Eating away at sustainability. Food consumption and waste patterns in a US school canteen

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All authors contributed equally to the conception and design of the study. Garcia-Herrero, Costello and Schreiber collected data at school canteen level (primary data), and supported secondary data collection regarding the nutritional approach. Garcia-Herrero and De Menna contributed to secondary data collection regarding the environmental and cost dimensions. Vittuari provided supervision and coordination. All authors contributed equally to data analysis and interpretation and to the writing and review processes.

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Abstract

In order to achieve a sustainable diet, perfect understanding and coordination of the production and consumption aspects of the food system need to be achieved, including inefficiencies as food waste. Food waste rates in developed countries are increasingly perceived as a failure in the system. Within school canteens high levels of food waste are generated, in a location where habits about sustainable consumption should be transmitted to the next generation. This gap between education on best practices and student behavior should be addressed by contextualizing and characterizing meal services within sustainable diets. This research assessed the impacts of food consumption and wastage, including the nutritional characteristics through a case study in a school canteen located in Columbia, Missouri, US. It combines life cycle assessment, environmental life cycle costing, nutritional evaluation, and a food waste audit using weighing, visual assessment, and sorting techniques to estimate the food waste of different canteen users (students and faculty members). The novelty of this research relies on the integration of recognized life cycle thinking methods, including the role of embedded impacts within environmental, cost, and nutritional attributes. Food wasted at the canteen represented between 28-53% (by weight) across canteen users of the food served as meals, accounting for 10-35% of nutrients. The highest environmental contribution occurred at the food procurement stage (85%), while the lowest occurred at food preparation (2%). The largest costs are associated with food preparation activities and food purchases (39% meal cost). The embedded food waste impact accounts for 40-57% of the total global warming potential and about 27% of the total cost. Interventions are proposed and evaluated to improve the diet performance, which could be extended to further canteen scenarios.

1. Introduction

Global food production, including agriculture, forestry and land use activities, causes up to 37% of all anthropogenic greenhouse gases (Garnett, 2011). An important part of the emissions can be attributed to food loss and waste (FLW) which accounts for about 3% of the total carbon dioxide-equivalents (CO_2eq) and about USD 1 trillion each year (FAO, 2014; IPPC, 2019). Although there is not a common definition of food loss and food waste, this research follows the FAO (2019) suggestion that food loss concerns all stages of the food supply chain without including final consumer, retail, and food service, while food waste concerns to the decrease in the quantity or quality of food from the rest of the supply chain actors. In developed countries, more than 50% of food waste (FW) occurs at the household level (Janssen et al., 2016; Vittuari et al., 2019). Consequently, the concept of sustainable food production and diet should consider the whole supply chain, including nutritional, cultural, environmental, and affordability aspects (Burlingame and Dernini, 2012).

School canteens represent a unique scenario where education purposes and nutrition converge at the consumer level. For this reason, they have been studied as behavioral labs to improve food consumption habits (Balzaretti et al., 2018; Derqui et al., 2016; Wyse et al., 2017), to assess the efficiency of catering procurement policies (Cerutti et al., 2018), to calculate the environmental impacts of meals by life cycle assessment approach (Cerutti et al., 2016; Mistretta et al., 2019), and to quantify the amount of FW (Blondin et al., 2017; Buzby and Guthrie, 2002; Costello et al., 2017, 2016; Derqui et al., 2018; Eriksson et al., 2018; Liu et al., 2016). Food waste might lead to a nutritional loss and an unbalanced diet, as the food provided at the school level must usually meet nutritional requirements for a healthy development where Blondin et al. (2017) remark even focusing in a single food item as milk. In the United States of America (US) between1,200-1,400 calories and 33g of protein per capita per day are wasted – mainly from fruits and vegetables – and other nutrients that are currently consumed below recommended levels are wasted in notable amounts (Conrad et al., 2018; Spiker et al., 2017).

While in the EU, the study of Garcia-Herrero et al. (2019) explored the environmental and cost impacts of canteen meals in Italy following a life cycle perspective; in the US, the second-largest

GHG emitters in the World (WRI, 2017), no study has specifically applied a methodology to assess the sustainability of canteen meals, considering the role of food waste in nutrition, environment, and cost from a life cycle thinking approach. Hence, it is a relevant setting considering that food waste at the consumer level represents about USD 161billion in the US (Buzby, Jean C; Wells, 2014), and plate waste represents over USD 600 million (Buzby and Guthrie, 2002).

This research presents an assessment of the environmental and cost impacts of food provided and wasted in a US school canteen, including quantification of the amount of food served, consumed and wasted, and the corresponding nutritional content related to four school canteen user types: elementary, middle and high school students, and faculty members. A food waste audit was carried out combining direct weighing and digital photography to quantify the mass and identify specific types of foods waste. Life cycle assessment (LCA) and environmental life cycle costing (E-LCC) were employed to assess the environmental and cost impacts of the evaluated meals. The nutritional composition was calculated by using the standard references from the USDA Food Composition Databases (USDA, 2020). Results allowed the building of the baseline situation of food consumption and waste at a school in the US, highlighting areas to target diets to reduce food waste, and improving environmental and cost performance from a life cycle perspective.

2. Materials and methods

Case study description

The present case study is focused on a private school located in Columbia, Missouri, US. The school was selected based on its interest in improving the sustainability performance of the school - in 2017 the school conducted an internal waste audit, showing high levels of waste – and, because this school covers a wide age-range: 4-18 years old and faculty members.

The school canteen is shared by all students and faculty members in different turns. The meal is prepared by an external catering service in the school kitchen. The school lunch plan follows the patterns recommended by USDA (2019), therefore it can be compared with other school canteens located in the same country following USDA recommendations. The USDA recommends a minimum of nutritional content per serving and serving of specific food items, e.g., fruits, and it does not include a recommendation on a maximum amount of food served per week which might lead to food waste if it exceeds consumption (USDA, 2015). Meals do not follow any seasonal rotation, except for typical dishes prepared for specific festivities. The catering service prepared about 370 meals/day for 170 days in the academic year 2018-19, which was the year of this assessment.

