution, acidification	

Table 1. *Cont.*

	Environmental Indicator	Effect	Footprint
6	NMVOC (Non-methane volatile organic compounds) emissions	Air pollution, Ozone formation	
7	SO_2 (Sulfur dioxide) emissions	Acidification	
8	H_2S (Hydrogen sulfide) emissions	Acidification	
9	HCl (Hydrochloric acid) emissions	Acidification	
10	N-surplus from mineral and agricultural fertilisers	Eutrophication, Human toxicity	
11	P-surplus from mineral and agricultural fertilisers	Eutrophication	
12	Blue water demand	Water scarcity, Water stress	Water footprint according to ISO 14046 (2014) [18]
13	Pesticides (a.i.)	Human and ecotoxicity	
14	Primary energy consumption	Resource consumption/scarcity	
15	Area required (conventional, organic agriculture) - Arable land - Grassland - Permanent crop - Forest area - Industrial land	Resource consumption/scarcity, Biodiversity loss (loss of species)	Land footprint according to [19,20]

3. Results

3.1. Food-Waste Quantities in the First and Second Monitoring Periods

Table 2 gives an overview of the observed food-waste quantities per serving obtained during the first and second monitoring periods comprising the serving of 489,185 meals (247,539 in the first and 241,646 in the second). Depending on the catering subsector and the meal category (breakfast, lunch, supper), the food-waste reduction achieved variess between 1.8% (breakfast in the healthcare sector) and 17.9% (lunch in the healthcare sector).

Figure 1 shows that the largest waste reductions were realized in the following areas (in descending order): surplus production (–15.5 g per serving), plate return (–6.9 g per serving) and preparation (–1.4 g per serving). The achieved savings in storage was marginal (–0.3 g per serving). Overall, an average saving of 24.1 g of food waste per serving was realized (from 124.7 g to 100.6 g, –19.4%) after implementation measures were developed and executed following the first monitoring period.

3.2. Environmental Impacts of the Food Waste in the First and Second Monitoring Periods

Taking the average food-waste compositions into account, a life-cycle assessment (LCA) was conducted according to the methods described (Section 2). Although different composition data from different data providers was used for business catering in terms of greenhouse gas emissions (GHG) and blue water use, the results are almost equal (GHG: $UAW_{business}$ = 2.27 kg CO2e per kg waste, $LP_{business}$ = 2.32 kg CO2e per kg waste, water use: $UAW_{business}$ = 72.3 L per kg waste, $LP_{business}$ = 72.4 L per kg waste).

Table 2. Amounts of food waste per serving in g in the partner companies during the first and second monitoring periods and achieved reduction in % (incl. 95% CI).

	1. Monitoring Period					2. Monitoring Period					
	Measurement Days (n)	Meals Served	Food Waste Per Serving in g (Weighted Average) (95% CI)			Measurement Days (n)	Meals Served	Food Waste Per Serving in g (Weighted Average) (95% CI)			Reduction in %
Healthcare	635	165,898	**152.1**	145.4	158.9	645	150,708	**126.5**	120.7	132.3	**−16.9% ***
Breakfast	108	17,649	79.9	71.2	88.6	104	17,261	78.5	69.4	87.7	−1.8%
Lunch	445	129,522	167.5	159.6	175.3	457	117,180	137.5	130.3	144.7	−17.9%*
Supper	82	18,727	114.2	107.6	120.7	84	16,267	98.0	93.8	102.3	−14.1%*
Business	66	72,375	**71.8**	65.3	78.3	67	76,447	**60.4**	55.1	65.6	**−15.9%**
Lunch	66	72,375	71.8	65.3	78.3	67	76,447	60.4	55.1	65.6	−15.9%
Hospitality	58	9266	**47.5**	33	62.1	74	14,491	**43.2**	37.9	48.6	**−9.1%**
Breakfast	29	6948	36.4	33.6	39.3	42	12,865	33.6	32.8	34.5	−7.6%
Lunch	29	2318	80.9	55.7	106.1	32	3743	70.7	57.9	83.5	−12.5%
Sum	759	247,539				786	241,646				
Weighted average			**124.7**	118.9	130.6			**100.6**	95.7	105.5	**−19.4% ***

* Significant changes with $p < 0.05$ (95% confidence interval).

In terms of land use and eco-points, both business scenarios differ more, but corresponding impacts are still lower than the food waste generated in healthcare and hospitality catering. In terms of GHG, land use and eco-points, the highest environmental burden was observed for hospitality food waste. The lowest water footprint has the food waste generated in healthcare catering (Figure 2, Table 3).

Table 3. Setting-specific environmental impacts in different gastronomy sectors per kg food waste

	GHG Emissions in kg CO2e Per kg	Water (Blue) Use in L Per kg	Land Use in m^2 Per kg	Eco-Points Per kg
Business (UAW 2017) [22]	2.1	109.7	1.2	93.4
Business (UAW 2021)	2.3	72.4	1.0	108.9
Business (Leanpath 2020) [12]	2.3	72.3	1.4	140.9
Healthcare (Leanpath 2020) [12]	2.9	48.4	1.9	150.5
Hospitality (Leanpath 2020) [12]	3.4	61.1	2.6	208.0

Overall, five sector-specific food-waste compositions were distinguished:

- Business based on UAW [11]: first composition assessment used in Knöbel et al. [22].
- Business updated based on UAW [11], here referred as "UAW 2021": updated composition assessment used in this study. Whereas in Knöbel et al. [22] it was assumed that "vegetables, salad and fruits" are composed of 50% vegetables and 50% fruits, in this study we assumed a composition of 45% vegetables (cooked), 45% vegetables (fresh) and 10% fruits.
- Business based on Leanpath [12]: see Materials and Methods for further details.
- Healthcare based on Leanpath [12]: see Materials and Methods for further details.
- Hospitality based on Leanpath [12]: see Materials and Methods for further details.

3.2.1. Savings by Implementing Reduction Measures

In Table 4, the quantities of food waste documented in the participating companies and corresponding environmental impacts of the first and second monitoring periods are presented. The net difference indicates that overall 5.1 tons of food waste could be saved (−16.4%)—equaling 14.4 tons of GHG, 268.4 m^3 water and roughly 9.1 ha of agricultural land, summing up in 0.8 million avoided eco-points.

Table 4. Sum of food waste and environmental impacts in the first and second monitoring periods (meal-number adjusted).