The school organizes grades as follows:

- Elementary (4-11 years old): 195 students
- Middle (12-14 years old): 90 students
- High (14-18 years old): 43 students
- Faculty: 42 professors and other staff

All canteen users, except for elementary school, have access to one hot meal, side dish and free choice of any product available in the free choice corners composed by salad bar, fresh fruit, sliced bread, butter, milk and, juice offered daily. Elementary school students must select every morning whether they prefer a cold or hot meal for lunch.

Data collection

The meal system was structured into three different stages:

- **Procurement stage** included primary production, processing, packaging, and transportation of ingredients from food producers to the school canteen.
- **Preparation stage** included all processes connected to preparing the food, such as cooking, cooling and washing activities, as well as the packaging and organic waste disposal.
- **Service stage** is related to the activities at the canteen, which refers to the users' meal consumption and organic waste.

Primary data on quantification and cost of inputs were obtained from the catering service company, the school board and the FW audit. Secondary data from the literature review and databases are detailed in the Supplementary Materials (SS.MM) were used to estimate the environmental impacts of food production, packaging, transportation, utilities, and waste management processes. Nutritional profiles were estimated by using the National Nutrient Database for Standard Reference Legacy Release (USDA, 2020), applied to the food categories' specific weight at serving and waste stages. The nutritional indicators assessed are those macronutrients recommended (type and quantity) to be served daily by the USDA-recommended lunch patterns (2019): energy (kcal), proteins (g), carbohydrates (g), total sugars (g), and saturated fats (g); and sodium (mg) as micronutrient.

Mass flow quantification

This study divided food mass into eight flows as figure 1 shows.

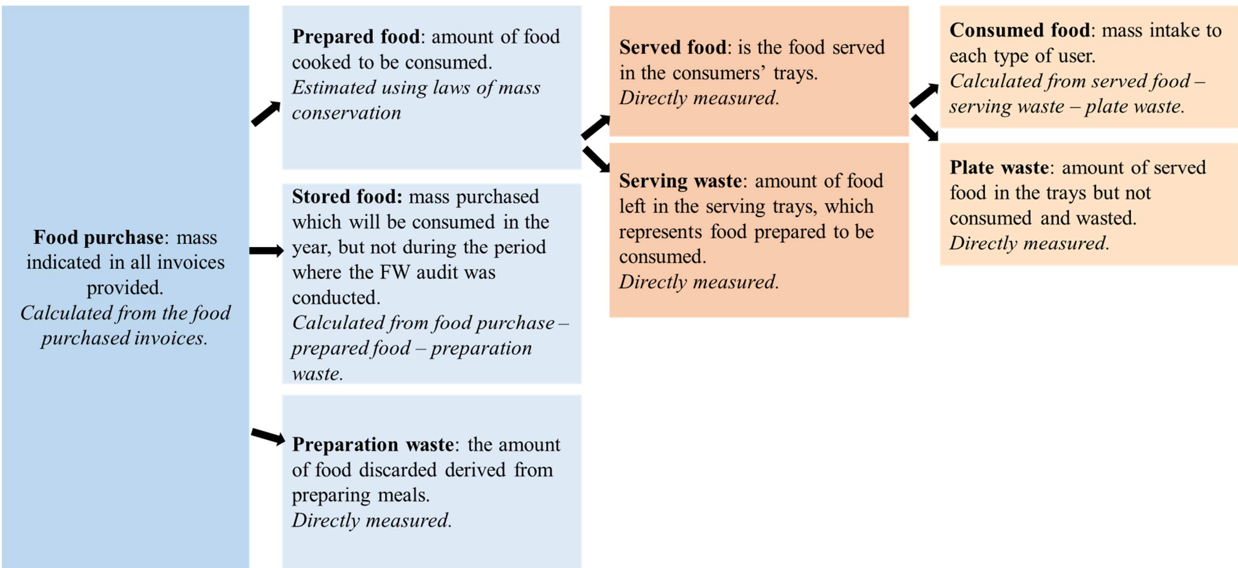

Figure 1. Food mass flows considered in this study and how the data were obtained. Note that the size of the boxes does not represent food quantity; see Figure 4.

Some considerations were made, such as that any weight change during cooking was negligible as many food items are highly processed and the weight is not likely to vary considerably between pre- and post-cooking. Although this fact could be considered a limitation and it was addressed in the sensitivity analysis, it should be considered in further research.

Food waste quantification was calculated by an audit over seven non-consecutive days during November and December 2018. Official data collection was preceded by a test day to understand the canteen functioning to adjust the data collection strategy to minimize interfering with usual operations. Days were selected from the two months of scheduled meals provided to the team to cover the different meal possibilities, i.e., major protein groups such as beef, chicken, fish, offered by the school within a year, to ensure data representativeness of the whole school year.

A combination of weighing, visual assessment, and sorting analysis were applied to quantify and identify the food items served, consumed, and wasted. Weighing is considered the most accurate methodology to assess FW (Liz Martins et al., 2014), although it is not commonly used due to limited time and financial resources (Getts et al., 2017). The FW audit started with placing a small card with a number and specific color on each user's tray. The number was randomly assigned while the color represented one of the four types of canteen users. Once the student or faculty member had their meal on a tray and prior to taking a seat in the canteen, the tray and meal were placed on a scale and a picture was taken. This allowed the weighing and visual assessment to occur at the same time. The pictures were taken by using two tablet devices supported with a tripod between the food serving line and seating, assuring that the weight shown on the scale, the tray number, and food composition were clear in the picture. When a user finished their meal, a similar photo was taken as the user returned their tray to the kitchen. Figure 2 shows an example picture. The visual assessment helped to understand the tray composition and portion size of all served meals. This technique represents a valid method to assess food intake (Marcano-Olivier et al., 2019; Winzer et al., 2018). As the trays were returned to kitchen staff, the waste audit team sorted the food remaining on the trays by aggregate type into containers for further food-specific weighing, if needed. This initial sorting was done to minimize inextricable mixing of foods. That is, milk was deposited into a bucket separate from meat items during the initial separation. The second sorting, if needed, involved, for example, separating sliced luncheon meats from other meats served regarding major category, e.g., beef, turkey. This staged sorting facilitated efficiency during hectic egress of students and faculty allowed for more accurate application of life cycle, cost, and nutritional data across ingredients. Preparation (mostly inedible peelings of fruits and vegetables) and serving waste were provided by kitchen staff in buckets and food containers and weighed each day by the waste audit team. The food items identified by the sorting phases were divided into thirteen categories: beef, pork, poultry, wheat, sugar, dairy-solid, dairy-liquid, fish, vegetables, egg, oils, fruit and miscellaneous. The categories were selected due to their prevalence in meals and due to additional knowledge of the relative environmental impact and cost.