	1. Monitoring (A)					**2. Monitoring (B)**					**2. Monitoring (Meal Adjusted) (C)**					**Net Difference C–A (Savings)**				
	Food Waste	**GHG Emissions**	**Water Use**	**Land Use**	**Eco-Points**	**Food Waste**	**GHG Emissions**	**Water Use**	**Land Use**	**Eco-Points**	**Food Waste**	**GHG Emissions**	**Water Use**	**Land Use**	**Eco-Points**	**Food Waste**	**GHG Emissions**	**Water Use**	**Land Use**	**Eco-Points**
	in t	**in t CO_2e**	**in m^3**	**in m^2**	**in million**	**in t**	**in t CO_2e**	**in m^3**	**in m^2**	**in million**	**in t**	**in t CO_2e**	**in m^3**	**in m^2**	**in million**	**in t**	**in t CO_2e**	**in m^3**	**in m^2**	**in million**
UAW 2017																				
… Business	5.2	11.2	570.1	6194	0.485	4.6	9.9	506.3	5501	0.431	4.4	9.4	479.3	5208	0.408	−0.8	−1.8	−90.8	−987	−0.077
UAW 2021																				
… Business	5.2	11.8	376.5	5077	0.566	4.6	10.5	334.3	4509	0.503	4.4	9.9	316.5	4269	0.476	−0.8	−1.9	−60.0	−809	−0.090
Leanpath 2020																				
… Business	5.2	12.1	375.5	7186	0.732	4.6	10.7	333.4	6381	0.65	4.4	10.1	315.7	6041	0.616	−0.8	−1.9	−59.8	−1145	−0.117
… Healthcare	25.2	73	1222.9	46983	3.8	19.1	55.1	923.6	35486	2.87	21	60.7	1016.7	39063	3.159	−4.2	−12.3	−206.2	−7920	−0.641
… Hospitality	0.4	1.5	26.9	1127	0.092	0.6	2.1	38.3	1603	0.13	0.4	1.4	24.5	1025	0.083	−0.04	−0.1	−2.4	−102	−0.008
SUM (based on LP 2020)	**30.9**	**86.6**	**1625.3**	**55296**	**4.624**	**24.3**	**68**	**1295.3**	**43470**	**3.65**	**25.8**	**72.2**	**1356.9**	**46129**	**3.858**	**−5.1**	**−14.4**	**−268.4**	**−9167**	**−0.766**
Overall reduction in % (C-A)																***−16.4%***	***−16.6%***	***−16.5%***	***−16.6%***	***−16.6%***

To avoid the bias due to different meal numbers, for the calculation of the net difference for the second monitoring period, the same serving numbers as for the first monitoring period were applied. The highest absolute (−4.2 tons of food waste) and relative reduction (−16.7%) amounts were achieved in the healthcare sector.

3.2.2. Factor in Company-Specific Menu Plans

In order to calculate the environmental impacts of the achieved waste savings more site-specifically, the menu plans of the involved catering companies during the first monitoring period were considered. In the Supplementary material, Figures S1 and S2 give an example of a menu plan and how the dishes offered were matched with 21 corresponding predefined dish categories. Next, taking the different data sources from UAW [11] and LP [12] into account, corresponding environmental burdens per kg of food waste were calculated for the 21 waste-specific meal categories (Table 5). The underlying 84 food-waste compositions are presented in the Supplementary material (Figures S9–S12).

Table 5 shows that in terms of greenhouse gas emissions, the waste footprints vary between 1.5 kg CO2e per kg of waste (vegan dish in business catering based on potatoes) and 8.0 kg CO2e per kg of waste (dish based on beef and rice in the hospitality sector). In terms of blue water use, the waste-specific footprints vary between 23.2 l per kg of waste (vegetarian sweet dish in healthcare catering) and 226.1 l per kg of waste (vegan dish based on rice in the hospitality sector). The lowest land footprints (each 0.3 m^2 per kg of waste) show vegan dishes based on potatoes and dishes based on fish and potatoes in business catering. In terms of the overall environmental burden, the waste footprints vary between 50.2 eco-points per kg of waste (vegan dish in business catering based on potatoes) and 458.7 eco-points (dish based on beef and rice in the hospitality sector). Generally, it can be observed that dishes based on rice and dishes based on beef/veal, pork and poultry (in descending order) show the highest environmental waste footprints in terms of GHG, land use and eco-points. In terms of blue water use, vegan dishes show the highest water footprint.

Menu plans for the first monitoring period were provided from three participating catering companies (1x business, 2x healthcare). The comparison with the average setting-specific environmental burdens (Table 3) shows that in terms of GHG emissions, water and land use as well as eco-points, the menu plan of company #1 (business) results in lower impacts, whereas the waste footprint of company #3 (healthcare) has higher impacts than the average (Table 6). In the case of company #2, the menu plan has only little effect on the environmental burden of the food waste generated.

In a further step, the menu-plan-specific results were included in the extrapolation on the company level. Figure 3c reveals that, when taking into account this additional "menu plan" factor, in environmental terms the results varied between −30.4% (water use) and 11.8% (land use) when the menu-plan-adjusted impacts are compared against the non-adjusted set.

Table 5. Environmental impacts of the 21 dish-specific waste types (conventional agriculture).

		PPo	PPa	PR	BPo	BPa	BR	CPo	CPa	CR	FPo	FPa	FR	vPo	vPa	vR	vsPo	vsPa	vsR	v+Po	v+Pa	v+R
GHG emissions kg CO2e/kg	UAW business 2021	2.0	2.1	2.3	3.1	3.3	3.5	1.8	1.9	2.2	1.7	1.8	2.1	1.8	1.9	2.1	2.0	2.1	2.3	1.5	1.7	2.0
	LP business 2020	2.1	2.3	2.4	3.8	3.9	4.1	1.8	2.0	2.1	1.7	1.8	2.0	2.0	2.1	2.3	1.7	1.8	2.0	1.6	1.7	1.9
	LP healthcare 2020	2.6	2.7	2.9	5.8	5.9	6.1	2.1	2.2	2.4	1.8	1.9	2.1	2.1	2.2	2.4	2.3	2.4	2.6	1.5	1.7	1.9
	LP hospitality 2020	3.2	3.3	3.6	7.5	7.7	8.0	2.4	2.6	2.9	2.1	2.2	2.5	2.9	3.0	3.3	1.9	2.1	2.3	1.7	1.8	2.1
Water (blue) use in l/kg	UAW business 2021	43.9	43.0	108.2	48.3	47.4	112.6	42.9	42.0	107.2	43.8	42.9	108.1	42.5	41.5	106.7	41.3	40.3	105.5	42.2	44.1	109.3
	LP business 2020	58.3	57.5	113.8	65.0	64.2	120.5	57.3	56.5	112.8	58.4	57.6	113.9	57.0	56.2	112.5	55.2	54.4	110.7	120.1	119.3	175.6
	LP healthcare 2020	32.9	32.1	93.4	45.3	44.4	105.7	30.1	29.2	90.5	32.5	31.7	93.0	29.1	28.3	89.6	24.0	23.2	84.5	58.0	57.2	118.5
	LP hospitality 2020	39.8	38.6	121.9	57.4	56.3	139.6	36.8	35.6	118.9	40.2	39.0	122.3	37.1	35.9	119.2	32.7	31.6	107.8	143.9	142.8	226.1
Land use m^2/kg	UAW business 2021	0.7	0.9	1.0	1.9	2.0	2.2	0.6	0.7	0.9	0.3	0.5	0.6	0.6	0.8	0.9	0.9	1.0	1.2	0.3	0.4	0.6
	LP business 2020	1.3	1.4	1.5	2.9	3.0	3.1	1.0	1.1	1.3	0.6	0.8	0.9	1.2	1.3	1.5	0.9	1.0	1.1	0.8	1.0	1.1
	LP healthcare 2020	1.6	1.8	1.9	4.8	4.9	5.1	1.2	1.3	1.5	0.4	0.6	0.7	1.3	1.5	1.6	1.5	1.7	1.8	0.6	0.7	0.8
	LP hospitality 2020	2.4	2.6	2.8	6.7	6.9	7.1	1.8	2.0	2.2	0.8	1.0	1.2	2.5	2.7	2.9	1.3	1.5	1.6	1.3	1.4	1.6

Table 5. *Cont.*

		PPo	PPa	PR	BPo	BPa	BR	CPo	CPa	CR	FPo	FPa	FR	vPo	vPa	vR	vsPo	vsPa	vsR	v+Po	v+Pa	v+R
Eco-points per kg	UAW business 2021	85.6	94.7	128.7	140.3	149.3	183.3	76.1	85.1	119.1	58.8	67.8	101.8	74.7	83.7	117.7	87.1	96.1	130.1	50.2	65.4	99.4
	LP business 2020	132.4	140.2	169.6	209.5	217.3	246.7	114.6	122.4	151.8	90.5	98.3	127.7	120.1	127.9	157.3	98.9	106.7	136.1	109.2	117.0	146.4
	LP healthcare 2020	136.5	145.0	177.0	290.5	299.0	330.9	109.9	118.4	150.4	61.1	69.6	101.6	109.6	118.1	150.1	112.4	120.9	152.9	66.6	75.1	107.0
	LP hospitality 2020	204.2	215.7	259.2	403.7	415.3	458.7	159.4	171.0	214.5	93.5	105.1	148.5	179.3	190.8	234.3	108.8	120.3	160.1	125.3	136.8	180.3

Legend

BPa	Waste composition based on a dish with beef and pasta
BPo	Waste composition based on a dish with beef and potatoes
BR	Waste composition based on a dish with beef and rice
CPa	Waste composition based on a dish with chicken and pasta
CPo	Waste composition based on a dish with chicken and potatoes
CR	Waste composition based on a dish with chicken and rice
FPa	Waste composition based on a dish with fish and pasta
FPo	Waste composition based on a dish with fish and potatoes
FR	Waste composition based on a dish with fish and rice
PPa	Waste composition based on a dish with pork and pasta
PPo	Waste composition based on a dish with pork and potatoes
PR	Waste composition based on a dish with pork and rice
v+Pa	Waste composition based on a vegan dish with pasta
v+Po	Waste composition based on a vegan dish with potatoes
v+R	Waste composition based on a vegan dish with rice
vPa	Waste composition based on an ovo-lacto-vegetarian dish with pasta
vPo	Waste composition based on an ovo-lacto-vegetarian dish with potatoes
vR	Waste composition based on an ovo-lacto-vegetarian dish with rice
vsPa	Waste composition based on a sweet ovo-lacto-vegetarian dish with pasta
vsPo	Waste composition based on a sweet ovo-lacto-vegetarian dish with potatoes
vsR	Waste composition based on a sweet ovo-lacto-vegetarian dish with rice

Table 6. Menu-plan-specific environmental impacts of partner companies per kg food waste (4 weeks).

	GHG Emissions in kg CO2e Per kg	Water Use in L Per kg	Land Use in m^2 Per kg	Eco-Points Per kg
Company #1 (business)				
Based on UAW 2021	2.0	50.4	0.8	87.5
Based on Leanpath [12]	2.1	69.3	1.3	131.8
Company #2 (healthcare)				
Based on Leanpath [12]	2.9	39.3	2.0	150.2
Company #3 (healthcare)				
Based on Leanpath [12]	3.0	48.1	2.1	157.6

3.2.3. Extrapolation on National Level

Based on the so-called baseline analysis of food waste on the national level in Germany [23,24], an extrapolation of the environmental impacts was conducted. Figures 4 and 5 and Table 7 show that in the food-service sector, the largest amount of food waste accumulates in the hospitality subsector, followed by the business, healthcare and education subsectors, where the largest components are characterized as avoidable waste. Food waste occurring in prisons and in the armed forces is of minor relevance in this regard.

Table 7. Food-waste quantities in the food-service sector in Germany in 2015 (based on [23,24]). The uncertainty interval is based on waste coefficients from literature (see [24] for further details).

	Food Waste (t/a)			Avoidable Food Waste (t/a)		
	Mean	Lower	Upper	Mean	Lower	Upper
Business	**297,255**	244,133	350,376	**240,742**	176,318	305,166
Healthcare	**198,995**	198,995	198,995	**159,365**	159,365	159,365
Hospitality	**920,916**	865,390	976,442	**582,974**	550,121	615,827
Education	**190,873**	176,926	204,820	**181,736**	176,926	186,544
Armed forces	**7562**	6522	8601	**3857**	3326	4387
Prisons	**17,505**	17,505	17,505	**8971**	8971	8971
Sum	**1,633,106**	**1,509,471**	**1,756,739**	**1,177,645**	**1,075,027**	**1,280,260**
Avoidable share in %				72.10%	71.20%	72.90%

3.2.4. Greenhouse Gas Emissions, Blue Water Use, Land Use and Eco-Points of Food Waste on the National Level

Based on the subsector-specific environmental coefficients (Table 3) and the quantities obtained from the baseline analysis [24], GHG emissions stemming from the accumulation of food waste in the food-service sector add up to 4.9 million tons CO2e per year, with an avoidable share of 3.4 million tons CO2e (Figure 6, Table 8). In the context of the report of SAB-BMEL ([25], p. 234), which states that, "If avoidable waste were reduced, 2.6 to 3.2 million t CO2e could be saved [yearly in Germany in the food-service sector]", our extrapolated sum of 3.4 (3.2–3.7) million tons of avoidable CO2e is slightly higher. This is due to the fact that in this study, subsector-specific waste compositions could be used for the hospitality, business and healthcare subsectors for the first time. In terms of blue water use, the waste accumulating in the food-service sector causes a water withdrawal of 103,057 m^3, with an avoidable share of 74,857 m^3 (Figure 7, Table 9). In terms of land use, the waste accumulating in the food-service sector causes a land demand of 322,838 ha, with an avoidable share of 221,374 ha (Figure 8, Table 10). In terms of the overall environmental indicator of ecological scarcity, the waste accumulating in the food-service sector causes 278 billion eco-points, with an avoidable share of 193 billion eco-points (Figure 9, Table 11). As the average waste compositions in the subsectors of education, prisons and armed forces were not known, corresponding environmental impacts were conservatively extrapolated based on the UAW-business-coefficient (Table 3).

a) Sum of food waste and environmental impacts in 1. and 2. monitoring period in the companies, which provided menu plans for lunch