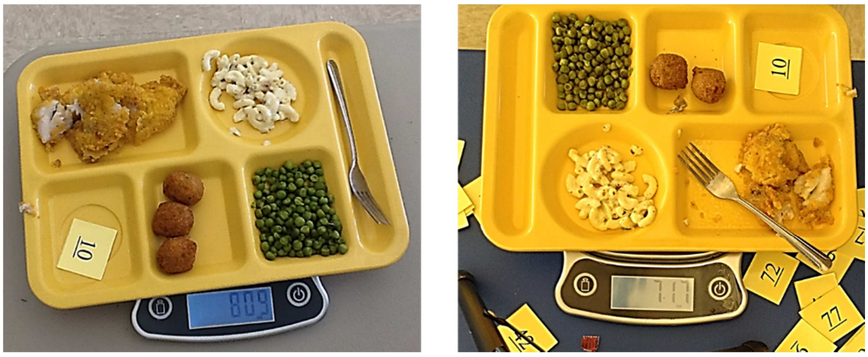

Figure 2. Example of pictures taken.

As noted in Figure 1, invoices with quantity ordered and weight data were provided by the catering company allowing for the quantification of the total weight of food entering the school. Three FW flows were identified: preparation, plate, and serving waste. Preparation waste occurs at the beginning of the process and it has strong relation with the nature of the food product, e.g., use of fresh onions results in inedible fractions being discarded. Serving waste, is related to how the catering staff estimate servings demanded, overprepare, and handle the food. Plate waste falls on the users, while serving waste has a shared responsibility between catering staff, users and circumstances such as unexpected student/faculty absences during lunch.

Statistical analysis test - the Kruskal-Wallis - was conducted to test differences between the plate waste quantity and food category along the different days.

Life cycle environmental and cost assessment

The environmental impact has been characterized and classified through the performance of an LCA, a technique that analyses a product over its entire life cycle, quantifying its environmental impact (ISO, 2006, 2002). The cost impact was calculated by applying environmental life cycle costing (E-LCC), followed Hunkeler (2008) recommendations, which grounds on LCA phases. The direct environmental and cost impact of the functional unit (FU) and the embedded impact of FW were quantified through a combination of both methodologies following an attributional approach. This approach describes flows and systems considering the average values of inputs and outputs across the system boundary allocating them to each of the thirteen food products later combined to the FU. LCA and E-LCC methodologies include the end of life, adopting a "cradle-to-grave" perspective by goal and scope definition, life cycle inventory, life cycle impact assessment, and interpretation (results and discussion section).

The FU was defined as the meal served to all canteen users, with the goal of this FU being to supply lunch. In this case, all elementary, middle, high school students, and faculty members were considered. It considered the average meal provided within two months of assessment, following a mass-based allocation. It considers the sum over all food in a day divided by the number of canteen users. The FU could be extended to the whole year, as the meal is repeated during each month without major variations. All impacts, including FW disposal, were first attributed to this FU and then allocated respectively to the meal consumed and all FW flows. Figure 3 below represents the system boundaries and inputs considered, while the SS.MM shows specific allocation considerations, such as the appliances multi-impact allocation, and the inventory.

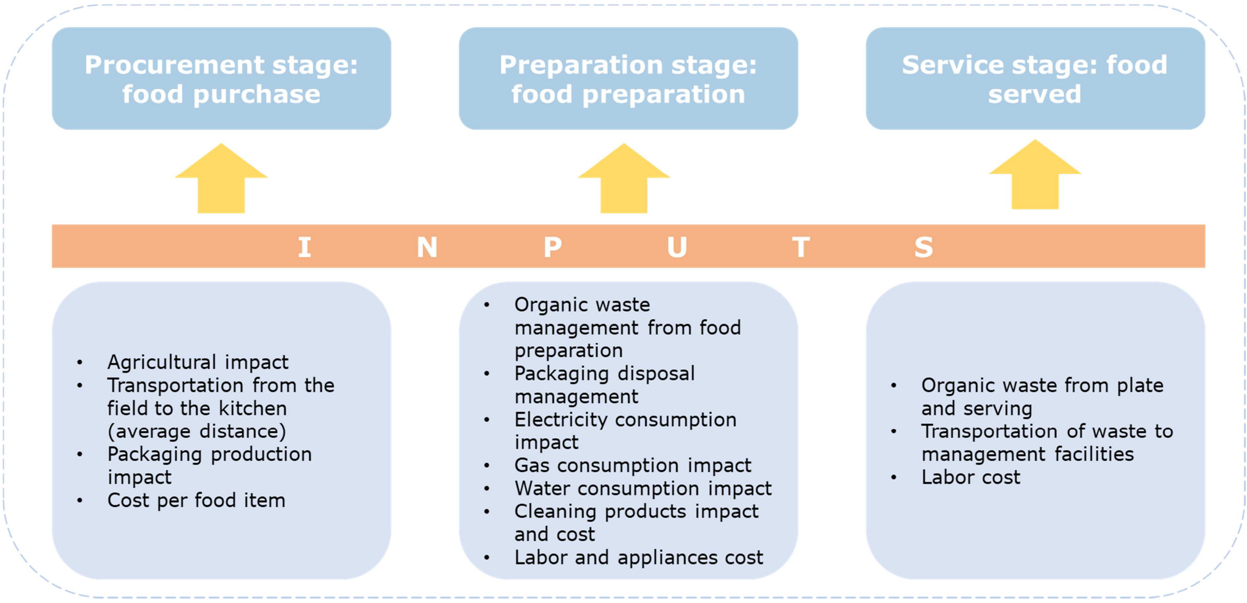

Figure 3. System boundaries and inputs considered in this study.

The life cycle impact assessment followed the EPD 2013 method (EPD, 2019), which contains four selected indicators properly representing the impact of studied products – mainly food products – and processes in the environment, and they are well known in communicating environmental impacts (Schau and Fet, 2008; Strazza et al., 2016).

The environmental impact categories assessed were global warming potential (kg CO_2 eq.) (IPCC, 2013), photochemical ozone creation potential (kg C_2H_4 eq.) ("ReCiPe," 2008), acidification potential (kg SO_2 eq.) (Hauschild and Wenzel, 1998), and eutrophication potential (kg PO^{-3}_4) (Heijungs, 1992). The cost impact applied was USD/meal served. Cost is covered by the parents within the school fee.

Environmental data sources included Environmental Product Declarations (EPD) (International EPD ® System, 2015), the literature review of previous LCA studies, and ecoinvent database version 3 (Wernet et al., 2016).

3. Results and discussion

Food waste quantification and nutritional characteristics

Figure 1 summarizes the data, while figure 4 indicates the different mass flows. It reports every type of flow considered in this research and its quantification during the two-month assessment, which was extrapolated to the whole year. Food purchased is represented by 100% as it refers to the food entering the school. About 5% of food purchased is stored and consumed in the following months, they are mainly products with long shelf lives that will be consumed later.

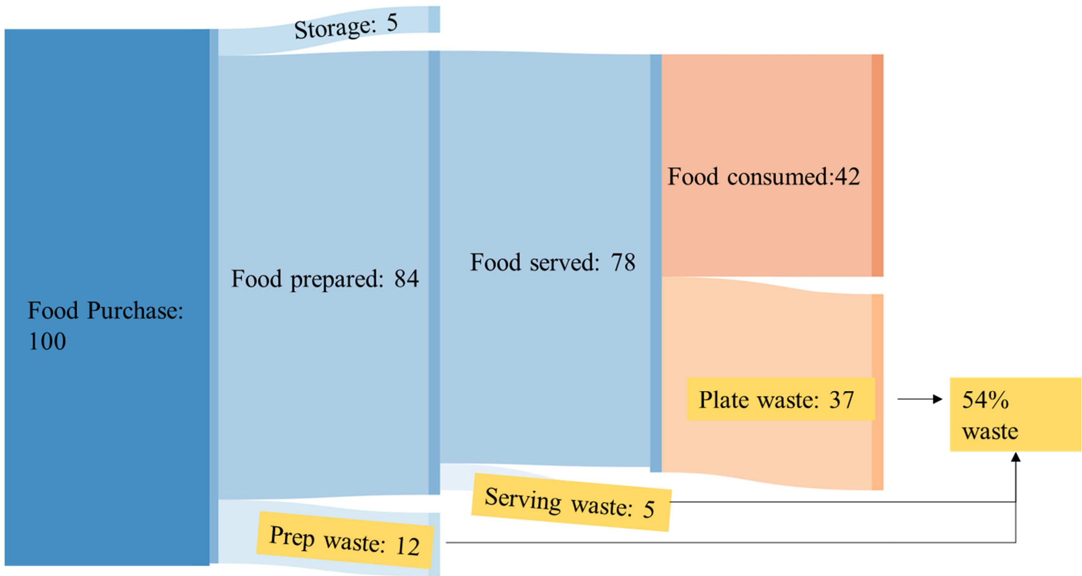

Figure 4. Percentage of mass flow at the canteen during the research. Totals may not sum due to rounding.

The amount of preparation waste amounts to 12% of the food purchased, a figure slightly lower compared to other studies assessing canteens (Betz et al., 2015; Fieschi and Pretato, 2017) as it is mainly processed or highly processed - mainly veggie options such as burgers, legumes and fruit - requiring a low level of preparation at school canteen. The natural composition of this flow at the canteen is unavoidable for cultural aspects, as they are mainly peels and damaged leaves; and most of the legumes and fruit are canned, French fries are pre-cut, and non-meat burgers are ready to eat after heating them.

About 83% of the weight of purchased food is prepared to be consumed. Prepared food weight was calculated from the recorded weight of food served and serving waste. The buffet option inevitably involves more FW in this stage, as other studies also found that to be true mainly for vegetables (Eriksson et al., 2017; Silvennoinen et al., 2015).

When moving towards a detailed discussion, differences between the amount of food served between users as well as the amount per food category are found, as the statistical analysis revealed. The percentages were designed according to the food purchase invoices and, adjusting the percentage of food category served depending on users through the revision of the pictures from the FW audit (SS.MM).

The outcomes from the FW audit indicate that elementary school students left more food on the tray (plate waste), but they are also getting a larger amount of food (served food) than middle school students. This is a competing issue between providing elementary students a variety of foods to hit nutritional needs and food waste.

Table 1 provides the percentage of average food wasted in each group as well as the average amount of food eaten and served in grams. Plate waste ranges from 27-53% of the food served, representing approximately 37% of the total food purchased, equivalent to 47% of the total food prepared.

Table 1. The average daily amount of food served, consumed, and wasted per canteen user.