	1. monitoring (A)					2. monitoring (B)					2. monitoring (meal adjusted) (C)					Net difference C – A (Savings)				
	Food waste in t	GHG emissi-ons in t CO2e	Water use in m³	Land use in m²	Eco-points in million	Food waste in t	GHG emissi-ons in t CO2e	Water use in m³	Land use in m²	Eco-points in million	Food waste in t	GHG emissi-ons in t CO2e	Water use in m³	Land use in m²	Eco-points in million	Food waste in t	GHG emissi-ons in t CO2e	Water use in m³	Land use in m²	Eco-points in million
Company #1 (business)																				
... based on UAW 2021	2.1	4.7	150.0	2023	0.225	2.0	4.5	144.8	1953	0.218	1.8	4.1	132.2	1783	0.199	-0.2	-0.6	-17.8	-240	-0.027
... based on Leanpath 2020	2.1	4.8	149.6	2863	0.292	2.0	4.6	144.4	2764	0.282	1.8	4.2	131.8	2523	0.257	-0.2	-0.6	-17.8	-340	-0.035
Company #2 (healthcare)																				
... based on Leanpath 2020	17.4	50.4	844.1	32431	2.623	12.1	35.1	587.7	22580	1.826	14.2	41.0	687.0	26395	2.135	-3.2	-9.4	-157.1	-6036	-0.488
Company #3 (healthcare)																				
... based on Leanpath 2020	4.0	11.7	196.2	7537	0.610	3.9	11.2	187.0	7184	0.581	3.8	10.9	182.7	7020	0.568	-0.3	-0.8	-13.4	-516	-0.042
SUM (based on LP 2020)	**23.5**	**66.9**	**1189.9**	**42830**	**3.524**	**18.0**	**50.9**	**919.1**	**32527**	**2.689**	**19.8**	**56.1**	**1001.6**	**35938**	**2.960**	**-3.8**	**-10.7**	**-188.3**	**-6892**	**-0.565**
Overall reduction in % (C-A)																***-16.0%***	***-16.1%***	***-15.8%***	***-16.1%***	***-16.0%***

b) Sum of food waste in 1. and 2. monitoring period in the companies which provided menu plans for lunch (menu plan adjusted)

	1. monitoring (A)					2. monitoring (B)					2. monitoring (meal adjusted) (C)					Net difference C – A (Savings)				
	Food waste in t	GHG emissi-ons in t CO2e	Water use in m³	Land use in m²	Eco-points in million	Food waste in t	GHG emissi-ons in t CO2e	Water use in m³	Land use in m²	Eco-points in million	Food waste in t	GHG emissi-ons in t CO2e	Water use in m³	Land use in m²	Eco-points in million	Food waste in t	GHG emissi-ons in t CO2e	Water use in m³	Land use in m²	Eco-points in million
Company #1 (business)																				
... based on UAW 2021	2.1	4.2	104.4	1622	0.181	2.0	4.0	100.8	1566	0.175	1.8	3.7	92.0	1430	0.160	-0.2	-0.5	-12.4	-193	-0.022
... based on Leanpath 2020	2.1	4.4	143.5	2717	0.273	2.0	4.3	138.6	2623	0.263	1.8	3.9	126.5	2394	0.240	-0.2	-0.5	-17.0	-322	-0.032
Company #2 (healthcare)																				
... based on Leanpath 2020	17.4	51.1	684.1	34317	2.618	12.1	35.6	476.3	23893	1.823	14.2	41.6	556.8	27930	2.130	-3.2	-9.5	-127.3	-6387	-0.487
Company #3 (healthcare)																				
... based on Leanpath 2020	4.0	12.1	194.7	8430	0.638	3.9	11.6	185.6	8035	0.608	3.8	11.3	181.4	7852	0.594	-0.3	-0.8	-13.3	-577	-0.044
SUM (based on LP 2020)	**23.5**	**67.7**	**1022.3**	**45463**	**3.529**	**18.0**	**51.4**	**800.5**	**34551**	**2.694**	**19.8**	**56.8**	**864.6**	**38176**	**2.965**	**-3.8**	**-10.9**	**-157.7**	**-7287**	**-0.563**
Overall reduction in % (C-A)																***-16.0%***	***-16.1%***	***-15.4%***	***-16.0%***	***-16.0%***

c) Percental change ((b/a)-1)

	1. monitoring (A)					2. monitoring (B)					2. monitoring (meal adjusted) (C)					Net difference C – A (Savings)				
	Food waste	GHG emissi-ons	Water use	Land use	Eco-points	Food waste	GHG emissi-ons	Water use	Land use	Eco-points	Food waste	GHG emissi-ons	Water use	Land use	Eco-points	Food waste	GHG emissi-ons	Water use	Land use	Eco-points
Company #1 (business)																				
... based on UAW 2021	0.0%	-11.2%	-30.4%	-19.8%	-19.6%	0.0%	-11.2%	-30.4%	-19.8%	-19.6%	0.0%	-11.2%	-30.4%	-19.8%	-19.6%	0.0%	-11.2%	-30.4%	-19.8%	-19.6%
... based on Leanpath 2020	0.0%	-7.6%	-4.1%	-5.1%	-6.5%	0.0%	-7.6%	-4.1%	-5.1%	-6.5%	0.0%	-7.6%	-4.1%	-5.1%	-6.5%	0.0%	-7.6%	-4.1%	-5.1%	-6.5%
Company #2 (healthcare)																				
... based on Leanpath 2020	0.0%	1.5%	-19.0%	5.8%	-0.2%	0.0%	1.5%	-19.0%	5.8%	-0.2%	0.0%	1.5%	-19.0%	5.8%	-0.2%	0.0%	1.5%	-19.0%	5.8%	-0.2%
Company #3 (healthcare)																				
... based on Leanpath 2020	0.0%	3.6%	-0.7%	11.8%	4.7%	0.0%	3.6%	-0.7%	11.8%	4.7%	0.0%	3.6%	-0.7%	11.8%	4.7%	0.0%	3.6%	-0.7%	11.8%	4.7%
SUM (based on LP 2020)	0.0%	1.2%	-14.1%	6.1%	0.1%	0.0%	1.1%	-12.9%	6.2%	0.2%	0.0%	1.2%	-13.7%	6.2%	0.2%	0.0%	1.2%	-16.3%	5.7%	-0.2%

Figure 3. Sum of food waste and non-menu-plan-adjusted (**a**) vs. menu-plan-adjusted (**b**) environmental impacts, while (**c**) reflects the % changes between both scenario.

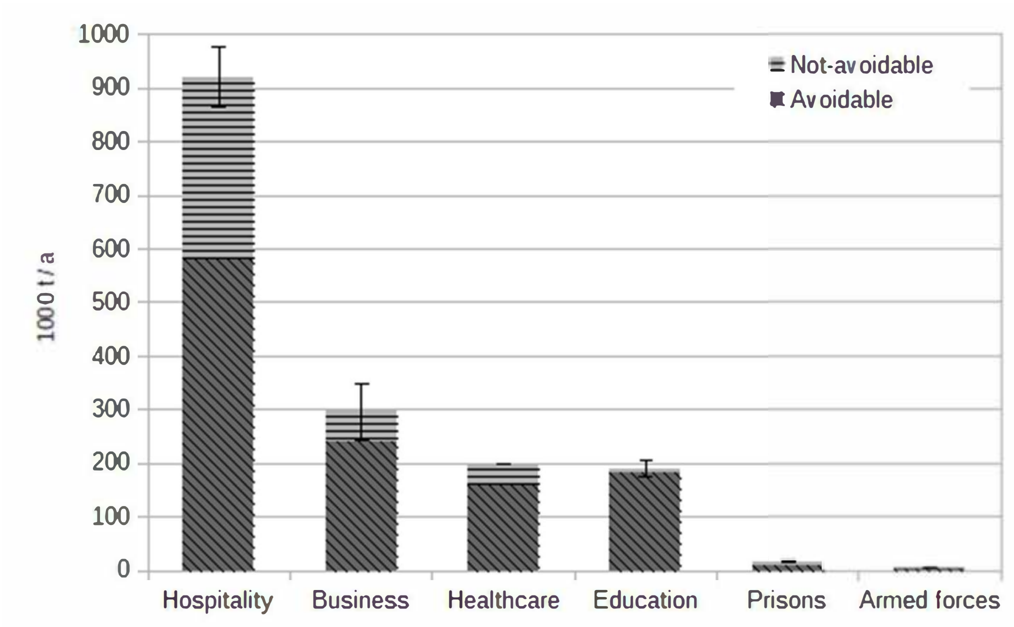

Figure 4. Food-waste quantities in the food-service sector in Germany in 2015 (based on [23,24]). The uncertainty interval is based on waste coefficients from literature (see [24] for further details).