Level of school	Eaten (g)	Plate waste (g)	Total	% wasted
Elementary	229	263	491	53
Middle	227	229	456	50
High	336	178	514	34
Faculty	417	158	574	27

Plate waste quantification was statistically tested to determine if there were differences between the quantity across data collection days in each food category. The Kruskal-Wallis test was performed using Real Statistics demonstrates that the null hypothesis cannot be rejected ($p>0.92$), at 0.05 level of significance, thus the amount and distribution of plate waste along the days could be considered similar.

Percentages of plate waste obtained are comparable to other studies executed in the US (Marlette et al., 2005; Smith and Cunningham-Sabo, 2014) but they differ compared to other schools in other countries. A study in Sweden showed that plate waste accounted for 23% of total food served (Eriksson et al., 2017); in Italy between 20-29% (Boschini et al., 2018; Vittuari et al., 2019); and in Spain about 30% (Derqui et al., 2018). Cited studies provided a lower amount of food served, but they were also quantified under different methodologies than this research.

Focusing on the categories, the amount of plate waste per food category distribution is analogous to cited school canteens studies. Students, from all grades, waste vegetables and fruit categories the most, representing more than the 50% of their plate waste. Faculty members waste about 43% of these categories. Because they are most highly wasted, understanding the extent to which fruit and vegetable offerings in school lunches are likely to be accepted by children has important implications for school meal policies and children's health (Newman, 2013). Egg and poultry were the least wasted categories (between 0-2). Table 2 shows the outcomes of the nutritional balance. The FW audit allowed understanding of the type of food category wasted the most each day of data collection, covering the aim of this research for environmental and cost purposes. Nevertheless, the selection of specific days instead of a random sampling could lead into a bias in case other parameters need to be studied, such as food waste per day.

Table 2. Nutritional balance of food served and plate waste per meal.

		Elementary	**% wasted**	**Middle**	**% wasted**	**High**	**% wasted**	**Faculty**	**% wasted**
Energy (Kcal)	Served	650		631		693		820	
	Wasted	163	25	133	21	109	16	103	13
Proteins (g)	Served	22		22		25		28	
	Wasted	5	23	3	14	4	16	4	14
Carbohydrate, by difference (g)	Served	62		62		71		87	
	Wasted	22	35	18	29	14	20	13	15
Total sugars (g)	Served	25		22		23		24	
	Wasted	7	28	6	27	5	22	4	17
Sodium (mg)	Served	1096		1170		1104		1281	
	Wasted	283	26	218	19	190	17	166	13
Saturated fats (g)	Served	22		21		25		31	
	Wasted	7	32	5	24	4	16	5	16

The amount of kcal served corresponds to the amount recommended in the lunch meal pattern according to the group of age, with the exclusion of high school students which should get between 750-850 kcal/day while they received on average 60-160 kcal less than recommended (USDA, 2019). Saturated fats should be <10% total calories but served food contained a higher amount of saturated fats for all canteen users. A study reveals that students consumed about 32% of their total calories as empty calories - the sum of energy from added sugar and solid fat - at school (Poti et al., 2014), which could arrive from the excess of saturated fats in this case study for the lunch meal. Sodium levels followed the recommendations established until July 2024 (≤1,230 mg) but is larger across all canteen users based on recommendations from 2024 onwards (between 935 and 1080 mg at maximum).

The products presented in the assessed school correspond to the trend of highly processed food items in school canteens identified in the literature (Neri et al., 2019), as well as those indicated in the USDA lunch patterns . The ratio between nutrients provided and wasted is higher than other studies in US, where also food nutrients associated with fruit and vegetables are wasted the most (Niaki et al., 2017; Peckham et al., 2019).

Meal impacts

Life cycle assessment

The results of the environmental impact per meal and user type are presented in Table 3.

Table 3. Environmental impact category per canteen user meal.

	GWP (kg CO_2-eq)	**PQO (kg C_2H_4-eq)**	**AC (kg SO_2-eq)**	**EU (kg PO^{-3}_4-eq)**
Elementary	2.28	9.46×10^{-4}	2.28×10^{-2}	9.63×10^{-3}
Middle	2.18	8.94×10^{-4}	2.18×10^{-2}	9.26×10^{-3}
High	2.30	9.70×10^{-4}	2.35×10^{-2}	1.01×10^{-2}
Faculty	2.29	1.05×10^{-3}	2.36×10^{-2}	9.76×10^{-3}

GWP (global warming potential); PQO (photochemical ozone creation potential); AC (acidification potential); EU (eutrophication potential).

Overall figures are higher compared with other studies assessing school meals, such as the GWP, which includes 1.43-1.67 kg CO_2 eq./meal (Cerutti et al., 2018; Mistretta et al., 2019). Cited investigations comprised longer transportation routes from the kitchen to the school, or disposable tableware, while in the studied school these aspects were not present. Other studies assessing other environmental impact categories in meals have not been found.

On average, about 85% of the overall impact is associated with procurement activities, 13% to preparation, and about 2% to service stage. Figure 5 shows the percentages of the average meal in each stage.

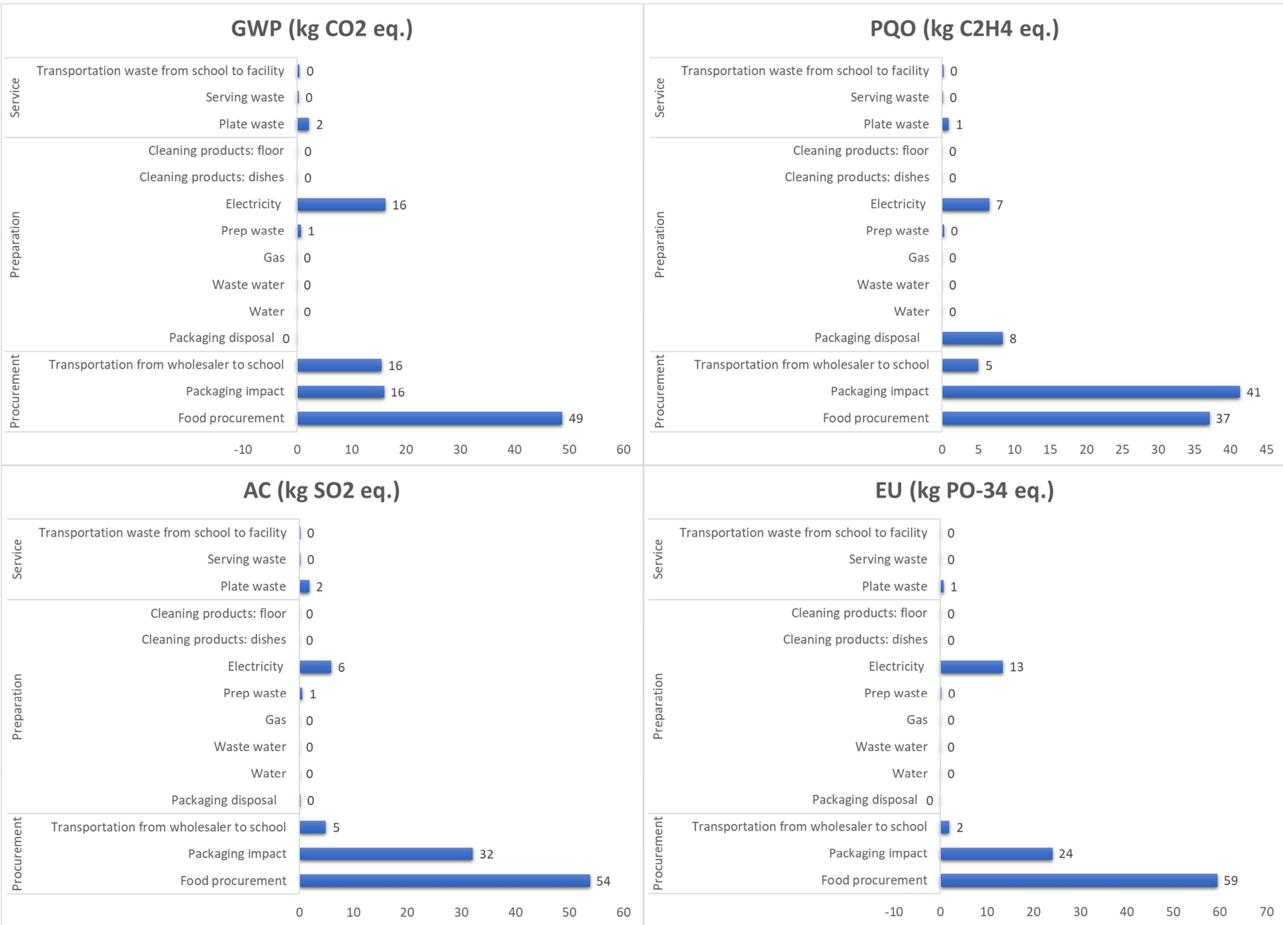

Figure 5. Percentage of environmental impact category per stage in an average meal.

Procurement includes the impacts of food production, its packaging and transportation from the field to the school. Food production accounts for more than 60% of the impact of this stage. Analyzed on a mass-based approach, this substage shows the biggest GWP under the food category beef, followed by dairy-liquid and poultry. At the lower end of environmental impacts, there are sugar, egg and oil categories. The greatest value of PQO belongs to the vegetable category because of products such as cucumber and green pepper. When analyzing the AC, the main impact is associated with beef, pork and poultry categories. The difference between the greatest and the lowest food impact is more than 10^3 kg. Each substage, packaging and transportation, accounts for about 20% of the total GWP. On the packaging contribution, the higher amount of GWP, PQO and AC impact came from tin packaging. Many food items, such as fruit cocktail or legumes, are canned and served as a ready-to-eat meal. The production of this type of packaging is about 10 times greater than the average of the rest of the packaging types observed in this research. EU is led by the mix of plastic/carboard packaging (Tetrapak formula), as per kg/packaging the impact is about 20% higher than the average of the other packaging materials assessed. The food transportation impact is strongly related to the amount of km travelled, the weight of the load, and the type of food; being higher when it requires refrigeration.

Approximately two-thirds of the purchased food was highly processed. This fact could cause a higher environmental impact in the procurement than in the preparation, as ready-to-eat meals do not need extensive, or sometimes any, cooking process; but not large enough to alter the most environmental contributor which it is at farm-level. Sonesson et al. (2005) did not find great differences in the environmental impact from analyzed processed and non-processed meals, while Rivera et al. (2016) revealed a small difference between them, having better environmental performance for home-prepared meals. The studies emphasized that the larger environmental contribution derives from agricultural stages, which are common to both product types.

At the preparation stage, most of the environmental impacts are associated with electricity (due to refrigeration and cooking), waste management and cleaning, while the lowest impacts are in other utilities. In the service stage, the major environmental contributor in all substages is the plate waste, due to its treatment as waste. This is followed by the management of serving waste, and the transportation from the kitchen to the waste management facility. In the waste processing, waste transportation was the major GWP contributor, while it is also the highest item in the EU contribution. The negative value obtained from packaging disposal reflects that there is a percentage of packaging going to recycling facilities. The action of recycling, even though it requires the consumption of resources such as water or energy, avoids the emissions from raw materials to create new ones having a negative balance in the GWP score.

Life cycle costing

The cost per meal paid per served meal by the school board is \$4.62. It is a flat rate for all ages, hence per FU.

The costing analysis has coupled the meal with the corresponding cost to each life cycle phase. Table 4 lists each cost item considered. When the cost paid to the catering service includes the utility bills paid by the school, the overall cost per meal reaches \$4.83.

Table 4. Costing item percentage per stage and final meal cost.