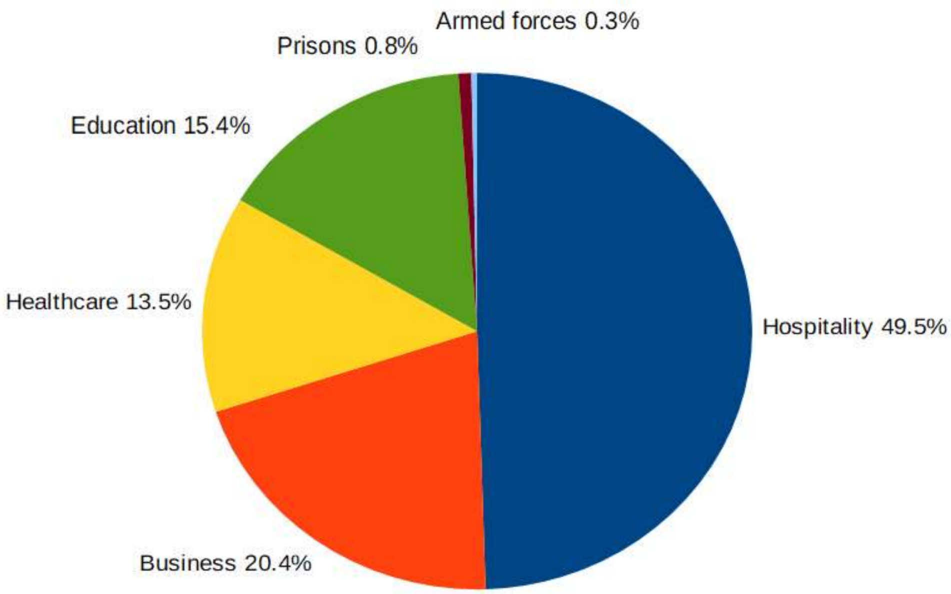

Figure 5. Shares of the food waste in subsectors in % of the food-service sector in Germany in 2015 (based on [23,24]).

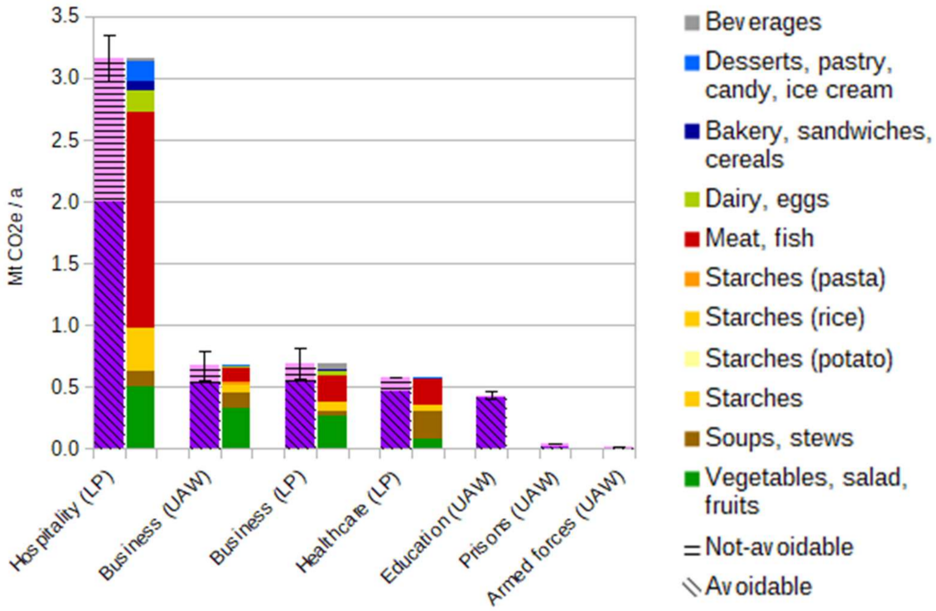

Figure 6. Greenhouse gas emissions in million t CO2e in 2015 stemming from food waste in the food-service sector in Germany. The subsectors of education, prisons and armed forces were calculated based on UAW 2021 for the business subsector.

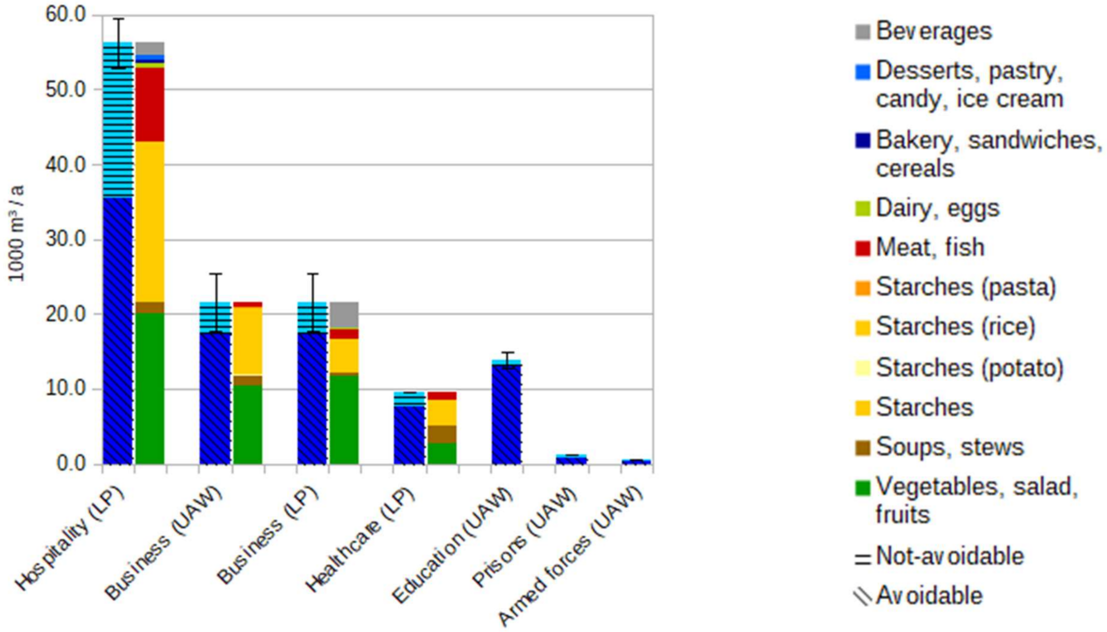

Figure 7. Water (blue) use in 1000 m^3 in 2015 stemming from food waste in the food-service sector in Germany. The subsectors of education, prisons and armed forces were calculated based on UAW 2021 for the business subsector.