Stage	Item	% per meal
Procurement	Food	38.83
	Cooking-electricity	0.18
	Refrigeration-electricity	2.16
	Gas	0.10
	Water	0.08
	Wastewater	0.13
	Dish soap	0.11
Preparation	Floor detergent	0.06
Preparation/ Service	Labor + other costs	56.75
	Solid waste	1.60

Another study showed similar cost distribution, allocating the highest cost share in labor and food procurement items. Other phases, such as utility consumption were higher in the Italian case due to the preparation needed, as in that school no ready-to-eat meal were present (García-Herrero et al., 2019). In this research, labor includes other costs described in the materials and methods section. If the Italian study is utilized to disaggregate the figure of labor and other costs (administrative, general cost and profit), the percentage distribution across the meal will be about 34% allocated to labor cost, and 18% to other costs.

Ready-to-eat meal products could be cheaper (about 11% in the case of chicken) when they are compared to home-made ones, while frozen and home-made meals have a comparable life cycle cost (Rivera and Azapagic, 2016). Ready-to-eat cost distribution is equal to the environmental one, having the largest influence at the raw material purchase, followed by food preparation, packaging, manufacturing and disposal.

Analyzing the food category percentage distribution per canteen user, the largest expenses are under the vegetable, fruit and wheat categories. They are the most purchased food categories in terms of mass. Instead, when the price/kg is analyzed, the largest cost falls in the miscellaneous category, mainly made of meat substitutes, such as veggie burgers (highly processed food) and sauces, followed by meat products such as pork (with pork bacon products having the largest price) and poultry, with premium chicken being the most expensive product in this category. Lowest price per mass emanates from dairy-liquid products (such as milk or chocolate milk).

Vázquez et al. (2019) proposed the nutritional-cost footprint to quantify the nutritional-economic cost of food categories. This life cycle indicator could be integrated in the E-LCC being relevant when dealing with FW valorization options.

The embedded impact

The embedded environmental impact includes the impact of procurement stage, calculated for each of the three FW mass flows in the meal system, and adding the waste transportation to the waste management facilities, as well as the FW management of mentioned flows as organic and packaging. The understanding of the FW embedded impact required specific analysis of food categories composition. Table 5 shows the embedded FW impact per user type.

Table 5. Embedded environmental FW impact per meal and user type.

	GWP (kg CO_2 eq.)	PQO (kg C_2H_4 eq.)	AC (kg SO_2 eq.)	EU (kg PO^{-3}_4 eq.)
Elementary	1.34	6.88×10^{-4}	1.40×10^{-2}	6.07×10^{-3}
Middle	1.23	6.25×10^{-4}	1.27×10^{-2}	5.56×10^{-3}
High	1.04	5.37×10^{-4}	1.09×10^{-2}	4.72×10^{-3}
Faculty	9.56×10^{-1}	5.03×10^{-4}	1.02×10^{-2}	4.37×10^{-3}

The embedded environmental impact of FW in terms of GWP represents between 40-57% of the meal's total impact, being larger at elementary school students and lower at faculty members, as well as the PQO ranging from 45-71%, and AC from 41-61%, and between 25-56% of the total meal EU impact. Elementary students are those with largest amount of plate waste, while faculty members left less food on the plate. Beef waste is the biggest impact contributor in elementary students, pork in middle school, dairy solid in high school students, and dairy liquid in faculty members.

The embedded cost of FW has been calculated by applying to the mass of preparation, serving and plate waste the cost of purchasing it as food. It also includes preparation cost, derived from the plate and serving waste mass, which includes utilities and cleaning products. Labor and profit items have not been included as it is expected to be equal with or without waste coming from mentioned FW flows, as well as the tipping fee. The value obtained, $1.34 per meal, represents the cost wasted due to FW. It is about 23% of the total price per meal, of this, 20% derives from the preparation waste, 70% for plate and serving waste, and 10% in the preparation stage. If FW reduction aims to be targeted, measures to reduce plate waste should be prioritized, from a costing and ethical perspective.

Some studies obtained promising results after modelling optimized diets, mixing nutrition, economic or environmental characteristics (Larrea-Gallegos and Vázquez-Rowe, 2020; Westhoek et al., 2014). The limitation found in cited studies is the uncertainty of food waste quantification when designing the model constraints, which is an essential element to improve theoretical models into real situations. This research could improve the introduction of waste quantification per food item into the simulations, while proposing the addition of embedded impact to maximize the optimization.

Sensitivity analysis

Different scenarios were tested to prove the uncertainty and robustness of the results. They were elaborated identifying major impact contributors and sources of uncertainty of this research. Note that GWP will be the only environmental indicator utilized.

A scenario with zero waste at plate and serving flows was tested, assuming that all food prepared is consumed. If zero waste occurs the GWP will diminish by about 3% the overall meal impact. The cost of reaching this zero-waste scenario would not change as the tipping fee is fixed, without considering the amount of the mass, which was transported and managed. The costing aspect could change if some policies encouraging organic waste reduction are implemented.

Another scenario considered not purchasing the food that was wasted, therefore reducing food purchased by 54%. The procurement stage was reduced by 54%, and the preparation stage was reduced by 54% with the exception of cleaning products and electricity, as they will depend on the cooking functioning and number of meals, regardless the amount of food purchased. This scenario considers plate and serving waste zero. After conducting the test, about 47% of the environmental impact would have been reduced, showing the strong impact the amount of food purchased has on the overall meal impact. The cost would incur a reduction of about 21%. Another major cost is labor, and it will not change.

The procurement stage has the largest environmental relevance, 80% of the GWP meal impact in all users, being also the biggest contributor in other environmental indicators (PQO and EU). Food categories with greater environmental impact are beef, dairy-liquids, fish, pork and poultry with ranges per kg/product between 5-21 kg CO_2eq. By testing the value's resistance to change, a variation of ±10% in the environmental impact of cited animal-based products have been applied, resulting in a 5% of the total GWP meal impact variation. From a costing perspective, food category data was collected directly from the purchase invoices, thus, it is expected to be a consistent source. If the price of food items, suffers a variation of ±10%, the meal cost would vary about ±4%.

In the preparation, the main environmental contributor is the electricity, followed by the waste management, and cleaning products. By changing the electricity impact by ±20%, the GWP per meal would change about 3.2%, while the final cost would be altered less than ±0.1% (excluding labor cost).