Table 8. Total and avoidable greenhouse gas emissions in t CO2e in 2015 stemming from food waste in the food-service sector in Germany. The subsectors of education, prisons and armed forces were calculated based on UAW 2021 for the business subsector.

	GHG Emissions of Food Waste (t CO2e/a)			**Avoidable GHG Emissions of Food Waste (t CO2e/a)**		
	Mean	**Lower**	**Upper**	**Mean**	**Lower**	**Upper**
Business (based on UAW 2021)	**673,321**	552,993	793,647	**545,312**	399,383	691,240
Business (based on LP 2020)	**690,411**	567,029	813,791	**559,153**	409,520	708,786
Healthcare (based on LP 2020)	**575,352**	575,352	575,352	**460,770**	460,770	460,770
Hospitality (based on LP 2020)	**3,158,742**	2,968,288	3,349,196	**1,999,601**	1,886,915	2,112,287
Sum (based on UAW 2021, LP 2020)	**4,407,416**	4,096,633	4,718,196	**3,005,683**	2,747,069	3,264,298
Sum (based on LP 2020)	**4,424,506**	4,110,669	4,738,340	**3,019,525**	2,757,206	3,281,843
Education (based on UAW 2021)	**432,352**	400,760	463,944	**411,656**	400,760	422,546
Prisons (based on UAW 2021)	**39,651**	39,651	39,651	**20,320**	20,320	20,320
Armed forces (based on UAW 2021)	**17,129**	14,773	19,482	**8737**	7534	9937
Total sum (based on UAW 2021, LP 2020)	**4,896,548**	**4,551,818**	**5,241,273**	**3,446,396**	**3,175,683**	**3,717,102**

Table 9. Water (blue) use in m^3 in the year 2015 stemming from food waste in the food-service sector in Germany. The subsectors of education, prisons and armed forces were calculated based on UAW 2021 for the business subsector.

	Water (Blue) Use of Food Waste (m^3/a)			**Avoidable Water (Blue) Use of Food Waste (m^3/a)**		
	Mean	**Lower**	**Upper**	**Mean**	**Lower**	**Upper**
Business (based on UAW 2021)	**21,534**	17,686	25,382	**17,440**	12,773	22,107
Business (based on LP 2020)	**21,479**	17,641	25,318	**17,396**	12,740	22,051
Healthcare (based on LP 2020)	**9641**	9641	9641	**7721**	7721	7721
Hospitality (based on LP 2020)	**56,238**	52,847	59,629	**35,601**	33,595	37,607
Sum (based on UAW 2021 + LP 2020)	**87,413**	80,174	94,652	**60,762**	54,089	67,435
Sum (based on LP 2020)	**87,358**	80,129	94,588	**60,717**	54,056	67,379
Education (based on UAW 2021)	**13,827**	12,817	14,838	**13,166**	12,817	13,514
Prisons (based on UAW 2021)	**1268**	1268	1268	**650**	650	650
Armed forces (based on UAW 2021)	**548**	472	623	**279**	241	318
Total sum (based on UAW 2021, LP 2020)	**103,057**	**94,732**	**111,381**	**74,857**	**67,796**	**81,917**

Table 10. Land use in ha in 2015 stemming from food waste in the food-service sector in Germany. The subsectors of education, prisons and armed forces were calculated based on UAW 2021 for the business subsector.

	Land Use of Food Waste (ha/a)			**Avoidable Land Use of Food Waste (ha/a)**		
	Mean	**Lower**	**Upper**	**Mean**	**Lower**	**Upper**
Business (based on UAW 2021)	**29,044**	23,854	34,235	**23,523**	17,228	29,817
Business (based on LP 2020)	**41,104**	33,759	48,450	**33,290**	24,381	42,198
Healthcare (based on LP 2020)	**37,040**	37,040	37,040	**29,664**	29,664	29,664
Hospitality (based on LP 2020)	**235,654**	221,445	249,862	**149,177**	140,771	157,584
Sum (based on UAW 2021 + LP 2020)	**301,738**	282,339	321,137	**202,364**	187,662	217,065
Sum (based on LP 2020)	**313,798**	292,244	335,352	**212,131**	194,815	229,446
Education (based on UAW 2021)	**18,650**	17,287	20,013	**17,757**	17,287	18,227
Prisons (based on UAW 2021)	**1710**	1710	1710	**877**	877	877
Armed forces (based on UAW 2021)	**739**	637	840	**377**	325	429
Total sum (based on UAW 2021, LP 2020)	**322,838**	**301,974**	**343,701**	**221,374**	**206,151**	**236,598**

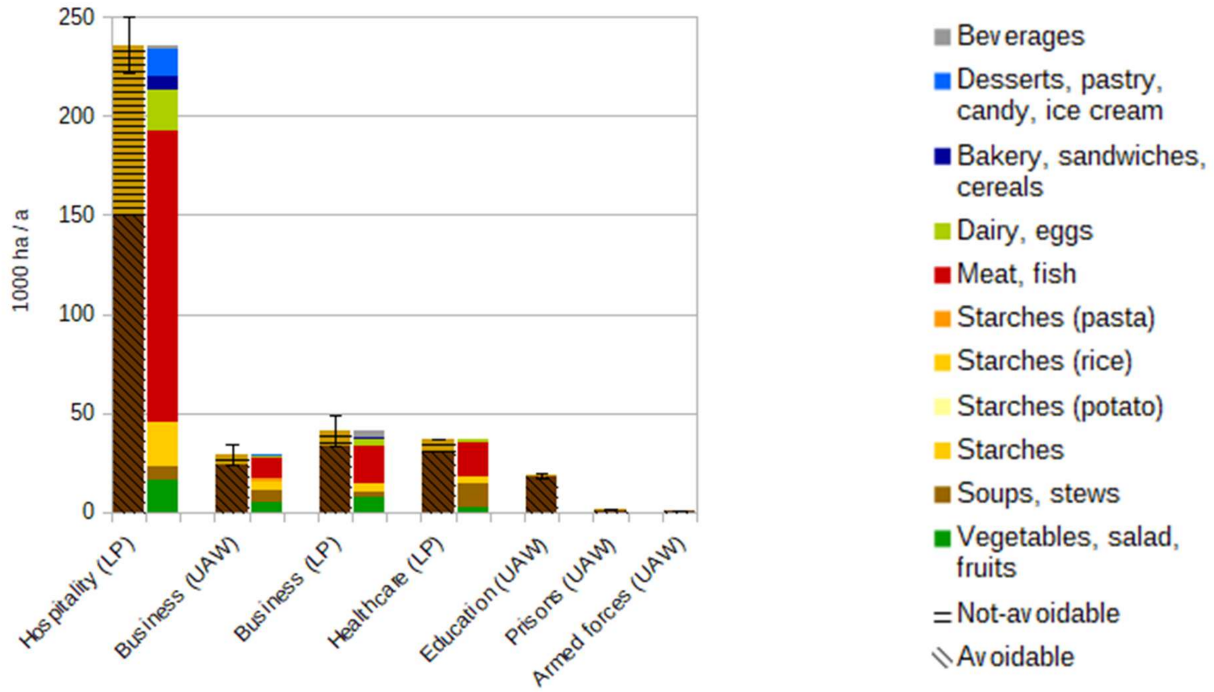

Figure 8. Land use in 1000 ha in 2015 stemming from food waste in the food-service sector in Germany. The subsectors of education, prisons and armed forces were calculated based on UAW 2021 for the business subsector.