Improvement interventions

After analyzing the embodied impacts of the food waste flows a massive impact is generated in support of food waste. Many interventions exist to mitigate this impact while also achieving nutritional goals. While alone they will not realize a sustainable food system, they represent the potential for significant reductions in impacts associated with the food system. Table 6 indicates in macro-categories the hotspots identified, interventions to address it, cases of success in the application of the intervention, and a final evaluation indicating the complexity to set the intervention. The evaluation was assigned accordingly to the main driver of the intervention which are:

- institutional level needed to accomplish the intervention: 1 point if at school level the intervention is feasible, 2 points if higher level is needed.
- economic cost and human resources involvement:
    - 1 point if any economic cost needed could be covered by the school; 2 points if external financial aid will be needed.
    - 1 point if no expertise to perform the intervention is needed, 2 points if the expertise is needed.
    - 1 point if less than 6 months will be needed to implement the intervention, 2 points if more than 6 months are needed.
- parents' engagement: 1 point if parents' engagement is not key for the success of the intervention, 2 points if parents' engagement is key.
- teachers' engagement: 1 point if teachers' engagement is not key for the success of the intervention, 2 points if teachers' engagement is key.

435 **Table 6.** Intervention and evaluation matrix: a preliminary assessment.

Hotspot	Intervention	Cases of inspiration	Evaluation
Large amount of plate waste	Adapt the amount of certain food served by reviewing the school meal planning.	Cohen et al. (2014)	**M**
	Information campaigns at the canteen. Social media within the school channels and pictures to raise awareness about the relevance of eat balanced and not waste food.	Goldeberg et al. (2015) Whitehair et al. (2013)	**M**
	Reduce the amount of food served per food item, keeping nutritional recommendations.	Reynolds et al. (2019)	**L**
	Improve food quality and national food policies.	Zhao et al. (2019)	**H**
Preparation waste	Improve cooking techniques to reduce preparation waste, and better planning system for dealing with serving waste to minimize its creation and increase its safe storage.	Tóth et al. (2017)	**M**
Serving waste	Reduce the amount of buffet options after assessing which food items are wasted the most.	Silvennoinen et al. (2015)	**L**
Environmental impact due to animal-based products	Reduce the animal-based food products - Substitute a percentage of animal-based products with plant-based, following nutritional guidelines.	Seconda et al. (2018) Westhoek et al. (2014)	**M**
Environmental impact due to transportation	Shortening the food supply chain - Prioritize the purchase of products produced within the State of Missouri and surrounding states.	Li et al. (2019) Malak-Rawlikowska et al. (2019)	**M-H**
Cost impact due to animal-based products	External measures such as environmental tax. The school could include more environmentally friendly measures, in the case of legislation changes the school would be ready.	Gren et al. (2019)	**H**
Cost impact in the purchase stage	Reduce those items with higher price and frequency leading with a high environmental impact. Beef has a lower price per kg than poultry, but a higher environmental impact. A balance to satisfy cost-environmental nutrition and cultural aspects should be carefully reviewed.	Chen et al. (2019) Ribal et al. (2016) González-García et al. (2018)	**M-H**
Food waste Environmental Cost Embedded impact	Sustainability plan addressing social, economic, nutritional, food waste and environmental aspects with key performance indicators.	Larrea-Gallegos and Vázquez-Rowe (2020) Liz-Martins et al. (2016)	**M-H**
	Follow the prioritizing food waste routes, from prevention, to recovery (food donation), and recycling (for example in compost).	ReFED, (2019)	**L**

Note that: Kitchen staff refers to the workers, while catering service includes the company they belong to. Difficulties: L=low (green ≤7 score); M=medium (yellow=8-10 score); H=high (red≥11).

SS.MM discloses complementary information of the improvement inventions.

The intervention matrix reveals multiple options to address sustainable diets at school lunch. It presents studies already showing successful results of interventions that make sustainable diets feasible under simultaneous measures. The evaluation indicates the complexity of implementing the proposed interventions according to the described drivers. That column could guide decision-makers to direct their investments into those interventions categorized in red. Although the evaluation was performed based on the US case, the interventions proposed as well as the criteria of evaluation could be extended to other cases.

4. Conclusions

Sustainable diet implies the supply and consumption of balanced nutrition. Consequently, food waste should be seriously addressed from both a nutritional, educational, environmental, and cost perspective. This research assessed the environmental and cost impacts, as well as the nutritional characterization of meal consumption and wastage at a private K-12 school in Columbia, Missouri (US). The novelty of this study relies on the integration of recognized assessment methods, including the concept of embedded impact, into a scenario widely identified in US schools. Results highlight a high food waste and environmental impact (GWP) per meal assessed compared with other national and international studies, while from the costing perspective, follows similar characteristics with the largest cost item associated with labor followed by food purchased. Additionally, the study provides an accurate frame to understand the current scenario and the preeminent hotspots to guide sustainable diets, including nutrition, cost and environmental characteristics. This frame could serve as a milestone to be developed in other canteens (even outside the school), countries and optimization models.

The limitations of this study are derived from the fact that it explores one case study which possesses the characteristics of a typical US school lunch, but it does not aim to be statistically representative. Food transportation, from the food origin to the main wholesaler might be undervalued, as no data was available for each food item, thus an estimation was utilized. Additionally, food processing environmental impacts might be improved as the study considered the raw food and not ready-to-eat meals.

Further research could focus on extending the outcomes of this research into different school types, considering the introduced embedded food waste impacts from three dimensions, nutritional (which could be enriched with social indicators), cost, and environmental.

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- Environmental, nutrition, cost and food waste should be addressed when assessing sustainable diets
- The integration of LCA and E-LCC reveals the environmental and cost impact of a meal
- Food waste quantification at school represents almost 50% of the food served
- The embedded food waste impact unhides several impacts beyond waste management
- Interventions to improve sustainable meals should include holistic analysis

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