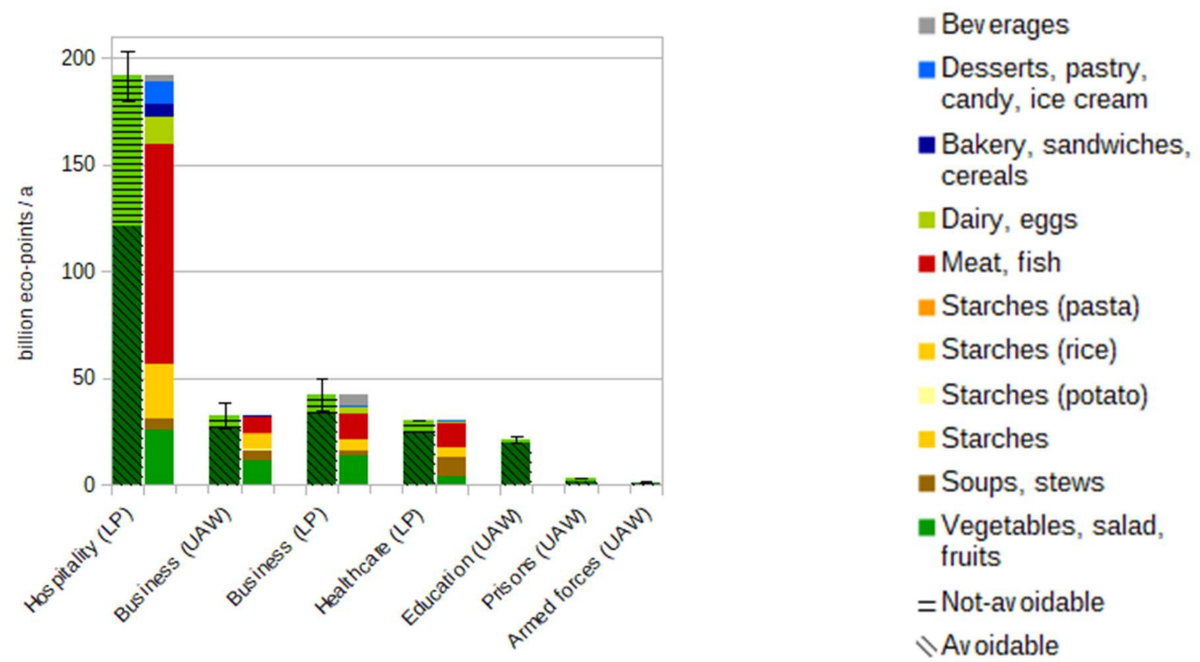

Figure 9. Environmental impacts in billion eco-points in 2015 stemming from food waste in the food-service sector in Germany. The subsectors of education, prisons and armed forces were calculated based on UAW 2021 for the business subsector.

Table 11. Environmental impacts stemming from food waste in the food-service sector in Germany in billion eco-points in 2015. The subsectors of education, prisons and armed forces were calculated based on UAW 2021 for the business subsector.

	Eco-Points of Food Waste (billion/a)			Avoidable Eco-Points of Food Waste (billion/a)		
	Mean	**Lower**	**Upper**	**Mean**	**Lower**	**Upper**
Business (based on UAW 2021)	**32.4**	26.6	38.2	**26.2**	19.2	33.2
Business (based on LP 2020)	**41.9**	34.4	49.4	**33.9**	24.8	43
Healthcare (based on LP 2020)	**30**	30	30	**24**	24	24
Hospitality (based on LP 2020)	**191.5**	180	203.1	**121.2**	114.4	128.1
Sum (based on UAW 2021 + LP 2020)	**253.8**	236.5	271.2	**171.4**	157.6	185.3
Sum (based on LP 2020)	**263.4**	244.3	282.4	**179.1**	163.2	195.1
Education (based on UAW 2021)	**20.8**	19.3	22.3	**19.8**	19.3	20.3
Prisons (based on UAW 2021)	**2.6**	2.6	2.6	**1.4**	1.4	1.4
Armed forces (based on UAW 2021)	**1.1**	0.9	1.2	**0.5**	0.5	0.6
Total sum (based on UAW 2021, LP 2020)	**278.3**	**259.3**	**297.3**	**193.1**	**178.7**	**207.6**

4. Discussion and Open Issues

In this study, we show that after monitoring and the consolidated implementation of reduction measures, 16% of the accumulated food waste in the food-service sector within one year could be saved (see Table 4), with the highest saving achieved in the healthcare sector (−17%), followed by the business sector (−16%) and the hospitality sector (−10%). However, taking the Sustainable Development Goal (SDG) 12.3 of 50% food-waste reduction by the year 2030 as reference, further action is needed [3]. The urgency for the implementation of proper reduction-management schemes was further underlined, taking the baseline analysis for Germany into account [23,24], which quantified a theoretical saving potential of 72% for the food-service sector (1.2 million tons out of 1.6 million tons of food waste in the food-service sector).

Besides the involvement of large-scale catering companies in this project, which demonstrated actual reductions of food waste, our study can be characterized by the following innovative aspects. To our knowledge, for the first time, subsector-specific waste composition data for hospitality, healthcare and business catering was used to calculate corresponding environmental impacts. Further, menu plans were used to quantify corresponding environmental impacts with greater specificity on the company level. To this end 84 meal-specific food-waste categories were derived. Finally, in addition to the carbon, water and land footprints, the method of ecological scarcity (in terms of eco-points) was applied to display the overall environmental burden of the food waste more comprehensively.

4.1. Comparison of Results

Compared with other studies, in terms of greenhouse gas emissions, our results were within the same range (Table 12). Although comparable studies are scarce in terms of blue water use and land use, the comparison with FAO (2013) also shows results within the same range (Tables 13 and 14). However, it must be stated that the study of FAO (2013) estimated corresponding impacts not on a national, but only on a regional (in this case European) level, and refers to the year 2009. Generally, the differences can stem from several reasons (methodology, different system boundaries and different data basis). A detailed comparison to the results of this study is therefore limited (see further comments in Table 12, Table 13, Table 14).

Table 12. GHG emissions in kg CO2e per kg of food waste (literature comparison).

Sector	GHG Emissions	Range		Study	Comments
	In kg CO2e Per kg	Lower	Upper		
Food-service: business (based on UAW)	2.3	1.5–	3.5	this study	Range based on 21 different meal types (conventional agriculture)
Food-service: business (based on LP)	2.3	1.6–	4.1	this study	Range based on 21 different meal types (conventional agriculture)
Food-service: healthcare (based on LP)	2.9	1.5–	6.1	this study	Range based on 21 different meal types (conventional agriculture)
Food-service: hospitality (based on LP)	3.4	1.7–	8.0	this study	Range based on 21 different meal types (conventional agriculture)
Food-service: business (based on UAW)	2.1			Knöbel et al. 2020 [22]	System boundaries: cradle-to-fork (regional focus: Germany)
Food + Food-service	2.1			FAO 2013 [26]	System boundaries: cradle-to-grave. No distinction is made between retail and wholesale trade, without emissions from LULUC (regional focus: Europe)
Food	1.9			Monier et al. 2010 [27]	System boundaries: cradle-to-grave. Only including the following sectors: manufacturing, households, others (food-service sector was not included) (regional focus: EU)
Food + Food-service	2.1			Scherhaufer et al. 2018 [28]	Bottom-up approach (regional focus: EU)
Food + Food-service	2.9			Scherhaufer et al. 2015 [29]	Top-down approach (regional focus: EU)
Food + Food-service	2.1			Venkat et al. 2011 [30]	System boundaries: cradle-to-grave. No distinction is made between retail and wholesale trade (regional focus: USA)

Table 13. Blue water use in L per kg of food waste (literature comparison).

Sector	Water Use	Range		Study	Comments
	In L Per kg	Lower	Upper		
Food-service: business (based on UAW)	72.4	40.3–	112.6	this study	Range based on 21 different meal-types (conventional agriculture)
Food-service: business (based on LP)	72.3	54.4–	175.6	this study	Range based on 21 different meal types (conventional agriculture)
Food-service: healthcare (based on LP)	48.4	23.2–	118.5	this study	Range based on 21 different meal types (conventional agriculture)
Food-service: hospitality (based on LP)	61.1	31.6–	226.1	this study	Range based on 21 different meal types (conventional agriculture)
Food-service: business (based on UAW)	109.7			Knöbel et al. 2020 [22]	System boundaries: cradle-to-fork
Food + Food-service	78.2			FAO 2013 [26]	System boundaries: cradle-to-grave. No distinction is made between retail and wholesale trade (regional focus: Europe)

Table 14. Land use in m² per kg of food waste (literature comparison).

Sector	Land Use	Range		Study	Comments
	In m² Per kg	Lower	Upper		
Food-service: business (based on UAW)	1.0	0.3–	2.2	this study	Range based on 21 different meal types (conventional agriculture)
Food-service: business (based on LP)	1.4	0.6–	3.1	this study	Range based on 21 different meal types (conventional agriculture)
Food-service: healthcare (based on LP)	1.9	0.4–	5.1	this study	Range based on 21 different meal types (conventional agriculture)
Food-service: hospitality (based on LP)	2.6	0.8–	7.1	this study	Range based on 21 different meal types (conventional agriculture)
Food-service: business (based on UAW)	1.2			Knöbel et al. 2020 [22]	System boundaries: cradle-to-fork
Food + Food-service	4.5			FAO 2013 [26]	System boundaries: cradle-to-grave. No distinction is made between retail and wholesale trade (regional focus: Europe)

4.2. Limitations and Data Uncertainties

As this study builds upon different primary and secondary data sets and—in the case where no data were available—also assumptions, it must cope with several limitations.

First, it should be noted that in all participating catering companies, the waste quantities were only documented in the four areas of (i) storage, (ii) preparation, (iii) surplus production and (iv) plate return (see Materials and Methods). A food-item-specific collection of waste was not conducted due to practical reasons. Therefore, two representative data sets had to be used to display the food-specific compositions of the accumulated wastes [11,12].

Second, coffee and tea residues, as well as oil and starch waste (collected in oil and starch separators), were not monitored in this project.

Third, concerning the data set from Leanpath [12], it must be noted that it was based upon 487,000 measurements across Europe (EU14 + Norway), whereas the geographical focus in this project is Germany.

Fourth, it must be noted that, when assembling the weighted product-based food-group compositions (see Supplementary material), the national average composition was assumed, as specific compositions for neither the whole food-service sector nor the subsectors were available.

Fifth, it must be mentioned that, when analyzing the company-specific menu plans (Section 3.2.2), corresponding sales numbers and recipes of the meals were not considered, as these were not provided by the companies. Instead, for every meal offered per day, the same sales share was assumed.

Sixth, as menu plans were only provided for the first monitoring period, the same menu offering was assumed for the second monitoring period.

Seventh, regarding the documented waste quantities and savings at the company level, the underlying sample, with only seven large-scale caterers who participated in this project, is statistically small. Hence, the derivation of national-subsector-specific benchmarks on this basis is limited.

Eighth, it must be mentioned that within the extrapolation, the reference years were not completely identical. Whereas the food-group-specific environmental impacts refer to 2015–2017, the food-waste quantities used on the national level refer to 2015.

Ninth, as representative food-specific waste compositions were not available for prisons, armed forces and the educational subsectors, for these sectors, the waste composition of the business subsector was applied (based on [11]).

4.3. Sensitivity Analysis

However, to attenuate the limitations discussed—wherever available—data ranges reflecting uncertainties were additionally computed in the assessment. First, based on the waste data recorded during the 1545 measurement days in the first and second monitoring periods, the 95% confidence intervals per serving in the subsectors and meal categories considered were calculated [31]. Second, based on the company-specific menu plans, the deviation from the average waste composition was quantified (Tables 6 and 7). Third, lower and upper bounds of the national waste quantities in the food-service sector were used as a basis for corresponding uncertainties of environmental impacts. However, as in the case of the national extrapolation, the underlying uncertainty ranges [23,24] did not follow a uniform statistical metric (such as 95% confidence interval, etc.), so further statistical checks are limited.

5. Conclusions

Although the COVID-19 pandemic has led to a tremendous decline of turnover in the food-service sector, the reduction of food losses and waste remains one of our most critical challenges—not only in economical, but also in ecological terms. In this study, we showed that the food-service sector in Germany is responsible for the emission of 4.9 million tons CO2e per year, a water withdrawal of 103,057 m^3 and a land demand of 322,838 ha, equaling 278 billion eco-points. If robust waste-management schemes are implemented in catering companies in the near future, coupled with political support for a proper monitoring architecture, the Sustainable Development Goal to halve food waste by 2030 in Germany is within reach. However, due to a diminishing marginal benefit, it must be stated that with each waste reduction achieved, the avoidance potential of future waste measurements becomes smaller, provided that it is accompanied by continuous employee empowerment.

Supplementary Materials: The following are available online at https://www.mdpi.com/2071-1050/13/6/3288/s1. Figure S1: Example of a 1-week menu plan in healthcare catering, Figure S2: Example of a matched 1-week menu plan with corresponding meal categories, Figure S9: Composition of the 21 meal-specific waste types based on UAW (2017)—Business, Figure S10: Composition of the 21 meal-specific waste types based on Leanpath (2020)—Business catering, Figure S11: Composition of the 21 meal-specific waste types based on Leanpath (2020)—Healthcare catering, Figure S12: Composition of the 21 meal-specific waste types based on Leanpath (2020)—Hospitality catering.catering Table S2: Segregation rules applied to allow a data matching with corresponding LCA processes.

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